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DRAFT for COMMENT

Environmental Noise and Health in the UK

A report published by the Health Protection Agency on behalf of an ad hoc Expert Group on the Effects of Environmental Noise on Health

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Chairman: Professor Robert Maynard

Editor: Dr Andy Moorhouse

Preface

Work on this report was begun when the Chairman of the ad hoc Expert Group on Environmental Noise and Health was employed by the Department of Health. Funding for the work was provided by the Department of Health and by the Department of Environment, Food and Rural Affairs. The work continued after the Chairman moved to the Health Protection Agency and the Agency is now publishing the report on behalf of the ad hoc Expert Group.

As they worked, Members were aware that this was the first officially sponsored report dealing with this subject for some time and that a mass of new evidence had appeared during the past few years. Drawing firm conclusions from such evidence is never easy and Members have been, in places, cautious about their interpretations. However, it is clear that many people are affected, some seriously, by exposure to environmental noise.

Members of the Group devoted many hours to the preparation of this report; for this I thank them. The report could not have been prepared in its final form without the major contribution made by Dr Andy Moorhouse, the editor of the report. He has, in fact, made an indispensable contribution to our work.

The views expressed in the report are those of the ad hoc group of experts alone and should not be taken as those of the Government Departments who sponsored the work nor of the Health Protection Agency.

R L Maynard

Chairman of the ad hoc Expert Group on Environmental Noise and Health

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Executive summary

1. Noise and sound need to be carefully distinguished. Sound is a term used to describe wave-like variations in air pressure that occur at frequencies that can stimulate receptors in the inner ear and, if sufficiently powerful, be appreciated at a conscious level. Noise implies the presence of sound but also implies a response to sound: noise is often defined as unwanted sound.
2. Sound levels, or 'noise' if suitable indicators are used, can be mapped geographically. This has been done in the UK and examples are presented in Chapter 3. A wide distribution of levels of sound has been revealed. The distribution of sound levels can be expressed in a variety of ways but defining the percentage of the population living in areas where sound levels exceed a specified figure is easy to grasp. For example, in the UK about 10% of the population are thought to live in areas where daytime sound levels exceed 65 dB $L_{Aeq,16\text{-hour}, 07:00-23:00}$. Note the detail included in the definition of the sound level: the A weighted scale is used (see glossary), sound levels are averaged over a 16-hour period and this period is specified as between 07:00 and 23:00.
3. The results of surveys discussed in Chapter 5 show there to be a considerable variation in levels of environmental noise across the UK. Proximity to major sources of noise is obviously important. It will be noted that a significant number of people live in areas where the noise levels exceed World Health Organisation guidelines.
4. Attitudes to environmental noise in the UK are changing suggesting that people are increasingly dissatisfied with their noise environment, notwithstanding the fact that over recent years some of the important indicators actually show a reduction in sound levels and in the number of people exposed to high levels of environmental noise. In the UK, about 30% of the population express dissatisfaction with their noise environment.
5. Although complaint statistics are not always easy to interpret, it appears that complaints about noise are increasing in the UK and, although neighbourhood noise is outside the scope of the report, we note that complaints about noisy neighbours are increasing more rapidly than complaints about other sources of noise. It is important to be clear that broad surveys may not reflect concerns in local areas.
6. Levels of environmental sound do not reach the intensities needed for damage to hearing.
7. Annoyance is probably the most widespread adverse effect of noise. In general terms the likelihood of, and strength of, annoyance can be related to indicators of sound exposure. This observation has led to the development of dose-response curves that express the relationship graphically: mathematical descriptions of the relationships are also available. It is important to note that around the average response of a group of people there is a wide scatter of responses due to variations in individual sensitivity to noise and/or

susceptibility to annoyance. These variations are not well understood in physiological or psychological terms.

8. That sleep can be affected by noise is common knowledge. Defining an exposure response curve that describes the relationship between exposure to noise and sleep disturbance has, however, proved surprisingly difficult. Laboratory studies and field studies have generated different results. In part this is due to habituation to noise which, in the field, is common in many people.
9. Exposure to noise has been shown to be associated with increased levels of stress hormones in the blood. These include the adrenal cortico-steroids and also adrenaline and noradrenaline which reflect activity of the sympathetic system. Whether such increases in concentrations are harmful is uncertain but some authors have linked such changes with the possibility of long-term effects on blood pressure and on cardiovascular disease.
10. Long-term exposure to high levels of noise in the occupational setting has been shown to be related to the likelihood of individuals developing cardiovascular disease. Recent research in community settings shows a similar relationship between transport noise and elevated blood pressure and medication for hypertension and a small increased risk of cardiovascular disease.
11. It has been suggested that exposure to environmental noise is associated with an increased likelihood of development of mental illness. This assertion has attracted some attention but the evidence is by no means clear cut. In our view it has not been established that exposure to environmental noise is linked to the likelihood of developing mental illness, although further research is recommended.
12. Exposure to environmental noise has been shown to be linked with impairment of cognitive performance amongst children exposed to raised sound levels. A number of well conducted studies have confirmed this. Less clear are the long-term implications of this finding.
13. Complaints about low frequency noise come from a small number of people but the degree of distress can be quite high. There is no firm evidence that exposure to this type of sound causes damage to health, in the physical sense, but some people are certainly very sensitive to it. In some, but by no means all cases a source can be identified and controlled. For some who suffer from the effects of exposure to low frequency noise development of a coping strategy can be helpful.
14. A wide range of legislation applies to the control of environmental noise in the UK. A number of government departments and other bodies are involved in the regulation of

environmental noise. We think that there is a case for review and possible simplification of the regulation of environmental noise.

15. Environmental noise is a problem in the UK today and many people are concerned about its possible effects on health. In terms of wellbeing we have little doubt that a significant number of people are adversely affected by exposure to environmental noise. If it is accepted that health should be defined in such a way as to include wellbeing then these people can be said to suffer damage to their health as a result of exposure to environmental noise. There is increasing evidence that environmental noise, from both aircraft and road traffic noise is associated with raised blood pressure and with a small increase in the risk of coronary heart disease. Evidence that environmental noise damages mental health is, on the other hand, inconclusive.
16. We strongly urge that a programme of research into the effects of environmental noise on health in the UK be established. A number of recommendations for further research have been made.
17. We recommend that an Expert Advisory Committee on Environmental Noise and Health be established. The remit of the standing committee should be to advise government departments on the effects on health of exposure to environmental noise, to review the literature of the field on a regular basis and to advise on the need for further research.

Chapter 1. Introduction

- 1.1 This report is a response to increasing public concern about possible adverse effects of noise on health. There is a need for noise and health issues to be taken into account in noise policy wherever they can be supported by scientific evidence. The main objective of this report is to provide policy makers with a critical review of the best information currently available on the health effects of noise. An important aspect of the current context is the recent adoption of the Environmental Noise Directive (END) by EU member states which has led to the production of 'noise maps' of urban areas in the UK. Therefore, the END and noise mapping are discussed in the report.
- 1.2 Some of the available evidence is inconclusive or even contradictory. The report represents the considered views of the ad hoc Group of experts all of whom have many years experience in this field. It is possible that further research might support an alternative view of some of the issues discussed in this report.
- 1.3 The report is essentially concerned with environmental noise arising from external sources such as road vehicles and aircraft impacting the general outdoor environment. Noise from neighbours, that generated inside the home, inside buildings or vehicles and at the workplace are all excluded except in so far as evidence from research on the effects on health of noise from these sources can form part of the context in which environmental noise is considered. Noise exposure from leisure activities, including from fireworks and music is also excluded from the scope, although we note in passing that there is some worrying evidence relating hearing damage to amplified music, including through headphones, and that further research is needed in this area.
- 1.4 The definition of health is that used by the World Health Organisation (WHO), i.e. "*a state of complete physical, mental and social well being and not merely the absence of disease or infirmity*". Thus, in this report we consider broad aspects of quality of life and general wellbeing that could be influenced by environmental noise.
- 1.5 In many other areas of pollution, policy decisions are made on a cost-benefit basis. This may be possible if there is a quantifiable relationship between the quantity of the pollutant and the adverse effect it causes, in other words, if there are known and well-defined dose-response relationships. Given that human response to noise may involve more subjective factors than that to other kinds of pollution, it is reasonable to ask if a dose-response approach can beneficially be applied to noise issues, and if so whether sufficient information is available for it to be implemented.

1.6 In considering the evidence the committee developed a list of questions:

- What is noise, and how does it differ from sound? How is noise quantified? How are the effects of noise quantified?
- To what extent are people exposed to environmental noise in the UK? Where does noise feature in public perception compared with other environmental issues? What are the main sources of noise, and what is their relative importance? What are the trends in noise; is the UK becoming noisier or quieter, and are more or fewer people affected by environmental noise?
- Taking a broad definition of health, which aspects of health or quality of life, if any, might be adversely affected by environmental noise? Is there evidence of statistical associations between indicators of the above-mentioned aspects of health or quality of life and environmental noise? If so, is there any evidence of causal links? If there is a causal link, at what levels of exposure to noise are the adverse health effects noticeable?
- To what extent have dose-response relationships already been established between sound level and any health indicators? If such relationships are established, can these be used reliably and beneficially for policy and planning? In the event that for some health effects, established dose-response relationships are not considered to be sufficiently reliable or perhaps they do not yet exist, are there alternative ways to quantify the adverse effect?
- Is there evidence of health or quality of life *benefits* from particular sound environments, like parks and quiet areas, and if so can these benefits be quantified?
- What is the potential impact of current noise policy drivers, such as the END, and new noise information sources, such as strategic noise maps, and to what extent are health effects accounted for? What are the current controls on noise, how are they implemented and enforced? Are there significant health effects not dealt with by current legislation? What metrics are used to quantify environmental noise within existing UK legislation? How appropriate are they when considering health effects? How might existing environmental noise legislation be improved to bring about improvements in health?
- Are there any noise and health topics or issues in which new research might be able to make an important contribution? If so, and bearing in mind both the relative importance of each of these topics or issues for public policy, and the relative likelihood of targeted research to be able to contribute conclusive results within affordable budgets and timescales, which particular topics or issues can be recommended for new research?

1.7 The remainder of this report considers the available scientific evidence in the light of these questions.

1.8 This is a challenging list and we have been able to answer only some in a way that we regard as satisfactory. In a number of cases the evidence needed is simply not available. In such cases we have recommended that research be undertaken.

Chapter 2. Sound and how it is quantified

Introduction

- 2.1 In this Chapter we first draw a distinction between the objective nature of 'sound' and the subjective nature of 'noise'. Parameters and key concepts involved in the measurement of environmental sound are then introduced and defined; measurement of noise is discussed in the next Chapter.
- 2.2 All noise is sound, but not all sound is noise. Sound is simply a mechanical vibration transmitted through the air, which is audible to persons with normal hearing. Most sound, such as natural sounds, speech and music, is either neutral or beneficial in its effects. Sound only becomes noise (often defined as 'unwanted sound') when it exists in the wrong place or at the wrong time such that it contributes to some harmful or otherwise unwanted effect, such as annoyance. Therefore, 'noise' depends not just on the physical aspects of the sound itself, but also the human reaction to it, which brings into play a raft of complex psychological and other factors.
- 2.3 'Sound' can be quantified objectively according to traceable international standards. 'Noise' on the other hand is a subjective phenomenon and its measurement requires a different approach. Sometimes physical measurements, such as EEG responses, are used, particularly in respect of sleep research, but more often noise is 'measured' by means of questionnaires and surveys. Another approach is to try to infer the degree of unwanted sound by interpreting complaint statistics. There are difficulties with all these approaches which make quantifying 'noise' considerably more difficult than quantifying the 'sound' itself. However, for policy purposes it is clearly necessary to be able to evaluate the negative effects of 'noise'. Considerable research effort has been directed towards finding objective measures of sound that correlate with the unwanted or harmful effect of noise, and this is discussed in Chapter 3.
- 2.4 Where in the report an objective aspect of noise is being considered we have tried to use the term 'sound' rather than 'noise', although this is not completely achievable. For example we refer to 'noise maps' which, according to the above definitions, are actually maps of objective sound levels that may or may not correlate well with the adverse reaction to that particular sound. Noise tends to be used as a term to describe sound which people are concerned about or simply don't like.

Categories of noise

- 2.5 The types of noise experienced can be classified into some fairly broad categories: occupational noise, which is experienced in the workplace; neighbour or neighbourhood noise caused by individuals or small groups of people in or around their homes; and environmental noise which is generated by transport, industry and general recreational

activities. The focus of this report is on the latter category, Environmental noise, although Occupational and Neighbourhood noise are mentioned briefly.

Quantifying sound

- 2.6 Many members of the public are aware that sound is quantified in decibels, abbreviated dB, but one needs to be aware that decibels are used in a variety of ways. Note that two variations on dB are commonly used, dB and dBA. The upper case 'A' appears in most measurements of environmental sound, and indicates that the measurement has been 'A' weighted. The 'A' weighting is applied to mimic the frequency response of the human ear, so that the contribution of sounds at frequencies (pitches) to which we have lower sensitivity are reduced and those to which we are most sensitive are emphasised. (For example, very high frequency sounds, audible to bats but not humans would not register on an A weighted measurement).
- 2.7 Sound consists of small, rapid, fluctuations in air pressure above and below atmospheric pressure, and is measured in units of pressure, Newtons per square metre or Pascals. However, the sound pressure values in environmental sound vary so widely (from a few millionths of a Pascal to about 1 Pascal) that it is not convenient to use pressure as an everyday measure. The decibel scale has been adopted so that the range of sounds commonly encountered can be conveniently measured on a scale of roughly one to a hundred, rather like the centigrade thermometer, so:
- 0 dBA corresponds, in broad terms, to the threshold of hearing i.e. the quietest sound that can be heard
 - 90 dBA corresponds approximately to the level of background sound in which one needs to shout to be heard by a listener one metre away
 - 130 dBA corresponds typically to the threshold of pain, i.e. the sound level above which the ear is painful.
- 2.8 Levels as low as 10 dBA can be encountered, for example inside rural or suburban dwellings at night. At the upper end of the scale, levels of 75 dBA or more are rare inside dwellings, although at a busy roadside, levels could occasionally rise to above 90 dBA.

Table 2-1 Summary of common indicators for environmental sound

Indicator	Defined in	Use	Description
$L_{Aeq,T}$	BS7445-1:2003	As a general descriptor of environmental sound exposure	The equivalent continuous sound pressure level, i.e. the sound pressure level of a hypothetical constant sound containing the same energy as the actual sound whose level may vary over the measurement period. It can be helpful to think of it as an average level, (although strictly speaking this is not quite correct). The measurement period, T, must be stated, so for example we have $L_{Aeq,16\text{-hour}, 07:00\ 23:00}$.
L_{A90}	BS7445-1:2003	As an indicator of the steady background sound level	The sound level exceeded for 90% of the measurement period. Broadly speaking this corresponds to the steady background sound level ¹ .
L_{A10}	BS7445-1:2003	To determine eligibility for insulation grants for traffic noise	The sound level exceeded for 10% of the measurement period. ¹ This is an indicator of the higher levels occurring during the measurement period.
L_{AE}	BS7445-1:2003	To quantify sound events, like pass-by sound from trains	Sound exposure level: the sound pressure level of a hypothetical constant sound which, if maintained constant for one second, would contain the same energy as the actual sound over the measurement period (which may be longer, or shorter than one second). It does not correspond to a level actually experienced by a listener but is mostly used for calculation purposes.
L_{day} $L_{evening}$ L_{night}	European directive 2002/49/EC and the Environmental Noise Regulations ²	'Noise' mapping	Day, evening and night levels. These are similar to $L_{Aeq,T}$ for the following time periods: Day - 07:00-19:00 Evening - 19:00-23:00 Night - 23:00-07:00 However, they are long term averages, i.e. determined over all the day/ evening/ night periods of the year.
L_{den}	European directive 2002/49/EC	'Noise' mapping	Day-evening-night level: this is similar to an $L_{Aeq,24\text{-hour}}$, but sound occurring during the evening is given a 'penalty' of 5 dB and that occurring during the night is penalised by 10 dB.

¹ Generally any percentage value could be used. These descriptors are known generically as 'percentile' levels.

² The indicator is defined in the European Directive, although the time periods corresponding to day, evening and night are defined in the national legislation.

Noise indicators

2.9 A variety of different noise indicators are used to describe environmental noise, for example $L_{Aeq,T}$, L_{A90} etc. The uppercase 'L' indicates that the quantity is a 'Level', measured in dB. Uppercase 'A' in the subscript, as per the previous section, denotes that the measurement is 'A weighted'. The other parts of the subscript are needed since sound levels vary with time. The most common indicators are summarised in Table 2-1.

Comparing noise levels

2.10 As a guide, an increase of 10 dBA in sound level is usually associated with a *subjective* doubling of loudness. Conversely, a decrease of 10 dBA is associated with a subjective halving of loudness. A change of 3 dB either up or down is often quoted as the smallest change in sound level that can be noticed by an average listener, (although under controlled conditions many people can detect a change of 1 dB or less). It should be emphasised that these rules of thumb are subjective, not objective and the figures can be expected to vary between individuals. Furthermore, they might not apply to changes in environmental noise level indicators as given in Table 2-1 if the character of the noise changes as well as its level; for example, many people would be expected to notice a 50% increase in the number of vehicles passing their house even though the corresponding increase in the $L_{Aeq,T}$ would be less than 2 dB. Nevertheless, these rules of thumb can serve as a useful guide if properly used.

2.11 On the other hand, in *objective* terms a reduction (or increase) of only 3 dB is an objective halving (or doubling) of sound energy. This distinction between subjective and objective comparisons has important implications for noise control: to produce a subjective halving of loudness the sound energy has to be reduced to a tenth of its original value, which could be difficult, expensive or impossible to achieve by engineering means. By the same token, to produce a just-noticeable reduction in noise emission from, for example, aircraft engines, would usually require a lengthy and sophisticated programme of redesign.

2.12 For the above reasons, when comparing two sounds it is generally misleading to use the usual arithmetic comparisons, for example it is misleading to say that one sound is 30% greater than another, twice as large etc. Instead, the comparison should be made in dB, for example 3 dB greater than, 10 dB less than, etc.

Characterising sound sources - sound power level

2.13 In the majority of instances and throughout most of this report, measurements in dB or dBA are used to indicate sound levels³ at a given *receiver* location, for example, we may

³ Strictly speaking these are 'sound pressure levels', but we will use the term 'sound level' throughout the report, except where a more formal definition is required.

quote the $L_{Aeq,T}$ outside a dwelling or at 10 metres from the edge of a motorway. However, it is important to appreciate that the units, dB and dBA can be used in quite a different way when characterising sound *sources*. The “Outdoor Equipment Directive” (European Commission, 2000) aims to improve control of noise from a very wide range of more than fifty types of outdoor equipment including, for example, lawnmowers, refuse collection vehicles, dozers, concrete breakers and even bottle banks and mobile waste containers (wheelie bins): the sound emission is quantified in terms of sound power level (given the symbol L_{WA} , W denoting power). It is important to appreciate that sound power levels, which characterise a source are *not* directly comparable to sound pressure levels which apply at a given location. This is a common cause of confusion since both use the dB scale. Sound power level provides legislators with a useful tool for controlling many of the sources of environmental sound, but is not generally used for transportation sources (rail, road or air vehicles) and will not be used further in this report. There are various sources of guidance should the reader require further explanation of these concepts (see for example the Environment Agency 2002).

The character of noise

- 2.14 Sounds with identical $L_{Aeq,T}$ may differ considerably in their capacity to cause annoyance or disturbance because of the character of the sounds. Two of the main elements contributing to the character of a sound are its time structure and frequency content. For example, a series of short impact sounds has a very different time structure to a continuous sound, such as that from a fan, and in most cases would be more disturbing for the same $L_{Aeq,T}$. Even for steady sounds, a wide range of character can result from differing frequency content: for example, sounds like distant thunder with a predominantly low frequency content might be described as ‘rumbling’ or ‘booming’, whereas sounds with high frequency content, like brake squeal might be described as ‘screeching’, ‘squealing’, ‘shrieking’, ‘hissing’ etc. Probably the most neutral frequency content is found in white noise (waterfall noise) which contains equal energy at all frequencies. Another aspect of the frequency content of sound that has a pronounced effect on character is the presence or otherwise of recognisable notes or tones. Notes or tones at low frequencies would often be described as ‘humming’, whereas high frequency tones might elicit descriptions such as ‘whistling’, ‘singing’, ‘screeching’ etc. Generally, sounds containing distinguishable tones are more noticeable, and potentially more annoying than sound without such features.
- 2.15 It is clear that there is a great deal of complexity in the experience of hearing sounds, and for this reason, the approach that seeks a single objective parameter to correlate with such an experience is considered by some to be simplistic. However, efforts by various researchers over many years have shown that it is difficult to account for all relevant features in a reliable, objective manner, and so the single $L_{Aeq,T}$ descriptors for environmental noise are likely to remain important for the foreseeable future. However, it is also important to realise that other parameters, such as the predictability and potential control of the noise may also be important. Similarly, specific noise sources,

such as irrelevant speech, may produce a unique profile of effects (see Smith and Jones, 1992). Measurement of the effects of environmental noise is discussed in the next Chapter.

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Chapter 3. How the effects of environmental noise are quantified

Introduction

- 3.1 Assessing noise and quantifying its effects is a complex process. This Chapter describes some of the methods which are commonly used to examine both the extent of noise impact, and the likely effectiveness of measures taken to mitigate noise.
- 3.2 Over the years different techniques have evolved to represent human response to noise, and to assist in identifying the most efficient means of minimising adverse effects. To some extent the method appropriate to a specific situation depends upon the particular effect that is under consideration, for example annoyance caused by noise, sleep disturbance, or simply exposure to noise. Similarly, the methods used can have a significant influence on decisions to be made concerning action to reduce noise.
- 3.3 Given noise at a particular level the data may be presented in many different ways, for example in terms of numbers of people affected, percentage of the population affected, area or population exposed and so on.

The assessment of environmental noise

- 3.4 The assessment of environmental noise depends upon two major factors. First, some measure of the extent of exposure, for example the number of people exposed to sound of a certain level, or the percentage of the population 'highly annoyed' by a particular noise source is required. In addition to this, some judgement as to the acceptable level of the noise under consideration must be made. This judgement is usually based upon the results of social and noise surveys or, less frequently, laboratory studies. In all cases a person's subjective or physical response to a noise, such as 'highly annoyed' or 'somewhat disturbed' is compared with the measured sound level. If sufficient numbers of subjects take part in such studies, it may be possible to derive a 'dose-response' relationship for a particular source/situation. A dose-response relationship usually takes the form of a graphical or mathematical relationship between sound levels and some measure of response to noise (such as percentage of respondents highly annoyed), from which it is possible to estimate the likely response of a population to a particular sound level, or the level at which a certain reaction is likely to occur (see Appendix B for further discussion of dose-response relationships). Once a relationship between sound levels and some response is established, a further decision has to be made regarding what is an acceptable level of response, for example what percentage of the population can be considered as an acceptable percentage to be 'highly annoyed' by a noise.

Figure 3-1: Individual annoyance responses to railway noise (Fields and Walker, 1982)

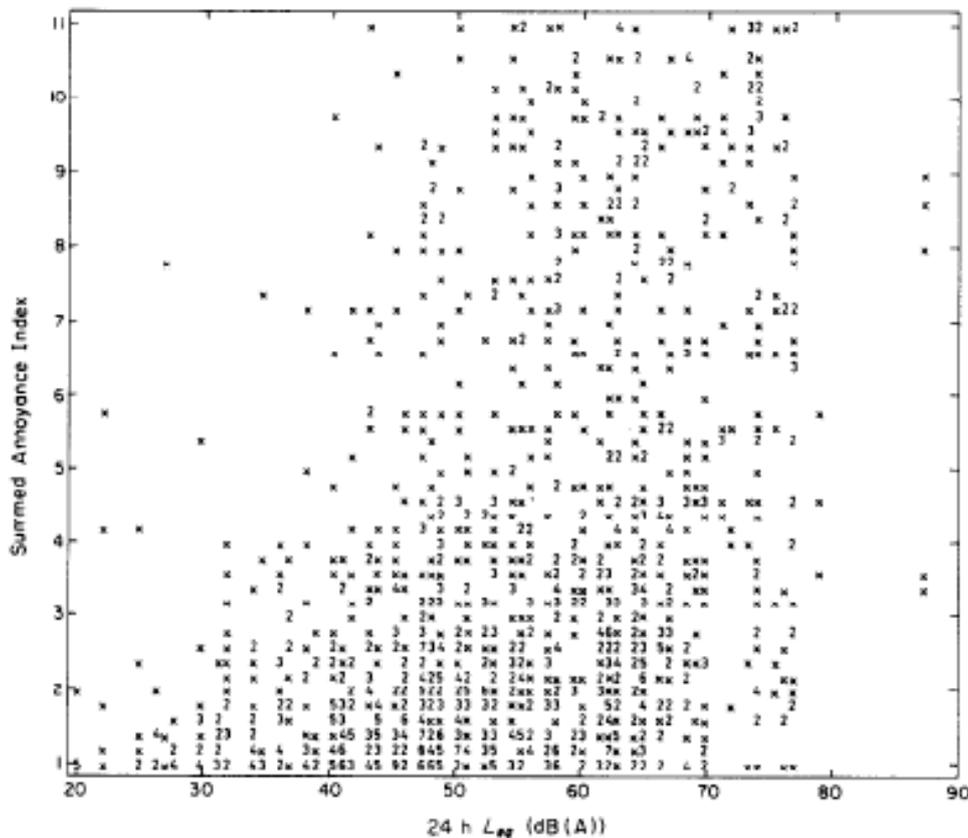
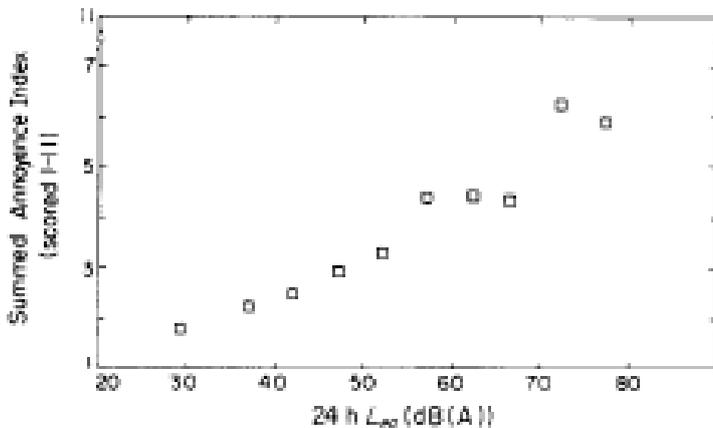


Figure 3-2: Average responses to railway noise at different levels (Fields and Walker, 1982)

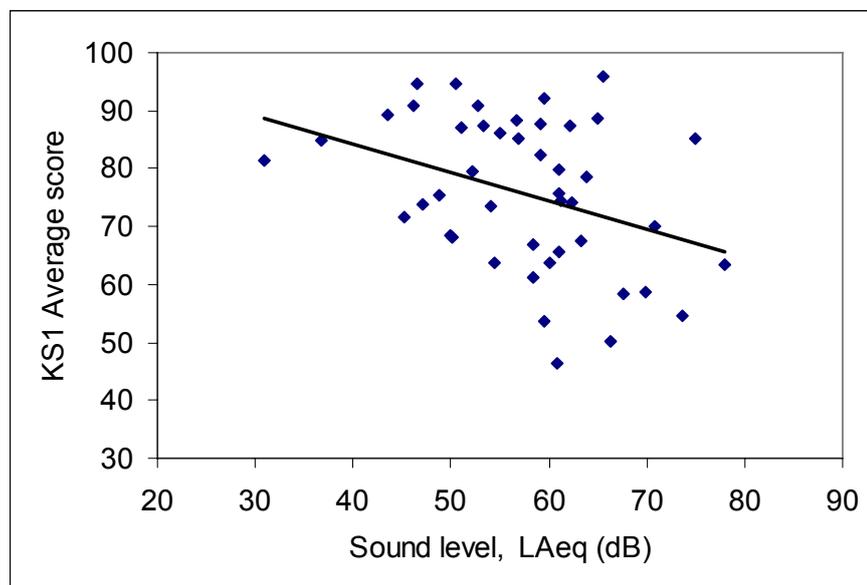


3.5 Dose-response relationships have been derived for many different sources and many different effects. Figure 3-1 shows the individual annoyance responses to railway noise in a study by Fields and Walker (Fields and Walker, 1982), which has become widely accepted as the definitive study of annoyance caused by noise from trains. The y axis is the 'summed annoyance index', a measure of response, and the x axis is the L_{Aeq,24-hour}. By

averaging these responses the trends were more clearly illustrated as shown in Figure 3-2 (Fields and Walker, 1982). Fields and Walker were thus able to fit a line through these points and hence derive a dose-response relationship.

- 3.6 Figure 3-3 illustrates the linear relationship found between external sound levels and test results in London schools (Shield and Dockrell, 2008). The figure shows the points representing individual schools and the corresponding regression line which may be taken as a general relationship between test results and sound levels.

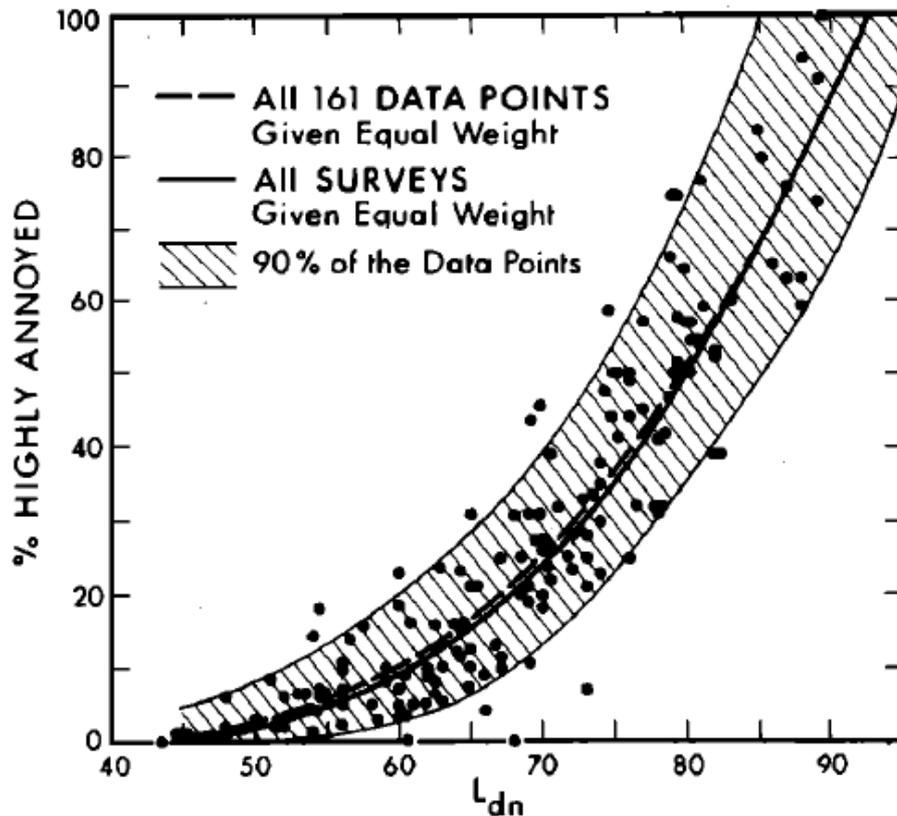
Figure 3-3: Relationship between external sound levels and test scores of 7 year olds (Shield and Dockrell, 2008)



- 3.7 As is suggested by the above figures and as discussed further in Appendix B, dose-response relationships should be interpreted and used with caution. There is likely to be a very wide range of responses to noise at a particular level as response to noise varies widely from individual to individual and is affected by many personal, psychological and other factors. This variation is shown in the wide scatter of points around an averaged response or regression line or curve as can be seen in Figure 3-1 and Figure 3-3. From Figure 3-3 for example it can be seen that some schools achieved high test results with high external sound levels. The dose-response relationship shown by the regression line is merely an indicator of a general trend.
- 3.8 Another issue to be borne in mind when considering the implications of dose-response relationships is that some results are based upon a relatively small sample of subjects or on people living in a relatively small area, and the relationship found may not extend to the wider population. Furthermore, it is difficult to combine or compare results of different surveys. Studies may differ in emphasis, in types of questions asked, and

response scales used. In addition, language and cultural diversity may make it difficult to compare or combine results obtained from studies in different countries.

Figure 3-4: Schultz curve showing community response to transportation noise (Schultz, 1978)



3.9 Nevertheless, a synthesis of responses to surveys of transportation noise was carried out by Schultz in 1978 (Schultz, 1978). Schultz modified and combined the results of 11 surveys of community response to noise from road, rail and air transport to produce a single curve showing the relationship between sound level and annoyance, shown in Figure 3-4. The 'Schultz curve' has been updated several times over the past 30 years, notably by Fidell *et al* (1991) and Finegold *et al* (1994), who have included more recent data in the analysis. The Schultz curves have played a very significant role in the assessment of environmental noise. The original Schultz curve is shown in Figure 3-4, and the Finegold version in Figure 3-5; a comparison of the Schultz, Fidell and Finegold versions of the curve is made in Figure 3-6 (taken from van Kempen *et al*, 2005).

Figure 3-5: Finegold version of Schultz curve showing community response to transportation noise (Finegold *et al*, 1994)

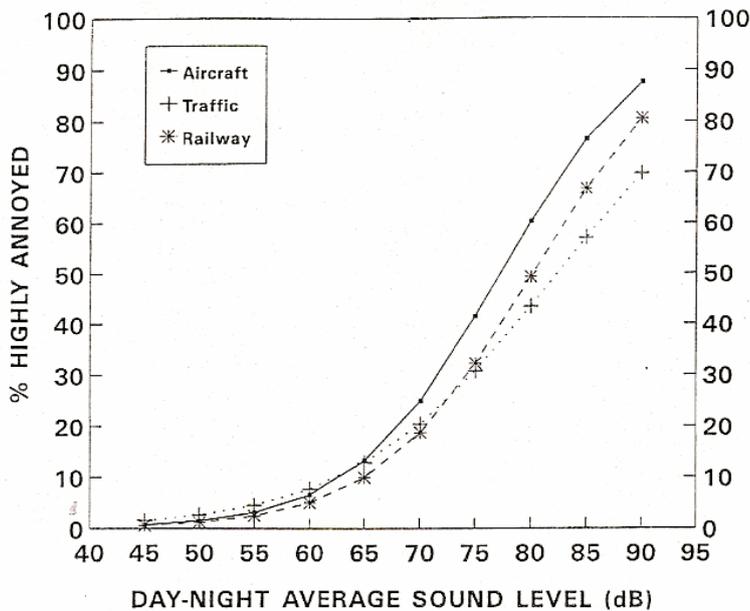
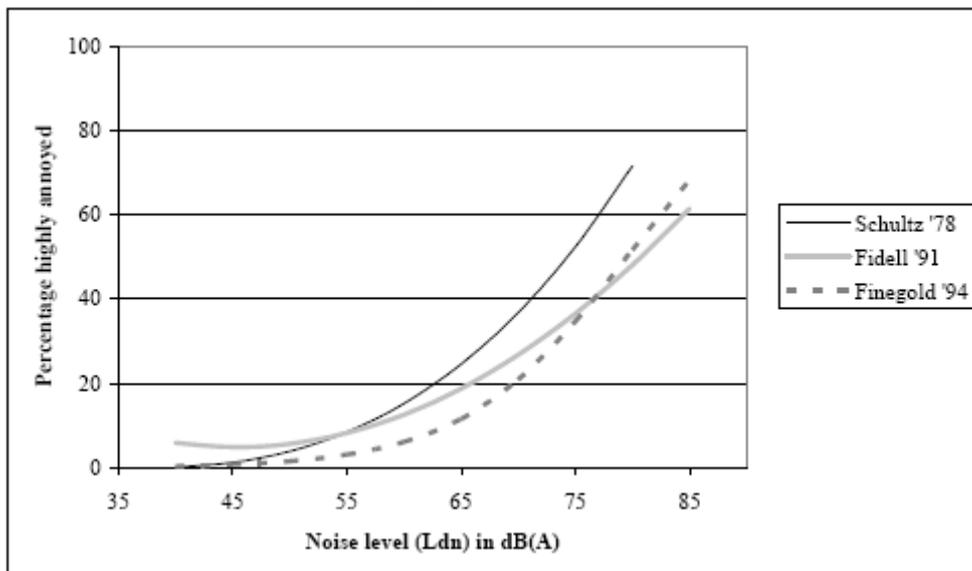


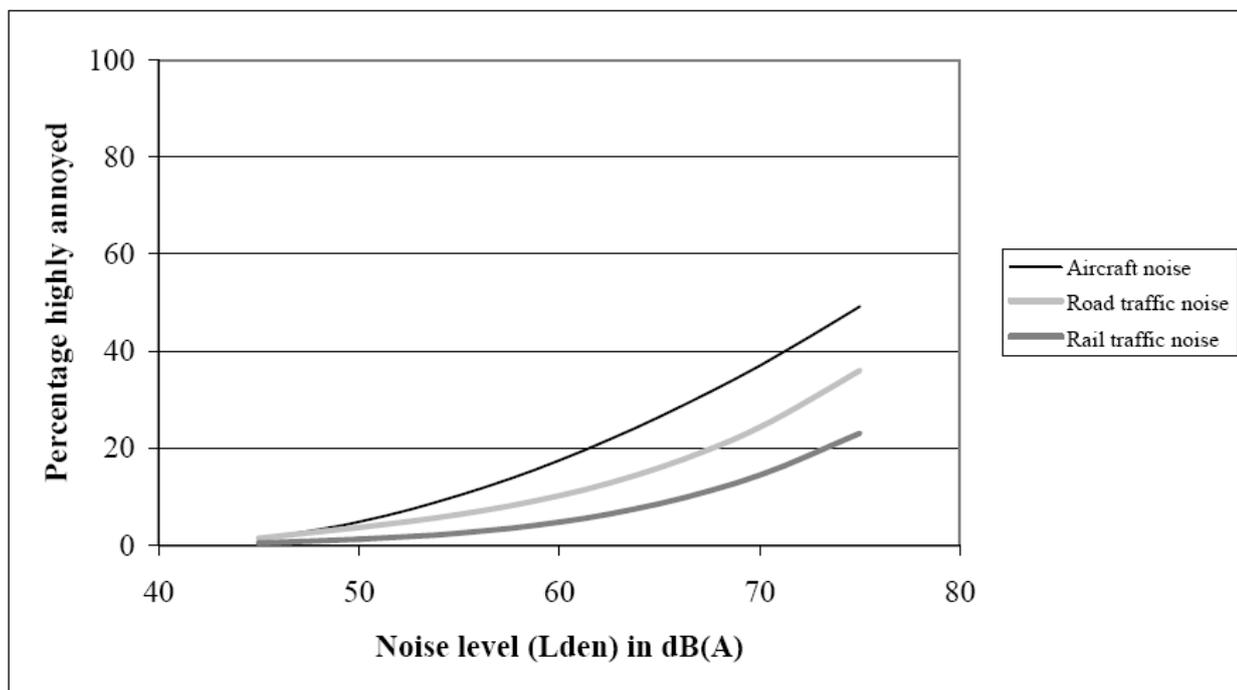
Figure 3-6: Comparison of the Schultz, Fidell and Finegold versions of the Schultz curve (van Kempen *et al*, 2005).



3.10 The validity of using a single curve to establish response to noise from different sources has been repeatedly questioned (Kryter, 1982, 1983, 2007; Miedema and Vos, 1998). An alternative approach is to treat different sources separately as done by Miedema and Oudshoorn (2001), who amalgamated several surveys of noise from road, rail and air traffic to derive dose-response curves representing sound level/annoyance relationships for each type of source. These curves are shown in Figure 3-7 (taken from van Kempen *et*

al, 2005), and are regarded as being the most reliable curves currently available; they are discussed further in Chapter 5. As can be seen from Figure 3-8, these curves show a considerable difference between responses to noise from the three different sources. However, it must be remembered that each of these curves are themselves an amalgam of several surveys relating to each type of source, and therefore the reservations discussed above regarding the difficulty of combining surveys still apply.

Figure 3-9: Dose response relationships for the association between noise from different sources and annoyance derived by Miedema and Oudshoorn (2001) (from van Kempen *et al*, 2005).



3.11 Figure 3-4 provides further illustration of the wide degree of scatter that is obtained in social surveys of attitudes to noise. Although the general trend is for annoyance to increase with increasing sound level, at any one level of exposure there can be a wide range of responses. Thus it is not possible to predict with certainty what the public response will be to a particular noise. Furthermore, it can be seen that at low sound levels there can be quite a strong adverse response, while at higher levels of sound there may be only a fairly mild reaction.

Wilson Committee

3.12 The first major examination of the extent of noise problems and potential mitigation measures in an industrialised society took place in the UK in the early 1960s. In 1960 the government appointed Sir Alan Wilson as chair of a committee to 'Examine the nature, sources and effects of the problem of noise and to advise what further measures can be taken to

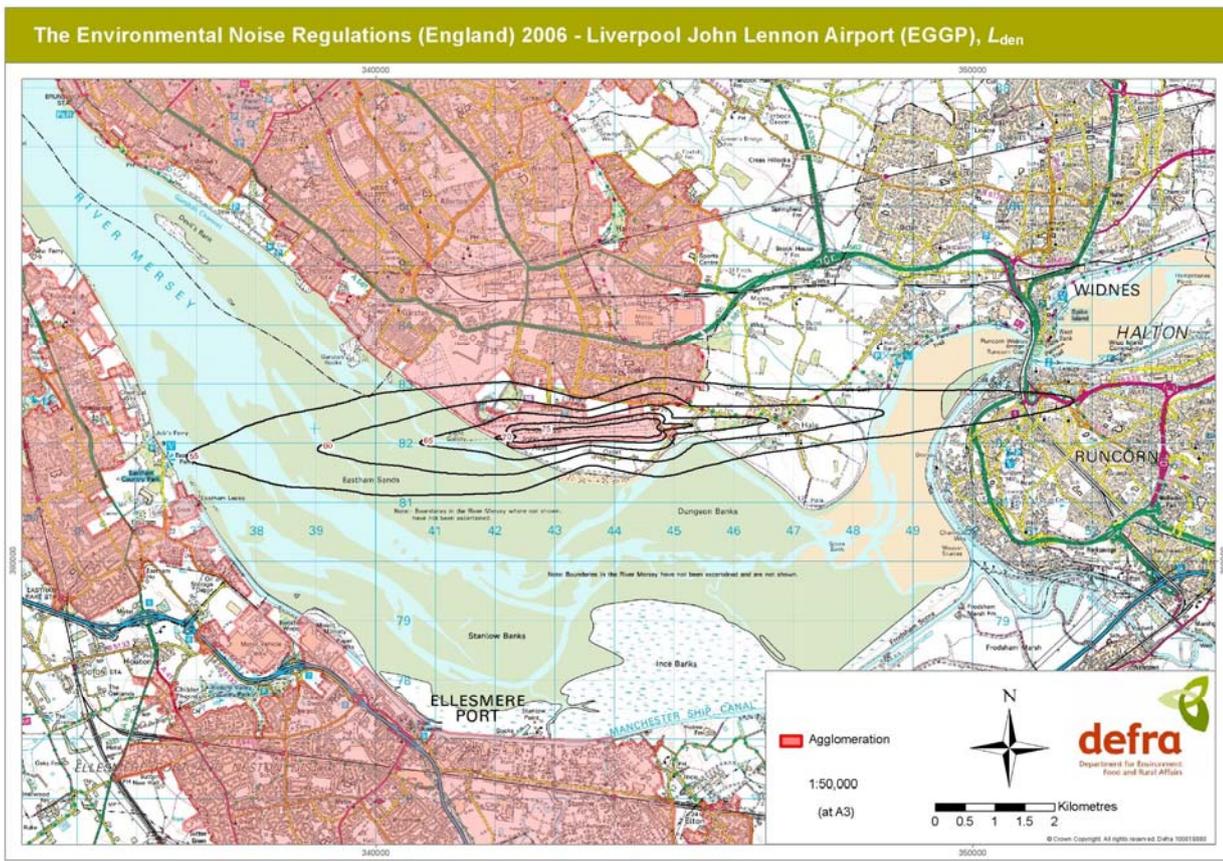
mitigate it' (Committee on the Problem of Noise, 1963). The Wilson Committee, as it became known, made a wide-ranging investigation of various aspects of noise including the law as it then stood, noise in towns, noise in the country and noise in buildings, plus noise from motor vehicles, railways, aircraft, industry, construction sites and entertainment activities. In 1963 the Committee reported on their deliberations and produced a document which for many years was regarded as the definitive statement on the nature and extent of noise in the country at that time (Committee on the Problem of Noise, 1963). The report has had lasting significance for the assessment of environmental noise.

- 3.13 The Wilson Committee was responsible for establishing several of the social surveys carried out in the early 1960s to establish acceptable levels of noise, in particular of noise from road traffic and from aircraft around Heathrow Airport. The Committee also established the concept of noise contour maps around airports. This has become the standard method of illustrating the extent of noise pollution around airports. Sound level contours together with other methods of illustrating noise exposure or response to noise are discussed in the following sections.

Noise contours

- 3.14 The first use of noise contours was to describe the extent of noise exposure around Heathrow airport in the 1960s. Noise contours are now commonly used to demonstrate noise exposure around all major airports. They are based upon standard methods of calculating sound levels due to aircraft which take account of numbers of take offs and landings, types of aircraft, weather conditions and so on. Figure 3-10 shows a noise contour map which illustrates the 55, 60, 65, 70 and 75 dBA contours around Liverpool John Lennon airport.

Figure 3-10: Noise contours around Liverpool John Lennon Airport (EGGP), L_{den}



3.15 From a noise contour map it is possible to determine both the area and the population exposed to noise above a particular level. It is then feasible to estimate the changes in the numbers of people exposed to aircraft noise at a certain level which would result from changes in flight paths, numbers of flights, numbers of night flights, new runways, and so on. Thus, by viewing contours in the knowledge of dose-response relationships and with an awareness of their limitations, it is possible to investigate potential changes in the population affected by aircraft noise, associated with operational changes at the airport.

3.16 Until recently the lowest aircraft noise contour plotted in the UK was the 57 dBA $L_{Aeq,16}$ -hour contour as this is the level of aircraft noise which was found to correspond with the onset of significant community annoyance in an extensive survey of response to noise from air traffic, published in 1985 (Brooker *et al*, 1985). This survey is known as the ANIS (Aircraft Noise Index Study) survey and has been accepted for the past twenty years as providing the most comprehensive and reliable information available regarding response to aircraft noise in the UK. Conversely, a recent survey (ANASE - Attitudes to Noise from Aviation Sources in England) has suggested that more people than found in the ANIS study are now annoyed by a given level of aircraft noise (see MVA Consultancy report on the DfT website: Department for Transport, 2007). However, there are

unresolved differences of opinion between the peer reviewers who have counselled against using the detailed results and conclusions from the study in the development of government policy, (Havelock and Turner, 2007; Brooker, 2008) and the ANASE study team. This current argument further illustrates the difficulties and discrepancies that can arise when trying to establish dose-response relationships.

Noise exposure and attitude surveys

- 3.17 An alternative method of quantifying the population exposed to environmental sound of a particular level is to carry out a nationwide survey, monitoring sound level at a representative sample of locations around the country, and extrapolating the results to the population as a whole. Such surveys were commissioned by Defra and carried out in 1990 and 1999/2001. The most recent National Noise Incidence Survey (NIS) survey involved monitoring sound levels over a 24-hour period at 1,160 locations around the UK (Skinner and Grimwood, 2002). The results, which are discussed in more detail in the next Chapter, showed a significant decrease in average daytime sound levels, and a slight increase in sound levels at night. Thus regular monitoring of the sound environment in this way provides some information on actual changes to the environmental sound climate over a period of time.
- 3.18 Attitudes of populations to noise can be investigated using large scale social surveys. Alongside the noise incidence surveys, noise attitude surveys (NAS) were carried out at approximately the same time, to gauge the attitude of the population as a whole to noise. The 2000/1 attitude survey (Ling *et al*, 2002) consisted of a questionnaire survey of around 5000 people which asked people which environmental noise sources they could hear, and whether they were 'adversely affected' by the noise of the various sources. Changes in response to noise can be studied by comparing the results of the 1991 and 2000 surveys (Grimwood *et al*, 2002). The results of the NIS and NAS are discussed in more detail in Chapter 4.

Noise complaints

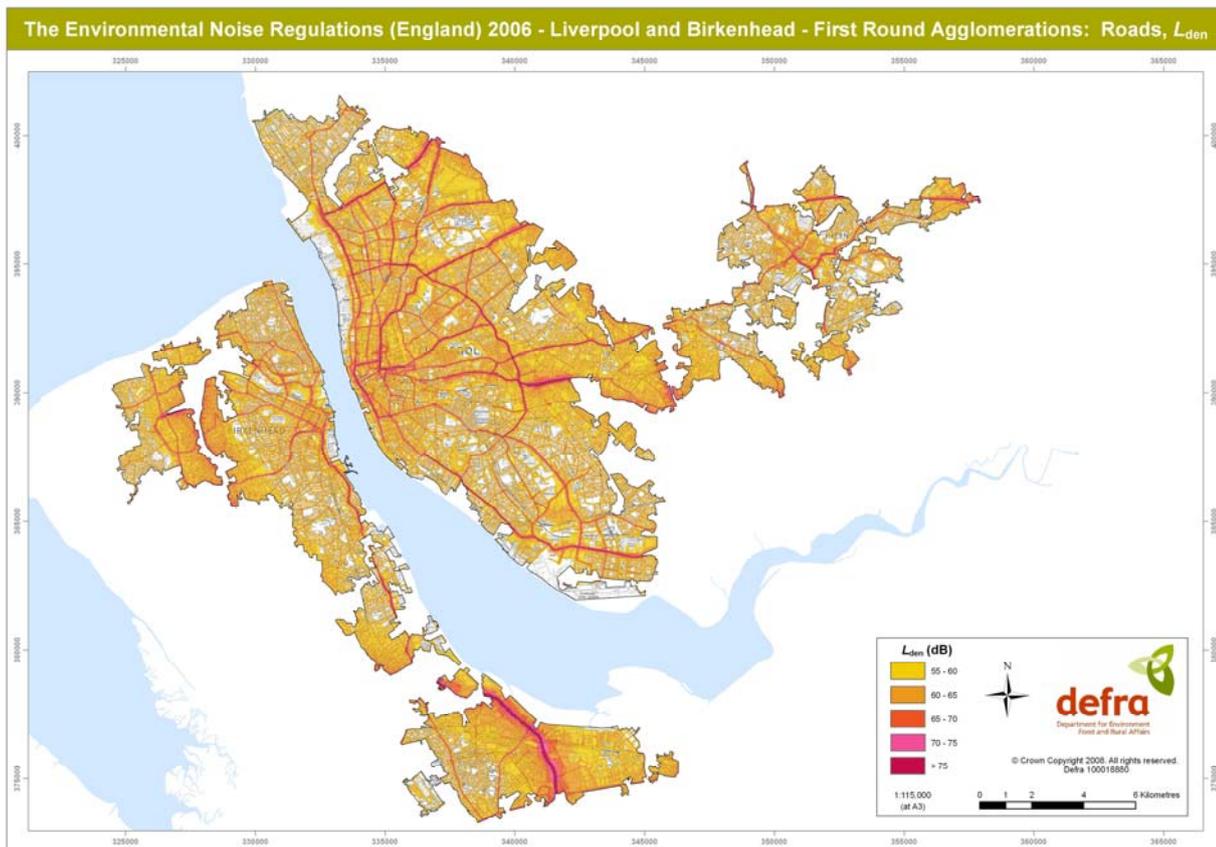
- 3.19 An additional method of quantifying annoyance caused by noise is by the monitoring of the numbers and types of noise complaints to local authorities. The Chartered Institute of Environmental Health publishes annual statistics on the numbers of people who complain to local authorities about noise from domestic, industrial and commercial premises and from road works and construction. Examining the changes in numbers of complaints from year to year, and relative incidence of complaints about different sources, gives an indication of changes in response to noise. However, statistics are only available for those local authorities which provide information and may not necessarily be a true reflection of the situation in the country as whole. Furthermore there are many reasons, not necessarily related to sound levels, why changes in numbers of complaints may occur, for example publicity given to noise as an environmental pollutant or health

hazard, and increased awareness of how and where to complain. Complaint statistics are discussed further in Chapter 4.

Noise mapping

- 3.20 European Directive 2002/49/EC on the assessment and management of environmental noise was published by the European Union on 25 June 2002 (European Commission, 2002). The aim of the Directive was to define a common approach across Europe to the avoidance, prevention and reduction of the harmful effects of exposure to environmental noise. As part of the action towards achieving this aim all member states are required to determine exposure to environmental noise through strategic noise mapping. The Directive required strategic noise maps to be produced by June 2007 for all major roads, major railways, major airports and agglomerations with populations of over 250,000. Mapping will be used for the evaluation of the numbers of people exposed at different sound levels, and for the identification of problems, and is to be repeated at 5 yearly intervals. All member States were required, by 2008, to draw up action plans, based on the maps, to reduce noise where necessary. These plans should include measures to protect quiet areas in agglomerations from an increase in noise.
- 3.21 It should be understood that in order to reflect accurately the noise climate the mapping needs to consider all transportation sources (road traffic, trains, aircraft) and industrial noise (noise from neighbours and other types of neighbourhood noise are not included in the maps). Mapping software is being developed which uses well established, standardised methods of calculating sound levels from the various sources. Figure 3-11 shows a noise map of Liverpool and Birkenhead for road traffic noise, the darker, redder colours indicating higher sound levels.

Figure 3-11: Noise map of Liverpool and Birkenhead for road traffic



- 3.22 In 2004, the results of the London Road Traffic Noise map were published. These showed the numbers of people affected by various levels of road traffic noise according to computer based modelling of the road traffic noise impact in the Greater London Authority area. From this study about 20% of the population of London were predicted to be exposed to traffic noise outside their homes at levels in excess of a daytime level of 60 dBA, $L_{Aeq,12\text{-hour}}$.
- 3.23 Noise mapping can be used to provide information in many different ways, for example by showing noise contours, areas subject to different sound levels, or properties and populations exposed to noise of different levels.
- 3.24 However, noise maps are only as accurate as the input data and techniques used to calculate sound levels. Furthermore, depending on scale, noise maps may not be able to accurately reflect the fine detail of variations in sound level which may occur locally, for example as a result of reflection or shielding of sound by a nearby surface. In order to accurately predict the noise climate in an area all sources of noise need to be considered. The relative benefits of reducing particular sources can then be estimated. However, as with other techniques discussed in this Chapter, a noise map is not intended as a measure of attitudes to noise or effects of noise in a particular area.

3.25 Using a noise map to investigate the effect of mitigating the noise from a particular source may also not accurately reflect the likely benefits which may be achieved. For example, in an area subject to high levels of aircraft noise, a reduction in the number of road vehicles may make no difference to the environmental noise indicator, yet may lead to greater satisfaction with the noise environment amongst people living in the local area.

International guidance

3.26 This Chapter has illustrated a selection of methods that are currently used in the UK for examining some of the effects of noise and likely benefits of noise mitigation. However, when community response to noise is discussed reference is often made to two important international documents: the World Health Organisation (WHO) community noise guidelines (World Health Organisation, 1999) and the European Noise Directive (European Commission, 2002). Both of these documents are discussed in more detail in Chapter 7.

3.27 In 1995 the WHO published a review of the current knowledge about the effects of noise and the levels of sound at which effects occur, and suggested guideline levels appropriate for various situations (Berglund and Lindvall, 1995). The final document, which was published in 1999, lists guideline values for environments such as dwellings (living and sleeping areas), schools, hospitals and parks. See Chapter 7 for a more detailed list of the guidelines values and specific health effects.

3.28 The European Noise Directive (END) was published in 2002, in order to develop a common approach among member states towards addressing problems of environmental noise. As seen above, one outcome of the Directive is the introduction of noise mapping across Europe, with associated action plans to manage noise. The END has also led to a harmonised system of noise indicators, as discussed further in Chapter 7.

Conclusions

3.29 As has been discussed briefly above, the assessment of noise and in particular the estimation of the prevalence of harmful effects is a complex process. There is no definitive method of determining the likely response to a particular situation, or the change in response if there is a change in the noise climate. Different sources affect people in different ways, at different levels. Thus estimating the likely effectiveness of alternative options for noise management is very difficult.

3.30 It must also be remembered that any dose-response relationship relating an effect of noise to a particular sound level is a statistical relationship, representing a general trend; there is always likely to be a wide degree of variation around the trend. Thus for a given source some people will be affected at sound levels considerably below the 'norm', while others will not be affected at all at much higher levels. Indeed, however stringent a noise

criterion might be it is highly likely that someone will still be adversely affected by the noise at or below the criterion level.

- 3.31 Noise contours or maps predict only sound levels, and not the corresponding response to the noise. In assessing changes in sound level which may arise due to particular measures to reduce noise, the implications of such changes need to be carefully considered. For example, a noise map, designed to show differences in sound level, may indicate that a large area or population will experience a reduction in sound level. However the significance of the change to people in the area will depend not only on the sound level but also on other factors such as the character of the noise, the source of the noise and its temporal variation. For example, in an area where aircraft flyovers are the dominant source of noise, a reduction of 3 dB in the L_{den} caused by halving of the number of flyovers is likely to be noticeable to residents. However, in an area where sound levels are predominantly steady, for example where many different noise sources contribute to the overall ambient sound, a reduction of 3 dB in the L_{den} might not be noticed by many people (see Chapter 1).
- 3.32 Thus any of the methods described in this Chapter for assessing response to noise need to be used and interpreted with caution, bearing in mind the implications of the particular method used.

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Chapter 4. The noise environment in the UK

Introduction

4.1 In this Chapter the current distribution of environmental noise in the UK is examined. We start by looking at the sound levels typically found around homes, and from a range of sources. In the later part of the Chapter we look at attitudes to noise and the incidence of complaints. This Chapter is heavily based on two large-scale surveys. The first, as mentioned in the previous Chapter, was a national study carried out on behalf of Defra in 2000/2001. The second was a local study carried out in the Merseyside area in 2004. Both studies included measurements of sound levels as well as surveys of attitudes to noise. The Defra-funded studies, the National Noise Incidence Study (NIS) and the National Noise Attitude Study (NAS), conducted in 2000/2001 were, in part, a repeat of a similar survey conducted ten years earlier, so that it is possible to determine trends in sound levels and attitudes over the intervening period⁴. In addition to these surveys, we review statistics on complaints about noise received by local authorities, which are compiled annually by the Chartered Institute of Environmental Health.

Sound levels outside the home

- 4.2 The measurement part of the national study is known as the National Noise Incidence Survey (NIS) (Skinner and Grimwood, 2002; Ling *et al* 2002a; 2002b; Skinner *et al* 2002a; 2002b). In the 2000-2001 NIS, external sound levels were measured outside 1,160 dwellings throughout the UK over 24-hour periods spread over the course of the year. The locations were selected to be statistically representative of the population, so it is possible to estimate the percentages of people exposed to given sound levels to within reasonable limits of uncertainty. Table 4-1 shows the proportion of the population of England and Wales estimated to be exposed to sound levels within 5 dB bands.
- 4.3 In the Merseyside study, 24-hour measurements were made at 90 locations. Whilst the Merseyside study is not statistically representative of the national picture, part of the rationale for the study was to determine whether a densely populated conurbation would differ significantly from the UK average picture produced in the NIS. Locations were selected on the basis of the noise sources in the vicinity, near airports, motorways etc. The disadvantage of this approach is that it is not possible to estimate the proportion of the Merseyside population exposed to given sound levels. The advantage is that it provides

⁴ The first NIS and NAS studies were conducted in 1990 and covered England and Wales. The follow-up study carried out a decade later was also extended to Scotland and Northern Ireland. Figures for the 2000/2001 study are therefore valid for the whole of the UK, but trends and comparisons over the intervening 10 year period apply only to England and Wales.

qualitative information about the relative importance of the various noise sources at the selected survey sites.

- 4.4 Average daytime sound levels in the UK in 2000/2001 were 57 dB $L_{Aeq,16-hour}$, and the same figure was produced on Merseyside in 2004. The corresponding average night time sound levels ($L_{Aeq,8-hour}$) were 48 dB in the UK as a whole and 50 dB on Merseyside.
- 4.5 It is interesting to note the observed differences between day and night time average sound levels between the two surveys. In the UK as a whole the night time period was an average of 9 dB quieter than the daytime, whereas on Merseyside a difference of only 7 dB was observed. It is not known whether this difference is due to the greater population density in the Merseyside study area compared with the UK as a whole, or is a result of, for example, differences in the amount of night time car usage between 2001 and 2004. It is theoretically possible that this difference could have occurred simply as a result of sample selection bias in the Merseyside study.

Table 4-1: Sound levels outside the facades of homes in England and Wales from the NIS (Skinner and Grimwood, 2002).

Façade level, dBA Day time (07:00-23:00)	Proportion in band	
	1990	2000
$L_{Aeq,16-hour} < 55$	8%	10%
$50 \leq L_{Aeq,16-hour} < 55$	32%	35%
$55 \leq L_{Aeq,16-hour} < 60$	30%	30%
$60 \leq L_{Aeq,16-hour} < 65$	18%	15%
$L_{Aeq,16-hour} \geq 65$	12%	10%

Façade level, dBA Night time (23:00-07:00)	Proportion in band	
	1990	2000
$L_{Aeq,8-hour} < 45$	34%	32%
$45 \leq L_{Aeq,8-hour} < 50$	32%	36%
$50 \leq L_{Aeq,8-hour} < 55$	19%	18%
$L_{Aeq,8-hour} \geq 55$	15%	16%

Comparison with recommended sound levels

- 4.6 The World Health Organisation (WHO) states that *'to protect the majority of people from being seriously annoyed during the day-time, the sound pressure level on balconies, terraces and outdoor living areas should not exceed 55 dB L_{Aeq} for a steady continuous noise.'*... *'At night,*

sound pressure levels at the outside façades of the living spaces should not exceed 45 dB L_{Aeq} and 60 dB L_{Amax} , so that people may sleep with bedroom windows open.' (WHO 1999)

- 4.7 The NIS study concluded that an estimated 55% of the population of the United Kingdom live in dwellings exceeding the recommended daytime sound level of 55 dB ($L_{Aeq, 16\text{-hour}}$), and that 67% live in dwellings exceeding the night-time recommendation of 45 dB ($L_{Aeq, 8\text{-hour}}$). These figures can be taken as representative of the population as a whole. The picture on Merseyside was broadly similar, with 48% of the locations exceeding the daytime WHO recommendations and 70% the night time recommendations. Note that the Merseyside figures cannot be extrapolated to the population as a whole, and the differences between the results of the two surveys could be, at least in part, due to the different sampling strategy. Nevertheless, it is clear that a significant proportion of the population is exposed above the WHO recommendations.
- 4.8 The percentage of the population of the UK exposed to sound levels exceeding 68 dB $L_{A10,18\text{-hour}}$, (the minimum level qualifying for sound insulation grants under the Noise Insulation Regulations for new roads), was calculated as 8% in the NIS. In the Merseyside study 14% of sampling locations exceeded this limit (again, caution is required if extrapolating this figure to the population as a whole). Again, despite differences in the figures between the two studies it is clear that a significant proportion of homes exceed the threshold limit for noise insulation grants.

Differences across regions and land use categories

- 4.9 A regional breakdown of sound levels in the NIS indicated that there are only small differences in the mean levels of various sound level indicators between individual regions of the UK. In the Merseyside study the difference in sound levels ($L_{Aeq, 16\text{-hour}}$) between the noisiest and the quietest local authority was around 5 dBA.
- 4.10 In the national study, the average levels for sites falling into the categories of "Urban (residential)" and "Predominantly residential but with some light industry or main roads" were typically 10 dB higher than those for the categories "Rural (residential)" or "Suburban, little road traffic". This difference was seen to be fairly uniform across the 24-hour day.

Changes in sound levels between 1990 and 2000

- 4.11 By comparing results from the 2000/2001 NIS with those produced ten years earlier, it is possible to establish trends in sound levels. The 1990 NIS, and therefore the comparisons, are limited to England and Wales. The L_{A10} (the level exceeded for 10% of the time), was found to have decreased during day-time periods between 1990 and 2000, while the L_{A90} , (the level exceeded for 90% of the time) increased at night. In both cases the changes were statistically significant, but small. These patterns are compatible with a model of noise exposure in which the levels of individual events (e.g. cars, aircraft etc.) have decreased, but the frequency with which such events occur has increased. Further study of the

variation in sound levels during the day showed the night-time increase in sound levels to be partially due to a shortening of the quiet night-time period, and partially due to increased minimum levels in the quietest part of the night.

- 4.12 The proportion of the population exposed to greater than the WHO recommended day time guideline value of 55 dB $L_{Aeq,day}$ decreased significantly between 1990 and 2000. As reported above, in 2000 an estimated 55±3% of the population of England and Wales lived in dwellings exposed above this level, whereas in 1990 the estimated figure was 60±3%. Thus, and possibly contrary to much popular belief, the trend is towards lower noise exposure of the population, at least as far as daytime sound levels are concerned.

Sources of noise in the UK

- 4.13 For policy purposes it is of interest to determine the relative importance of various noise sources, road traffic, rail, aircraft and industry, on the sound levels experienced by the population. The Merseyside survey provided useful information about sound levels in different categories of location. Not surprisingly locations near motorways, urban roads and transport interchanges were most likely to exceed WHO guideline values. The categories in order of decreasing daytime sound levels were: urban roads, motorways, transport interchanges, town centre, parks, railway, airport, rural, suburban. A possibly surprising result was the rank ordering of parks, where sound levels were not as low as might have been expected, although there is a technical possibility that this finding might have been biased by measurement locations near the borders of parks next to main roads. On the other hand, many urban parks are located in relatively densely populated areas where they provide much-valued havens of *relative* peace and quiet without necessarily being far enough distant from the main sources of noise to be '*quiet*' in an absolute sense.
- 4.14 Relatively detailed information exists on sound levels around many airports, where it has become standard practice to publish sound level contour maps on an annual basis. Changes in aircraft performance and improvements in engine technology have meant that the areas and numbers of people around airports affected by aircraft sound levels, measured in $L_{Aeq,T}$ have not been increasing as quickly as air transport movements and aircraft passenger numbers. In 2004, 240 thousand people lived within the 57 dB ($L_{Aeq,16-hour}$) contour around Heathrow Airport (corresponding to the official definition of the onset of significant annoyance based on the 1982 ANIS study) and 56 thousand people within the 63 dB contour.

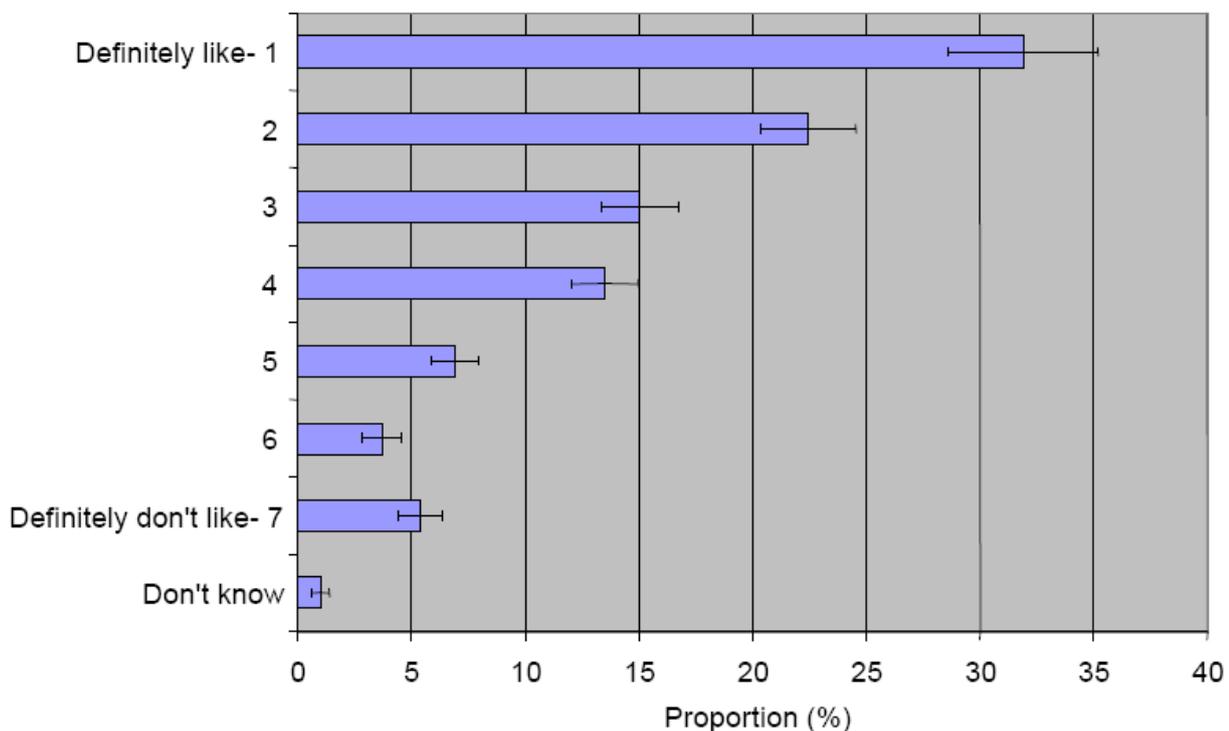
Attitudes to Noise

- 4.15 In addition to the NIS, the BRE also carried out a National Survey of Attitudes to Environmental Noise (NAS) in 1999/2000 (Ling *et al*, 2002a, 2002b; Skinner *et al*, 2002a, 2002b), which, again was a follow up of a similar survey conducted in 1991.

Attitudes to noise in the UK in 1999/2000

4.16 In the national study, respondents were shown a list of twelve environmental problems and asked which five they were most affected by. Noise was ranked ninth overall in the list of twelve problems, with 18% of respondents including it as one of the top five environmental problems which affect them. Top of the list were 'fouling by dogs', and 'litter and rubbish'. In the Merseyside survey, using a similar approach, but a different list, noise was ranked fourth in terms of negative impact, being chosen by 29% of respondents. 'Litter, dog fouling and graffiti' was the most common choice with 46%.

Figure 4-1: View on the amount of noise 'around here' (from Skinner *et al*, 2002a).



Error bars represent 95% confidence limits for scaling up the results to the whole UK.

4.17 Figure 4-1 summarises results from the NAS concerning attitudes to the amount of noise 'around here'. It is interesting to see that 32% of the respondents reported that they definitely liked the amount of noise (we can assume that most respondents understood this to mean an absence of noise, although some may have interpreted it differently). If this question is taken to describe respondents' attitudes to their noise environment in a general sense (whether it be loud or quiet), then, considering the top three categories together, 69% of the respondents reported general satisfaction with their local noise environment. In the Merseyside study, 6% always found noise a problem, 12% found it a problem most of the time and 26% never perceived it to be a problem. Furthermore, 9% considered that noise 'totally' spoiled their home lives, 16% thought it did so 'quite a lot', and 23% 'not at all'.

4.18 In another survey, Public Attitudes to Quality of Life and the Environment, carried out across England by Defra in 2001, 22% of people were 'very worried' by noise, and 35% 'fairly worried'. Overall, these figures indicate that while the majority of the population do not consider themselves to be significantly affected by noise, a significant minority are affected and many of these people consider some of the effects to be seriously damaging to their overall quality of life.

Changes in attitudes between 1991 and 1999

Table 4-2: Proportion of respondents in England and Wales who reported hearing noise, and being adversely affected by it (taken from tables 2 and 5 of Ling *et al*, 2002b)

Noise source	Proportion of respondents who reported hearing each category of environmental noise			Proportion of whole sample who reported hearing and being adversely affected by each category of environmental noise		
	1991	1999	Significant change ²	1991	1999	Significant change ²
Road traffic	48%	54%	Increase	29%	30%	
Aircraft	41%	43%		17%	17%	
Neighbours/ other people nearby	28%	38%	Increase	21%	26%	Increase
Trains or railways	13%	17%		4%	4%	
Building construction or roadworks	6%	7%		3%	4%	
Sports events	6%	7%		1%	2%	
Entertainment or leisure	5%	6%		3%	4%	
Farming or agriculture	4%	5%		1%	1%	
Factories or works	2%	4%		2%	2%	
Commercial premises	2%	3%		1%	2%	
None of these	22%	17%	Decrease			

1: Adversely affected' means that the respondent reported one or more of the following reactions to noise: personally object, irritated, disturbed, personally concerned, annoyed or upset at times, a nuisance to you personally.

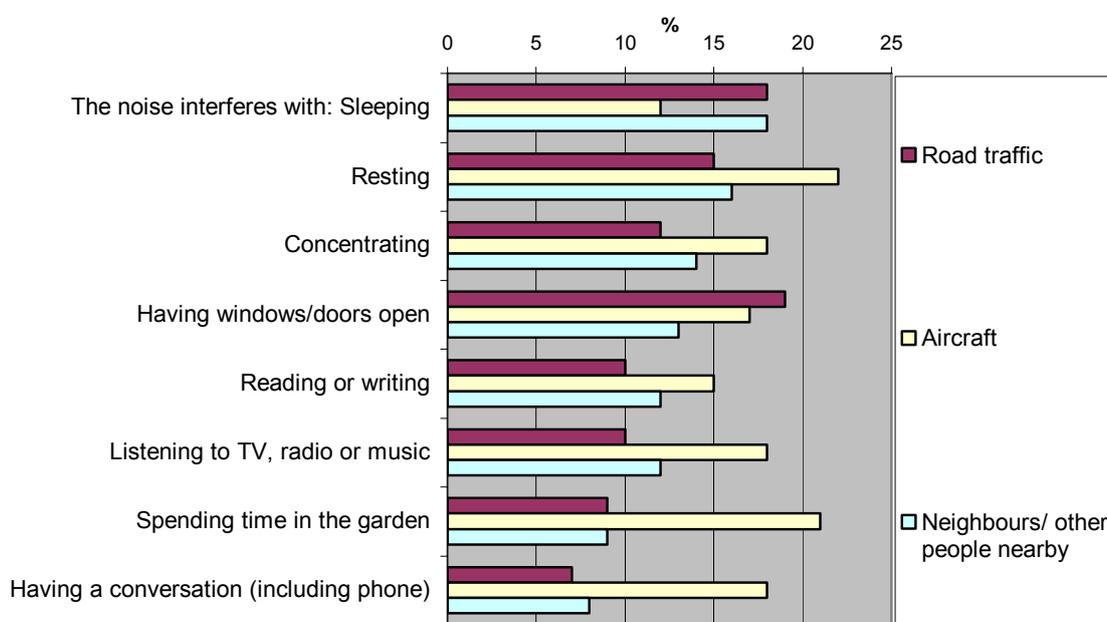
2: 95% confidence interval

4.19 Table 4-2 presents results from the NAS which is thought to provide a reliable indication of changes in attitudes between 1991 and 1999. The table shows the number and proportion of respondents in 1991 and 1999 that reported hearing noise from a range of different sources. Road traffic was shown to be the most commonly heard noise category and the proportion reporting it increased significantly (from 48 per cent to 54 per cent). The proportion of people reporting hearing noise from neighbours or other people nearby

also increased significantly from 28 per cent to 38 per cent. However there was no significant change for any of the other sources.

4.20 In the NAS, road traffic was found to be the most commonly reported source of noise in the UK, heard by 54% of respondents in 1999/2000 with 8% of respondents being 'very' or 'extremely' 'bothered, annoyed or disturbed' by it. Neighbours and aircraft were the next most commonly heard noise sources, with 9% and 2% of respondents respectively reporting being 'very' or 'extremely' 'bothered, annoyed or disturbed'.

Figure 4-2: Proportion of respondents reporting activity disturbance associated with different types of noise in the UK (data from the NAS, Skinner *et al*, 2002a)



4.21 The extent to which activities were disturbed by noise in 1999/2000 is shown in Figure 4-2. The disturbance depends to some extent on the noise source, for example, for road traffic noise 'having doors and windows open' was the most commonly reported activity to be disturbed, whereas for noise from aircraft and neighbours the most commonly disturbed activities were resting and sleeping respectively.

Table 4-3: Action taken by respondents to reduce noise, 1999/2000, UK (from Skinner *et al*, 2002a)

	Number who took type of action												
	Number 'bothered, annoyed or disturbed' 'moderately, very or extremely'	Complained to the person making the noise	Complained to the police	Complained to Environmental Health Department	Complained to Local Authority	Complained to landlord/housing association	Complained to a Government Department	Complained to MP/councillor	Campaign/ petition	Install double glazing	Something to help sleep (e.g. sleeping pills)	Took legal action/advice	No action taken
Neighbours/other people nearby:													
Radio, music, TV	201	87	15	7	14	9	0	5	1	6	6	0	87
Children	189	73	19	5	8	4	1	2	2	1	1	0	84
Teenager or adult voices	295	73	37	10	18	14	0	10	3	5	2	0	170
Parties (indoors)	81	27	14	5	7	4	0	1	0	0	1	0	40
Parties (outdoors)	74	12	9	4	4	1	0	0	0	2	2	0	45
Animals	229	29	6	5	5	3	0	1	0	0	1	1	176
Doors banging	141	28	5	2	7	6	0	2	0	1	0	0	90
DIY	110	27	0	4	4	3	0	3	0	1	1	0	75
Burglar alarms	150	16	11	2	2	0	0	3	0	2	1	0	112
Cars, motorcycles	137	23	10	2	10	1	0	1	3	5	0	0	95
Aircraft noise		3	0	0	2	1	1	1	5	11	2	0	346
		Proportion of sample who took type of action											
Road traffic noise		3%	2%	1%	2%			2%	2%	6%	1%		82%

Figures for neighbours/ other people nearby are actual numbers from a subset of 1835 respondents who were 'moderately, very or extremely' 'bothered annoyed or disturbed' by noise from neighbours or other people nearby

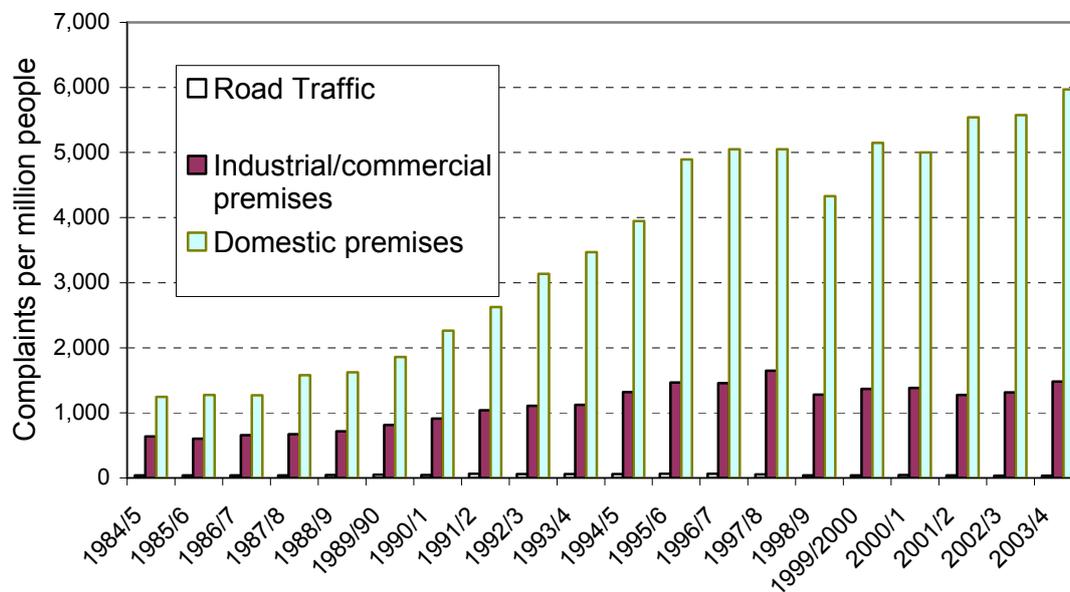
Figures for aircraft are actual numbers from a subset of 382 respondents for whom aircraft noise ranked in their top 3 noise categories of noise sources

Figures for road traffic are percentages from the total sample of 2849 respondents

Complaints about Noise and Action Taken

- 4.22 Table 4-3 shows details from the NAS of any action reported by respondents objecting to road traffic noise, noise from neighbours and aircraft noise. For all noise sources the most common response is to take no action. People bothered by noise from neighbours or other people nearby, if they took any action, were most likely to complain to the person making the noise, or to the police. The most common action by people reporting road traffic or aircraft noise disturbance is to do something to help them sleep, for example using ear-plugs or sleeping pills. However, very few people who reported road traffic noise or aircraft noise took any action at all.
- 4.23 Figure 4-3 summarises the number of complaints received by local authorities (those who provided information) between 1984/1985 and 2003/2004 (source: Chartered Institute of Environmental Health). Complaints about noise from domestic premises continue to be the most common complaint, accounting for over two-thirds of all noise complaints to Local Authorities in England and Wales. The data show an increase in the number of domestic complaints of almost five times between 1984/5 and 2003/4, although, as discussed later, this might not be a reliable indicator of changes in attitudes over this period. Complaints about road traffic and aircraft noise, for which Environmental Health Officers have no responsibilities under nuisance legislation, are likely to be understated in this data. Although the number of noise complaints reported has increased, this does not necessarily mean that there has been any increase in actual sound levels.
- 4.24 As mentioned in the previous Chapter, one needs to be cautious in interpreting complaint statistics as an indicator of attitudes to noise. First, not everyone who is adversely affected by a noise goes to the trouble of making a formal complaint. Also, complaints are recorded whether or not they prove to be justified, there is no means of checking the validity of, or justification for, complaints by any independent control. Furthermore, methods of collecting complaint statistics have changed over the years which make it difficult to establish reliable trends. This is particularly so over recent years because many local authorities have introduced new methods of call logging so that multiple calls about a single issue may be counted as separate complaints. Added to this, not all local authorities make returns every year, although this would clearly be desirable, again making it difficult to establish reliable information on trends.

Figure 4-3: Noise complaints per million of the population reported by local authorities 1984/5-2003/4



Reasons for noise complaints

- 4.25 Environmental Protection UK (formerly the National Society for Clean Air, NSCA) conduct annual surveys to gauge opinion of local authority officers who enforce current noise control legislation and to inform the debate about future policy development. The 2005 survey (NSCA 2005) asked, amongst other things, their opinion as to the reason for the level of noise complaints. Incompatible lifestyle with neighbours, selfish attitudes and higher expectation of quiet were seen as the main reasons for increasing levels of noise complaint.
- 4.26 The NSCA survey also collects information on the major sources of neighbourhood noise and other ambient noise sources being complained about to local authorities. Authorities were asked to rank each of eight sources of complaint in order of importance where 1 (one) signifies the most common source of complaint and 10 (ten) signifies the least common source of complaint. Table 4-4 summarises the results for England, Wales and Northern Ireland combined and for Scotland. Authorities were asked "*what in your opinion, were the major sources of complaint about noise nuisance to your authority?*" Amplified music is considered the most common source of complaint about neighbour noise in almost three quarters, and in the top three in 95% of authorities. Barking dogs are the second most common source of complaint. Authorities were also asked to rank other sources of complaint about ambient noise in order of importance. Pubs and clubs were the most common cause of complaint about noise in over half of authorities.

Table 4-4: Sources of complaints about noise nuisance to local authorities: as at March 2005

England, Wales and Northern Ireland		Number of local authorities								
neighbour noise										
Source of complaint	1 = most complaints, 10 = least complaints									
	1	2	3	4	5	6	7	8	9	10
amplified music	84	33	2	2	0	0	0	0	0	1
TV	2	10	33	14	16	11	2	4	1	3
dogs	35	64	17	6	3	2	2	0	0	1
voices	1	6	26	27	13	10	7	3	3	2
banging doors	1	2	9	24	20	17	18	8	5	4
DIY	1	1	21	16	28	24	16	6	2	0
children	0	0	5	9	10	20	22	24	10	8
intruder alarms	1	1	2	14	14	12	17	38	5	3
fireworks	0	1	0	0	4	5	7	13	42	29
laminates	1	0	1	1	2	4	7	6	23	50

ambient sources

Source of complaint	1 = most complaints, 7 = least complaints						
	1	2	3	4	5	6	7
traffic	5	4	4	15	23	14	26
industry	25	26	31	17	9	8	29
pubs/clubs	56	19	23	3	4	1	6
construction sites	16	41	28	13	27	3	1
outdoor events	1	5	14	39	22	5	9
car alarms	2	5	7	14	30	28	13
car stereos	2	3	0	6	9	36	39

Scotland		Number								
neighbour noise										
Source of complaint	1 = most complaints, 10 = least complaints									
	1	2	3	4	5	6	7	8	9	10
amplified music	2	8	3	0	0	0	0	0	0	0
TV	0	1	3	4	2	1	1	0	0	1
dogs	10	0	0	0	2	1	0	0	0	0
voices	0	0	1	3	2	0	3	3	0	0
banging doors	0	0	1	3	0	3	3	2	1	0
DIY	0	0	2	2	2	1	3	3	0	0
children	0	0	0	1	1	4	1	2	1	2
intruder alarms	1	1	1	0	0	1	0	2	6	1
other	0	0	3	0	4	1	1	1	5	9

ambient sources

Source of complaint	1 = most complaints, 7 = least complaints						
	1	2	3	4	5	6	7
traffic	0	0	3	2	5	2	0
industry	4	1	4	1	3	0	0
pubs/clubs	5	6	1	1	0	0	1
construction sites	4	4	1	2	0	1	0
outdoor events	0	0	3	4	3	1	1
car alarms	0	1	0	1	1	7	2
car stereos	0	0	0	1	0	2	9

4.27 A comparison of the NSCA data with the results of the NAS shows that what people complain about is not what necessarily affects them most. For example, in the NAS (Skinner *et al*, 2002a) 22% of people reported themselves bothered to some extent by the sound of voices, which ranked fifth in the NSCA list; fewer people (13%) reported themselves bothered to some extent by noise from DIY but this ranked higher (third) on the NSCA list.

Correlation between sound level indicators and adverse reaction

4.28 From the NIS and NAS surveys the L_{A10} indicators generally showed the strongest correlation with the majority of reactions to noise. Sound levels measured during the evening period (19:00-23:00) showed stronger correlation with reaction than sound levels measured in other periods of the day. The strongest correlation between the extent to which respondents reported being bothered, annoyed or disturbed by road traffic noise, was seen with the $L_{A10,4hr}$ index covering the evening period (19:00-23:00). This was also the case for the extent to which respondents reported being bothered, annoyed or disturbed during the day-time and night-time periods.

Discussion

4.29 The available data on measured sound levels and attitudes to noise paint a complicated picture of the noise environment in the UK. In 2000, 55% of the population lived in areas where external sound levels exceeded WHO daytime guideline values, and the corresponding figure at night was 67%. In terms of attitudes, complaints about noise have risen significantly over the last 20 years or so. Whilst neighbour noise is increasingly the dominant source of complaints, surveys also reveal significant dissatisfaction with environmental noise in general. Between 1990/1991 and 1999/2000 the proportion of people reporting hearing traffic noise increases significantly. Figures indicate that 8% of people in the UK are very or extremely bothered by road traffic noise. It is clear that the quality of life of millions of people is adversely affected by environmental noise in the UK.

4.30 However, whilst attitude surveys and complaint statistics suggest, if anything, growing dissatisfaction with the noise environment this does not necessarily imply higher sound levels. In fact, the percentage of the population exposed above the WHO daytime guideline values appears to have decreased significantly from $60\pm3\%$ to $55\pm3\%$ between 1990/1991 and 1999/2000. Another observation is that, over the same decade, the highest levels of environmental sound in the daytime decreased whilst sound levels in the quietest periods of the night increased. We can summarise these trends by noting that, whilst in some senses there is 'less noise', there is also 'less quiet'. This picture is broadly consistent with improved control of noise at source, counteracted by increased numbers of traffic movements, i.e. it suggests that the average sound level for 'noise events' (vehicle pass-bys etc.) has decreased but the number of events has increased spreading out over large areas of the countryside and for more hours of the 24-hour day and night period.

- 4.31 On the one hand, the above picture implies that legislative measures have been successful in terms of reducing average sound levels. On the other hand, if success is measured not in terms of sound levels, but in terms of the satisfaction of the general public then one might arrive at the opposite conclusion. Again, this apparent contradiction emphasises the crucial difference between objective and subjective measures of noise.
- 4.32 It is interesting to speculate on the incongruity between decreasing levels of environmental sound (at least according to some indicators) and the apparent rising levels of dissatisfaction. First we should note that the relatively small decreases in sound level, whilst identifiable on a statistical basis might not be particularly noticeable subjectively. Changes in the character of the sound might be more noticeable, for example if the number of noisy events, like vehicle pass-bys, has increased, this could give the impression of more 'activity' for the same average sound level ($L_{Aeq,T}$), which some people might find more disturbing. We can also speculate that the population could be responding more to the loss of 'quiet' during the night than to the reduction in sound level during the day. Finally, it may simply be the case that attitudes to noise are changing and that people are now less tolerant of noise than they used to be.

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Chapter 5. Annoyance and sleep disturbance

Introduction

5.1 This Chapter presents a review of previous research in the areas of annoyance and sleep disturbance. This review is based mainly on secondary sources to avoid duplicating a considerable amount of existing review material which is already widely available elsewhere. Reported annoyance in its various forms has attracted the most attention but sleep disturbance has also been quite widely researched. Strictly speaking, neither annoyance nor transient sleep disturbance would normally be considered as true 'health effects'. However, because both types of effects could in theory contribute to stress related illness and because, in its constitution, the WHO defines health as '*a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity*', some discussion of each is included in this report.

Annoyance

5.2 Annoyance can be defined as a negative attitude towards the source of an annoying factor which can be manifested in a number of different ways. Because people react to different situations in different ways, in the context of noise nuisance or disturbance, it is difficult to be precise about what 'annoyance' actually means. For some people, being annoyed implies being in a heightened emotional state associated with increased risk taking and an increased possibility of violence, in other words, being angry. For others however, being annoyed can lead to increasing feelings of powerlessness and frustration, which is widely believed to be at least potentially associated with adverse health effects over the longer term. Sometimes, people report a high level of annoyance when they are not actually annoyed in the emotional sense, but are instead reporting a strong negative attitude which might have had no other outlet until the opportunity to express or report annoyance occurs. In other cases, people may appear to have habituated to a noise and might only report annoyance when they are reminded of it. For this reason, some noise surveys deliberately conceal the true purpose of the questionnaire to discover to what extent noise might be mentioned spontaneously. Current practice, as recommended by ISO/TS 15666 (see discussion of ISO/TS 15666 below, International Standards Organisation, 2003) tends towards a more direct approach so that respondents understand exactly what is being asked of them, and responses are then taken at face value.

5.3 It is well known that people who are bothered or disturbed by noise do not always complain or take any other kind of action against the noise, and that the extent of complaints is influenced by the availability of a complaint recording system. However, practical experience shows that many people will agree to answer a properly designed questionnaire about noise annoyance, particularly if they understand that the data is being collected for research purposes only, that there will be no come-back depending on the answers given, and that the individual responses will remain confidential. Bias can never be completely

eliminated, but can be minimised by ensuring that the design and conduct of the survey is as scientifically satisfactory and as independent as possible.

- 5.4 In previous research, a wide range of questionnaire formats and detailed wordings have been used, but this has made comparisons between different studies highly dependent on a wide range of reasonable but essentially un-testable normalising assumptions. It can be quite difficult to avoid leading the respondent in particular directions by providing subtle clues within the questionnaire as to what kind of answers are expected. For example, just by giving a hint that the survey sponsor has a vested interest may be enough to bias the respondent in one direction or another. To help to resolve these difficulties, ISO Technical Report TS 15666 'Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys' (ISO 2003) defined noise-induced annoyance as '*a person's individual adverse reaction to noise*'. The definition in the standard is amplified by two notes as follows: *NOTE 1 The reaction may be referred to in various ways, including for example dissatisfaction, bother, annoyance and disturbance due to noise; NOTE 2 Community noise annoyance is the prevalence rate of this individual reaction in a community, as measured by the responses to questions specified in clause 5 and expressed in appropriate statistical terms.* The standard then specifies the precise questionnaire format to be used for measuring noise-induced annoyance (Figure 5-1):

Figure 5-1 Questionnaire format as proposed in ISO Technical Report TS 15666

Verbal rating scale

Thinking about the last (...12 months or so...), when you are here at home, how much does noise from (..noise source..) bother, disturb, or annoy you:

Not at all, Slightly, Moderately, Very, Extremely (*annoyed*)

Numerical rating scale

Next is a zero to ten opinion scale for how much (...source...) noise bothers, disturbs or annoys you when you are here at home. If you are not annoyed at all choose zero, if you are extremely annoyed choose ten, if you are somewhere in between, choose a number between zero and ten.

Thinking about the last (...12 months or so...), what number from zero to ten best shows how much you are bothered, disturbed, or annoyed by (...source...) noise?

Not at all annoyed 0 1 2 3 4 5 6 7 8 9 10 Extremely annoyed.

- 5.5 The ISO standard avoids the problem of not being able to define annoyance in any precise way by instead specifying the way in which it should be measured. In practice, 'noise annoyance' could mean many different things to different people depending on the context in which it occurs. By following the ISO standard, the meaning is defined by the standardised question. In order to carry out a survey which complies with the ISO standard or to use the responses in a meaningful way it is not necessary to understand why a person is annoyed or how their annoyance compares with that from factors other than the noise.

Annoyance has been defined simply by the way it is measured. Researchers may of course wish to consider using additional questionnaire items in an attempt to discover why people are reporting particular degrees of annoyance, and perhaps more importantly, what might be done about the problem, although in order to avoid potential bias, these types of questions might be better reserved for a follow-up survey.

- 5.6 It might not be immediately obvious that noise annoyance defined in this way should be considered as a definitive 'health' effect as defined in the WHO constitution. However, reported annoyance measured according to the ISO standard reflects the degree of adverse reaction in terms of perceived '*physical, mental, and social well-being*' as set out in the WHO constitution, and it is therefore legitimate to consider noise annoyance, reported in this way, as a health effect in these terms.
- 5.7 In addition, there is the theoretical possibility that annoyance may lead to stress responses and then to illness. If there is no annoyance then there can be no mechanism for any increase in stress hormones by this pathway. There is an implication for policy here; if stress-related adverse health effects are mediated solely through annoyance then any mitigation plan which reduces annoyance would be equally effective in reducing any consequent adverse health effects. It would make no difference whether annoyance reduction was achieved through actual reductions in sound levels, or by changes in attitude brought about by some other means. However, as discussed in Chapter 6, the evidence to support this mechanism is by no means clear cut, and a more direct mechanism of noise-induced stress has been postulated (the stress hypothesis) in which stress is not necessarily mediated by annoyance. In this case, a reduction in annoyance alone may not necessarily reduce stress-related health effects. To distinguish between these different possibilities, further research is required.

Annoyance and the Environmental Noise Directive

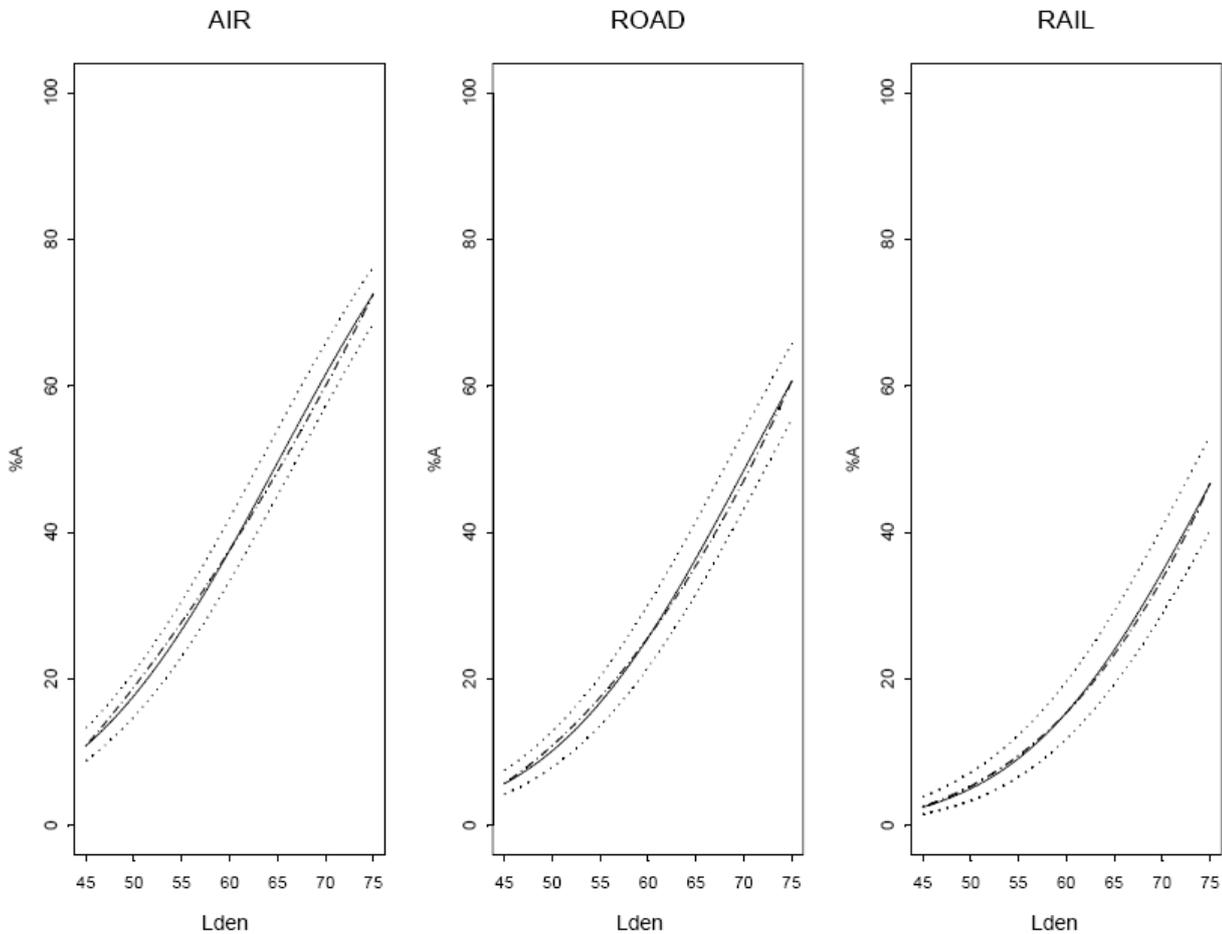
- 5.8 As a key component of European Union policy to achieve a high level of health and environmental protection, the main objective of the END (European Commission, 2002) is '*protection against noise*' (preamble clause 1). The stated aim was to '*to define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise*' (Article 1.1). Presumably, the use of the term "prioritised basis" implies that the use of resources would be justified by first estimating the scale of the problem in terms of the prevalence of harmful effects across the community, and secondly, by estimating the likely costs and effectiveness of alternative noise management action plans.
- 5.9 As part of the process of developing the END, the European Commission contracted Miedema from TNO in the Netherlands to derive dose-response relationships⁵ between

⁵ Further discussion of dose-response relationships is given in Appendix B.

transportation noise and annoyance for consideration by a Technical Working Group established to *'support the European Commission with the development of the dose-effect relations for the proposed framework directive on the assessment and management of environmental noise'*. The Working Group's position paper on transportation noise and annoyance (European Communities, 2002) was published at about the same time as the END. Miedema's work followed the same principles as earlier meta-analyses of existing field survey data by Schultz (1978), Fidell et al (1991), and Finegold et al (1994) as mentioned in Chapter 3, but, by being more recent, was able to take more data into consideration. The position paper showed average community noise annoyance increasing with long term average sound levels measured in L_{den} units for all noise sources considered (aircraft, road traffic and railway noise) as shown in Figure 5-2. The calculated dose-response relationships all start to increase above a low level of annoyance at around 50-55 L_{den} . The relationships for different sources then diverge at increasing long term average sound levels with the highest annoyance for aircraft noise and the lowest annoyance for railway noise. The observed thresholds at which annoyance effects start to increase above a low baseline are consistent with the current WHO guideline values (WHO 2000).

- 5.10 The EC position paper was based on a comprehensive meta-analysis of previous field studies of noise and annoyance. The position paper acknowledged that there was *'large variation in individual annoyance reactions to the same noise exposure level'*, and that attempts to integrate the results from different studies showed *'large variation in the relationships found in different studies'*. The position paper further acknowledged that, because of this variation, *'it is impossible to predict annoyance with satisfying accuracy'*. If there had been obvious consistency between the separate dose-response relationships observed in all the different studies, then meta-analysis would not have been required, or would have been uncontroversial. However, there is considerable variation between the different studies included in the meta-analysis. The position paper took the view that variation regarding individual or group reactions is not important for strategic noise policy and that instead, *'most policy is made with a view to the overall reaction to exposures in a population as a whole'*. It is clear that the working group and hence the position paper took the view that future noise policy should be based on the central tendency observed across the largest possible set of empirically derived results which implies that both individual and group variation above and below the central tendency should be treated as part of overall statistical uncertainty (i.e. as random error) rather than as issues of interpretation. There are both strengths and weaknesses with this point of view as discussed below.

Figure 5-2: The percentage annoyed persons (%A) as a function of the noise exposure of the dwelling (L_{den}). (From European Communities position paper 2002).⁶



5.11 In general, the prevalence of harmful effects across the community as a whole tends to increase with increases in sound level such that reductions in sound level measured across an entire population should achieve corresponding reductions in the overall prevalence of effects, notwithstanding any detailed variation above and below the norm attributable to local factors.

5.12 On the other hand, dose-response relationships which appear to work well at a strategic level might not apply at local level where variation due to local circumstances of differences in

⁶ The solid lines are the estimated curves, and the dashed lines are the polynomial approximations. The figure also shows the 95% confidence intervals (dotted lines).

individual sensitivity above and below the norm could be significant. In addition, in using strategic dose-response relationships small changes in sound levels for large numbers of individuals can appear to be as equally significant as large changes in sound levels for only small numbers of individuals. Such conclusions, if not properly interpreted, can give a misleading impression of the real impact of changes in sound level: if the changes in sound level are too small to be of any significance for individuals they do not become any more significant when more people are affected by them, and secondly, large changes in sound level are likely to be significant for those individuals who benefit from them, even if the numbers of people affected are small.

- 5.13 The overall intention of the END was that Member States would be able to interpret the strategic noise maps (which they were required to produce by 30th June 2007) (Article 7) in terms of the numbers of people '*annoyed*' and '*sleep disturbed*'. This approach was adopted because it was felt that European citizens would be more likely to understand statistics reporting the numbers of people 'annoyed' by noise than statistics dependent on physical or objective sound levels. Although somewhat impractical because of the excessive cost, in theory a perfectly viable alternative approach would have been to measure the number of people 'annoyed' directly using questionnaires. The intended approach was that the numbers of people 'annoyed' would be calculated from the noise maps by using the dose-response relationships recommended by the EC working group and discussed above. It should be noted that any errors or uncertainties in the assumed dose-response relationships would of course be compounded by any errors made when estimating objective sound levels for the production of the noise maps.

Meta-analyses

- 5.14 When carrying out meta-analysis of large numbers of separate research studies in this field, there are a number of technical problems which may need to be overcome.
- 5.15 The field study data included within the overall EC working group meta-analysis were not intended to be statistically representative of the European population as a whole and could therefore be subject to unknown sampling bias in this respect. The EC position paper gives three separate sets of dose-response relationships for aircraft noise, rail noise and road traffic noise which are subject to possible sampling bias due to the essentially accidental choice of airports, railway lines or road traffic noise exposed areas included within the overall meta-analysis sample. For example, sound level measurement uncertainty is likely to vary in different studies depending on the methods used in relation to the areas surveyed and this is likely to have affected the resulting dose-response relationships. For example, many areas exposed to aircraft noise and railway noise are also exposed to similar levels of road traffic noise whereas the majority of areas exposed to road traffic noise are not exposed to similar levels of aircraft or railway noise.
- 5.16 Methods for measuring and reporting sound levels have been under continuous development throughout the period covered by the meta-analysis leading to many

inconsistencies which could only be resolved by making a range of normalising assumptions. Similar considerations applied to the measurement and reporting of annoyance, a problem which the ISO Technical Report 15666, referred to above, was designed to solve. The EC researchers were obliged to convert the sound level indicators used in the original studies into equivalent values of the current EC harmonised indicator for long term average sound level, L_{den} , which required further assumptions to be made about day-evening-night distributions of events.

- 5.17 There are additional uncertainties in all field surveys of noise-induced annoyance associated with the use of outdoor sound level measurements to indicate community noise exposure. Mainly for practical reasons, long term average sound levels are measured at defined positions outside noise exposed residential properties as proxy indicators of individual noise exposure. However, outdoor measurements may provide only a relatively poor indication of indoor noise exposure. The contribution to indoor sound levels made by indoor sources is often more significant than the contribution made by outdoor sources even in areas normally considered to have high outdoor sound levels. Individual exposure to outdoor noise also varies significantly depending on the amount of time people spend indoors and outdoors in or around their home. The main argument in favour of using sound levels as measured outside noise exposed residential properties as the key indicator of environmental noise is that this feature of environmental noise is possibly the most easily controlled through planning and similar regulations. Indoor measurements are not practical for large scale surveys, and could not sensibly be controlled by regulations because of the confounding effects of internally generated noise. In addition, outdoor-to-indoor attenuation is a function of the building envelope and is irrelevant to regulations designed to control noise emissions at source.
- 5.18 Uncertainty over comparable measures of annoyance is also potentially significant. It is well known that source specific reported noise annoyance can be inconsistent with so-called overall reported noise annoyance, and that these inconsistencies appear to vary between different sources. For example, there are many indications that reported source specific annoyance may be differently affected by differences in sound quality, intermittency, irregularity, and apparent or perceived distance from source to receiver between different sources in terms of the way that respondents understand or interpret the actual questions asked. This kind of uncertainty is difficult to study, not least because the only way to find out about respondents' understanding of actual questions is to ask more questions which might in turn be understood differently in different contexts. Averaging across these possible differences as part of the procedure for meta-analysis introduces further possibilities of unknown uncertainty. It is by no means clear that scales of reported aircraft noise, road traffic noise, and railway noise annoyance are understood in the same way by different sets of respondents resident in different areas with different noise exposure histories, yet meta-analysis can only be carried out by assuming that none of these factors has practical consequences.

- 5.19 The field study database included in the meta-analysis is essentially historical, extending backwards over time, and does not therefore represent current conditions particularly well. There is accumulating evidence that attitudes and opinions may have been changing significantly over the past twenty or thirty years (Department for Transport 2007). The EC dose-response relationships for noise and annoyance cannot, by definition, reflect any changes that may or may not be occurring over time. Any such changes arising within the included field study data collection period are treated as adding to overall uncertainty and not separately distinguished as causal factors.
- 5.20 Most of the available empirical evidence suggests that different respondents tend to respond differently to different features of different noise environments at different times, and that the only consistency which exists is a general finding within each study considered separately that the proportion of the exposed population reporting significant annoyance tends to increase with increasing sound levels and vice versa. There is continuing debate about all of these issues and the effect that adopting different assumptions on each of these issues would have had on the findings of the study.

A current aircraft noise example

- 5.21 An example of changing attitudes to noise can be found by comparing two studies of attitudes to aircraft noise carried out mostly around Heathrow in 1982 (DfT 1985) and around most of the largest English airports (including Heathrow) in 2005 (The Attitudes to Noise from Aviation Sources in England study (ANASE), DfT 2007). There were significant differences between the results of the two studies, some of which may have occurred as a result of differences in the various methods used to collect the data, and it should be noted that the later ANASE study has been criticised in some respects, as mentioned in Chapter 3. Nevertheless, some relevant comparisons can be drawn.
- 5.22 Despite differences between the two studies it is clear that residents in 2005 were more annoyed at the same levels of exposure measured in L_{Aeq} than were those in 1982. This suggests that dose-response relationships for aircraft noise may not have been stable over time. Furthermore, the relative importance of the number of aircraft events as compared to the average sound levels of those events also appears to have changed significantly over the intervening 23 years. Based on the results of even earlier studies carried out in the 1960s, the UK government was using the Noise and Number Index to measure aircraft noise up until the 1982 ANIS study. The Noise and Number Index assumed that a doubling of the number of aircraft events was equivalent in terms of reported annoyance to a 4.5 dB change in average event sound levels. The 1982 ANIS study found that a better fit to the data could be obtained by measuring aircraft noise using L_{Aeq} , which effectively equates a doubling of the number of aircraft events to a 3 dB change in average event sound levels. The 2005 ANASE study suggests that residents have not appreciated the considerable reductions in average aircraft event sound levels to the extent expected in 1982, but they have noticed the increases in the numbers of those events. One of the main reasons that many of them are now reporting significant levels of annoyance appears to be because of the increasing numbers of

events. This was not the case in 1982 when there were many fewer aircraft but a high proportion were much noisier than today. There is also corroborative evidence that people's general attitudes to environmental issues may have changed and their willingness to report disturbances, annoyance and other complaints may have increased (as described in Chapter 4).

5.23 There are a number of policy relevant conclusions that could be drawn from this (although see §3.16). The general degree of instability over time suggests that any extrapolation of observed dose-response relationships outside of the conditions under which they were measured could be unreliable, and this adds uncertainty to any predictions of the likely effects of future development proposals. In addition, it seems likely that annoyance might be mitigated by measures which affect attitudes independently of any effect on actual sound levels, and this creates additional difficulties when attempting to predict annoyance based only on long term average sound levels. For these reasons there may be good reasons for separating the assessment of the physical or objective consequences of any development proposal from any assessment of the likely subjective effects of those changes. For example, predicted L_{Aeq} contours could continue to provide a reliable guide to long term average sound levels in the future, and hence provide some measure of control, even if some other parameter were to be used for prediction of annoyance.

Noise and sleep disturbance

5.24 Research on noise and sleep disturbance has been carried out in the laboratory and in the field. On the whole, the evidence from laboratory studies is stronger than that from field studies and it has been found that associations between outdoor aircraft noise exposure and sleep disturbance are tenuous (Michaud *et al*, 2007). During sleep there is no *cumulative* effect of number of noises and their intensity on sleep disturbance (Muzet, 2002): a single noise can be as disturbing to sleep as multiple noises and whether someone awakes may depend on the time of sleep, the time of the night and the current sleep stage.

5.25 Habituation occurs with an increased number of sound exposures by night and across nights. One laboratory study, however, found no habituation during 14 nights of exposure to noise at high levels of exposure. However, there is a weak association between outdoor noise levels and sleep disturbance. Several reviews have reported that night time noise can affect sleep (Health Council of the Netherlands, 2004; Porter *et al*, 2000). Miedema *et al*, (2003) carried out a meta-analysis of road traffic noise and sleep in 11 European studies, two Canadian studies and a Japanese study from the period 1975 to 2001 and additionally for rail traffic noise studied in six European studies and a Japanese study between 1983 and 2001. From this, and in a further analysis including more studies (Miedema and Oudshoorn, 2001) they derived two exposure response curves.

5.26 In the Civil Aviation Authority Study around Heathrow and Gatwick Airports, the relative proportion of total sleep disturbance attributed to noise increased in noisy areas but the level of total sleep disturbance did not. In effect, the work suggested a symptom reporting or

attribution effect rather than real noise effects. In a subsequent actigraphy study around four UK airports, sleep disturbance was studied in relation to a wide range of aircraft noise exposure over 15 consecutive nights (Civil Aviation Authority, 1992). Although there was a strong association between sleep EEGs, actigram-measured awakenings and self reported sleep disturbance, in the first experiment none of the aircraft noise events were associated with awakenings detected by actigram and in the second experiment only one in eighty eight such events were linked to awakenings. The chance of sleep disturbance with aircraft noise of less than 82 dB L_{max} was found to be insignificant (Horne *et al*, 1994). Although it is likely that the population studied was one already adapted to aircraft noise exposure, this study is also likely to be closer to real life than laboratory studies with subjects newly exposed to noise. However, use of the actigraph, as a sensitive measure of sleep disturbance, relying on bodily movements, has been questioned. Many body movements are not related to sleep disturbance. Despite changes in night aircraft noise exposure around two airports, no major differences in noise induced sleep disturbance were observed (Fidell *et al*, 2000). Such a “change study” is powerful methodologically and the absence of effects in response to changes in noise is additional evidence that the association between noise exposure and sleep is weak in community studies. On the other hand reduction in road traffic noise associated with the introduction of a new tunnel for road traffic was associated with less difficulty falling asleep, better sleep quality and more alertness in the morning. Interestingly, this was additionally associated with a decrease in overall sleep time (Ohrstrom, 2002).

- 5.27 Intervention studies often produce stronger evidence of meaningful causal effects; studies on noise abatement show that by reducing indoor sound levels the amount of REM sleep and slow wave sleep can be increased (Vallet *et al*, 1983). Noise exposure during sleep may increase blood pressure, heart rate and finger pulse amplitude as well as body movements. It seems that, although there may be some adaptation to sleep disturbance by noise, complete habituation does not occur, particularly for heart rate. A recent report from the Dutch Health Council has shown that the number of studies among children relating noise and sleep is limited (Health Council of the Netherlands, 2004). Children are less prone to awakenings due to noise than adults. On the other hand, the autonomic nervous system of children is more easily activated during sleep and children have more marked cardiovascular responses than adults (Muzet *et al*, 1980).
- 5.28 Noise is only one of many different factors which can contribute to disturbed sleep. In addition, since one of the main consequences of excessive sleep disturbance (from any cause) seems to be increased sleepiness, particularly on the following night, then there would seem to be an important role for compensatory mechanisms in adaptation and habituation which have not been fully researched in the area of noise and sleep.
- 5.29 Anecdotal evidence suggests that many individuals habituate or adapt to different night-time noise environments and might only be disturbed by unusual or unexpected events. Unusual events could even include absence of noise where sound levels are much lower than normally experienced. Both field and laboratory studies (Flindell *et al*, 2000, Basner *et al*,

2004) suggest that many residents in noisy areas such as near to main roads and airports are able to adapt to familiar noise such that even though short-term or instantaneous responses can be observed on EEG traces, there might still be surprisingly little additional behavioural awakening associated with specific noisy events.

- 5.30 Physiological and behavioural measurements usually tend to show much lower levels of actual disturbance measured objectively than might be inferred from subjective reports of perceived sleep disturbance. This apparent inconsistency can be explained by noting that when people are asleep, they have very little conscious awareness of what is going on around them and might therefore be less aware of the true cause of behavioural awakenings. Because of the time taken to waken from deep sleep, an aircraft flyover which actually caused an awakening might have gone past by the time that the person has been awakened sufficiently to be able to take note of the surroundings and register the aircraft flyover sound. On the other hand, a person might mistakenly believe that an aircraft flyover occurring after they have been awakened by some other cause is the true cause of the awakening. In addition, there is a widespread belief that aircraft noise can delay sleep onset or prevent people from going back to sleep after having woken up earlier than intended in the morning. The various possibilities for delayed sleep onset and problems of getting back to sleep have not been fully researched, possibly because they occur while people are awake and are not strictly speaking sleep disturbances at all.

Conclusions of the position paper on night-time noise

- 5.31 Following on from the publication of dose-response relationships for noise and annoyance the European Commission established a Technical Working Group to derive dose-response relationships for L_{night} , the EC indicator for sleep disturbance. The resulting position paper on dose-response relationships for night-time noise was published in November 2004 (European Commission, 2004), and was largely based on earlier reviews carried out by Meidema *et al* (2003) and Meidema and Vos (2004). The position paper summarises a number of possible effects of noise on sleep. For *instantaneous effects*, it suggests that valid dose-response relationships exist for behavioural awakening and railway and aircraft noise and for onset of motility (usually measured with a wrist-worn actigram) and aircraft noise. Available data on release of stress hormones, change in blood pressure, change in heart rate, vasoconstriction and change in sleep stage are not considered sufficient to support valid dose-response relationships. The position paper then goes on to derive alternative dose-response relationships between behavioural awakenings and noise induced motility and long-term average whole night noise exposure (L_{night}) using various assumptions about the numbers of events per night and the most likely relationships between maximum and average sound level for an event. There is no discussion of the relative importance of instantaneous behavioural awakening or noise-induced motility in the context of any longer-term or chronic effects.
- 5.32 Available data on use of sleeping pills and increased risk of hypertension or myocardial infarction is not considered sufficient to support valid dose-response relationships. In

connection with the derived dose-response relationships for self-reported sleep disturbance and night time noise measured by L_{night} , it should be noted that most of the points made in the previous commentary on the position paper on noise and annoyance also apply to the reported noise and sleep relationships, with the additional comment that while self-reported sleep disturbance may be considered important for policy, it is not usually a very good indicator of actual or objective sleep disturbance.

- 5.33 It should be noted that while quite a lot is known about physiological processes during normal and disturbed sleep, the biological purpose of sleep is not fully understood. This contributes to the difficulty of devising theoretical models or explanations of noise-induced sleep disturbance and leaves us without adequate theoretical explanations of habituation and adaptation in normal sleep. The guideline values for avoiding sleep disturbance provided in the WHO guidelines document, i.e. 30 L_{Aeq} and 45 L_{Amax} measured inside the bedroom (WHO, 1999), seem to be based on the lowest values at which any kind of physiologically measurable disturbance has been observed without making allowance for habituation and adaptation which undoubtedly occurs after long-term residence under road, railway, and aircraft noise exposure situations. On the other hand, it is likely that not everyone habituates or adapts to night-time noise to the same extent and that, as noted in the position paper, special attention might be justified in the case of vulnerable or sensitive groups. Unfortunately, there does not seem to be any objective way to identify especially vulnerable or sensitive groups except by self-report which may be considered unreliable.

Dose-response relationships

- 5.34 There is a widespread belief that noise can disturb sleep; that excessive sleep disturbance can cause people to feel bad or to perform less well the next day; and that excessive sleep disturbance continued for long periods of time could have significant adverse health effects. For these reasons alone, the END placed special emphasis on protection against noise at night, by first establishing a separate indicator, L_{night} , for sleep disturbance, and secondly by providing for separate dose-response relationships for sleep disturbance which were subsequently published in 2004. The position paper on dose-response relationships for night-time noise (European Commission, 2004) follows the same general principles as were adopted for the position paper on noise and annoyance dose-response relationships (European Commission, 2004) but appears to be much less confident about the results. The position paper lists a number of issues which still need to be resolved and which include at least the following items:
- limited epidemiological data to allow meta-analysis as a means of establishing best estimates of coefficients
 - the use of long-term (whole night) averaging to measure a problem which is essentially event based
 - possible differences between stationary and changing conditions of exposure
 - the use of different outcome measures
 - additional protection for vulnerable or sensitive groups.

Conclusions

- 5.35 To date, while the European Commission has published dose-response relationships for annoyance and sleep disturbance it has not published any equivalent dose-response relationships for any other assumed adverse health effects. This reflects the position adopted in the most recent World Health Organisation 'Guidelines for Community Noise' (WHO, 1999) which is reviewed in Chapter 7. Guideline values were provided for the prevention of annoyance, sleep disturbance, speech interference, and hearing impairment but not for any other assumed or supposed health effects. No guideline values were provided for cardiovascular and psycho-physiological effects, for mental health effects, for effects on performance and for the preservation of tranquillity, largely because of equivocal or inconclusive research findings in these areas. By providing guideline values for specific effects (annoyance, sleep disturbance, speech interference and hearing impairment), the WHO was effectively acknowledging the existence of dose-response relationships for those particular effects, even though it did not go so far as to make those relationships explicit in the 1999 document.
- 5.36 The underlying strategic approach adopted within the END is designed to encourage harmonised protection against noise with progress measured against long-term average sound levels. In order to use the noise mapping approach it is necessary to accept the assumption that there is a common and underlying dose-response relationship which applies to all European citizens. This approach takes no account of individual circumstances, sensitivities and conditions which are important for individual response.

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Chapter 6. Effects on physical and psychological health

Introduction

- 6.1 Exposure to continuous sound levels of 85-90 dBA, particularly over a working lifetime in industrial settings, can lead to a progressive loss of hearing, with an increase in the threshold of hearing sensitivity. This type of damage can also result from exposure to a small number of noisy events if the sound energy is high enough (peak sound pressure of 200 Pascals, equivalent to 140 dBC⁷). Hearing impairments due to noise are a direct consequence of the effects of sound energy on the inner ear. Noise exposure at these levels is usually associated with type of occupation, and is hence covered by Health and Safety legislation, although there are increased instances of hearing damage due to entertainment noise, both from amplified music and personal stereos.
- 6.2 However, in this Chapter we are primarily concerned with environmental noise, as opposed to occupational noise, for which the exposure levels are much lower and for which effects on non-auditory aspects of health cannot be explained as a direct consequence of sound energy. The amount of power in sound is considerably less than is often appreciated. To illustrate this, if we take a sound level of 57 dBA, which is the average external day-time level in the UK, the sound intensity is only $0.5\mu\text{W}/\text{m}^2$, or half a millionth of a Watt per square metre. To put this in context, the intensity of strong sunlight is about $1\text{kW}/\text{m}^2$, or one thousand Watts per square metre, i.e. greater than the acoustic intensity from typical environmental sound by a factor of around a thousand million. We can also compare the acoustic power incident on the body with that of typical body processes. If we take the average body as having a surface area of slightly more than one square metre, then the acoustic power incident on the body at 57 dBA will be of the order of one micro-Watt, i.e. one millionth of a Watt. The power of a typical beating heart in an adult is of the order of one Watt, i.e. greater than the acoustic incident power by a factor of a million. Furthermore, most of the incident acoustic power would be reflected, and only a small proportion would enter the body in the form of vibration. We can conclude that the acoustic power associated with environmental sound is extremely small compared with that of everyday occurrences and normal body processes. To many people this conclusion may present a difficulty, because it is common to experience sounds as 'powerful', whilst the above discussion indicates that the actual power involved in such an experience is extremely small. The apparent contradiction can be partly explained by the extreme sensitivity of the ear. We may also speculate that the *experience* of power arises because of association of certain sounds with powerful events rather than because the sound

⁷dBC is along similar lines to dBA, see Glossary.

itself is inherently powerful: for example, although the sound of a bulldozer carries very little energy, it is associated with the machine itself which has a sizeable mechanical power.

- 6.3 If noise does cause ill-health, other than hearing impairment, what might be the mechanism? Noise disturbs activities and communication causing annoyance. Perhaps either annoyance may lead to stress responses, then symptoms and possibly illness, or noise may influence physiological processes directly. Generally the mechanism suggested is that of the stress hypothesis in which noise exposure, results in acute defence/startle responses and 'fight or flight' reactions. Noise exposure over a long period may lead to raised stress-related hormones such as cortisol that can have adverse effects on bodily functioning. In general, the response to noise may depend on the characteristics of the sound including intensity, frequency, complexity, duration and the meaning of the sound.

Noise exposure and performance

- 6.4 Historically much of the research on noise and performance was initially concerned with accidents at work. However, even in studies investigating very loud noise exposures it was often unclear whether the sound level was causally related to accidents or merely an incidental correlate of hazardous factory operations (Smith and Jones, 1992). Early laboratory research also involved investigation of the acute effects of very loud noise. Such research showed that noise impaired monitoring tasks and tasks involving sustained self-paced responding. In addition, noise led to a concentration upon dominant or high probability task features at the expense of other aspects of the task. It is possible that such effects could also be observed with more prolonged exposure to moderate intensity environmental noise (see Smith and Miles, 1987).
- 6.5 The nature of the noise has been shown to be crucial in determining whether performance impairments are observed. For example, an intermittent noise burst will disrupt performance, especially if it is unpredictable and perceived as being outside of the control of the person (see Glass and Singer, 1972). Even at very low levels background speech will have damaging effects on the way verbal materials are remembered (Jones and Morris, 1992). Environmental noise exposure is often categorised by source or intensity and it is now crucial to determine whether established noise parameters (e.g. predictability and control) modify the effects of such exposure on performance. Similarly, the effects of noise depend on the nature of the task carried out and the strategies used to perform it. This plausibly explains the effect of habitual noise exposure on performance in quiet conditions and the role of individual differences such as noise sensitivity.
- 6.6 Evidence from laboratory studies has shown that noise exposure impairs cognitive performance and this is likely to be relevant to noise exposure for office workers. Performance may be impaired if speech is played while a subject reads and remembers verbal material. This effect has not been found with non-speech noise at similar intensity levels to speech. The effects of 'irrelevant speech' are independent of the intensity and meaning of the speech. Complex mental tasks are especially affected by irrelevant speech

which suggests that reading, with its reliance on memory may also be impaired. Perceived control over, and predictability of, noise have been found to be important in determining effects and after-effects of noise exposure. Glass and Singer (1972) found that tasks performed during noise were unimpaired but tasks that were carried out after noise had been switched off were impaired. This effect was reduced when subjects were given perceived control over the noise. Indeed, even anticipation of a loud noise exposure in the absence of real exposure may impair performance and an expectation of control counters this effect. Noise exposure may also slow rehearsal in memory, influence processes of selectivity in memory and choice of strategies for carrying out tasks. There is also evidence that noise may reduce social helping behaviour, increasing aggression and reducing the ability to detect social and behavioural cues in everyday situations.

Noise and cardiovascular disease

- 6.7 Study of the effects of noise on the cardiovascular system usually measured as high blood pressure (hypertension) and other cardiovascular disease was initiated through animal studies of prolonged noise exposure. Acute exposure to noise causes physiological activation including increases in heart rate and blood pressure, peripheral vasoconstriction with relative withdrawal of blood from the skin, and increased peripheral vascular resistance. On the whole there tends to be rapid habituation to brief noise exposure so that physiological responses to noise are short-lived but habituation to prolonged noise is less certain.

Occupational studies of noise and high blood pressure

- 6.8 The strongest evidence for the effect of noise on the cardiovascular system comes from studies of blood pressure in occupational settings. Many occupational studies have suggested that individuals exposed to continuous sound levels of at least 85 dBA over the long-term have higher blood pressure than those not exposed to such sound levels. In many of these studies, noise exposure has also been an indicator of exposure to other factors both physical and psychosocial which are associated with high blood pressure and unless these other risk factors are controlled, spurious associations between noise and blood pressure may arise. A pioneering longitudinal industrial noise study has shown that noise levels predicted raised systolic and diastolic blood pressure in those doing complex but not simple tasks (Melamed and Froom, 2002; Melamed *et al*, 2004). One possibility is that the effects of noise on blood pressure are channelled through an intermediate psychological response such as raised noise annoyance but there is only limited evidence to support this suggestion.

Environmental noise, hypertension and cardiovascular disease

- 6.9 The earliest community studies around Schiphol airport found that aircraft noise exposure was related to more medical treatment for heart trouble and hypertension, more cardiovascular drug use and higher blood pressure even after adjustment for age, sex, smoking, height and weight and socioeconomic differences (Knipschild, 1977). Until recently there was fairly little additional evidence to support these early findings.

- 6.10 In the large European HYENA study, night-time aircraft noise exposure and day-time road traffic noise were associated with increased hypertension after adjustment for confounding factors (Jarup *et al*, 2008). A 10 dB increase in aircraft noise exposure (L_{night}) was associated with increased odds of hypertension of 1.141 (95%CI 1.012-1.286); a 10 dB increase in road traffic noise exposure ($L_{\text{Aeq, 24-hour}}$) was associated with increased odds of hypertension of 1.097 (95%CI 1.003-1.29), stronger for men than women. In a subsample of the HYENA study, aircraft noise events at night were associated with substantial temporary elevation of blood pressure (Haralabidis *et al*, 2008). In a Swedish study, self-report of physician diagnosis of hypertension was higher among people exposed to aircraft noise levels of at least 55 dBA (L_{Aeq}), based on aircraft noise contours or maximum levels above 72 dBA (Rosenlund *et al*, 2001).
- 6.11 The evidence of effects of noise on other coronary risk factors has been less consistent; effects of noise have been shown on total cholesterol, total triglycerides, blood viscosity, platelet count and glucose level, but studies have not yielded a convincingly consistent pattern of effects. One problem with many of these studies, particularly relevant to road traffic noise studies, is that the potential effects of air pollution are not adjusted for in analyses of noise and cardiovascular outcomes. Babisch and colleagues found that the association between road traffic noise exposure and coronary heart disease was modified by pre-existent disease (Babisch *et al*, 2000). This needs further research but suggests the possibility of noise exposure having an exacerbating effect on coronary heart disease progression.
- 6.12 Meta-analyses have quantified the association between occupational noise and hypertension (van Kempen *et al*, 2002). Nine studies of occupational noise gave a relative risk of 1.14 (95%CI 1.01-1.29) for hypertension, while fewer studies of road traffic noise in relation to hypertension gave a relative risk of 0.95 (95%CI 0.84-1.08). In an updated review Babisch (2006) concluded that there was no evidence that environmental noise was related to raised blood pressure in cross sectional studies. Moreover, he regards the results of studies examining community noise and hypertension as showing an unacceptable degree of variability, and despite some evidence of an association between road traffic noise and hypertension in more recent studies (RR 1.5-3.0) overall, he concludes '*across all studies no consistent pattern of the relationship between community noise and prevalence of hypertension can be seen.*' However, the recent results of the HYENA study make this less likely to be true than previously. Noise measurements in these studies were largely daytime outdoor average A-weighted sound pressure levels. There was some diversity of measurement methods in these studies that make the combined results difficult to interpret: newer studies used weighted or non-weighted averages of 24h exposure (L_{eq} , L_{dn} , L_{den}) and some used unique national measures that were transformed by Babisch into L_{day} ; most used objective rather than subjective noise measures.
- 6.13 Overall coronary heart disease was related to road traffic noise with a relative risk of 1.09 (95%CI 1.05-1.13). A relative risk of 1.26 for aircraft noise (95%CI 1.14-1.39) was based on a single study and therefore cannot be relied upon. A more recent meta-analysis of studies of

road traffic noise and cardiovascular disease suggests that under 60 dBA there is no increased risk but over 60dBA ($L_{\text{day: 06:00-22:00}}$) the risk of myocardial infarction increases reaching as much as 1.2 for sound levels of 70 dBA (Babisch, 2005). This suggests a larger risk than previous meta-analyses that is largely due to the inclusion of more recent studies, nevertheless the confidence intervals still span zero for the highest risk. Babisch's updated review suggests an increased risk of coronary heart disease associated with sound levels above 65-70 dBA, largely from prospective studies, with relative risks between 1.1-1.5 (Babisch, 2006). Pooled results from a meta-analysis showed effect estimates of 1.19 (95%CI 0.9-1.57) for 71-75 dBA and 1.47 (0.79-2.76) for 76-80 dBA relative to L_{day} of 60 dBA or less.

- 6.14 There has also been a suggestion that noise exposure may stimulate secretion of stress hormones such as catecholamines and precipitate disorders of cardiac rhythm. This is an immensely difficult topic to study in the field because of the difficulty in predicting sudden acute noises and linking these to irregularities in cardiac rhythm. However, neither studies in coronary care units on the effects of speech noise, nor studies of noise from low altitude military flights on patients on continuous heart monitoring have detected changes in cardiac rhythm attributable to noise (Brenner *et al*, 1993).

Noise exposure, sleep and cardiovascular responses

- 6.15 As mentioned in Chapter 5, noise exposure during sleep may increase blood pressure and heart rate as well as body movements. It seems that, although there may be some adaptation to sleep disturbance by noise, complete habituation does not occur, particularly for heart rate. As mentioned in Chapter 5, children are less prone to awakenings due to noise than adults. On the other hand, the autonomic nervous system of children is more easily activated during sleep and children have higher cardiovascular responses than adults (Muzet *et al*, 1980).
- 6.16 The long-term effects of sleep disturbance on health are uncertain. Whereas there is evidence that insomnia is related to mortality and physical morbidity, it is unclear whether environmental stressors, such as noise, can give rise to long-term health effects mediated through sleep disturbance. A more parsimonious explanation is that sleep disturbance early in the night is an indication of the onset of ill health that is, in itself, a risk factor for illness and mortality.
- 6.17 There is still a need for further field research on noise and sleep disturbance. In addition, the links between long-term sleep disturbance by noise and health outcomes, particularly increased risk of coronary heart disease need to be explored.

Endocrine responses to noise

- 6.18 Occupational exposure to high intensity noise has been linked in occupational studies to raised levels of catecholamines (noradrenaline and adrenaline), hormones secreted by the adrenal gland to stimulate short term physiological responses to stress. There is a fairly

consistent body of evidence supporting these findings and in one study catecholamine secretion decreased when workers wore hearing protection against noise (Melamed and Bruhis, 1996). Some studies, but not all, have shown raised cortisol levels in relation to high levels of noise exposure. Cortisol is a hormone secreted by the cortex of the adrenal gland that has been implicated in both immediate and long-term responses to environmental stress, acting to mobilise energy reserves by raising blood glucose concentration and promoting fatty acid release from fat tissue. Women exposed to road traffic noise at night were found to have higher levels of noradrenaline in overnight urine if their bedroom faced a noisy road (Babisch *et al*, 2001) and children exposed to high levels of road traffic noise at night showed raised cortisol secretion in the first half of the night (Ising and Ising, 2002). The general pattern of endocrine response to noise is indicative of noise as a stressor, exciting short-term physiological responses. In this context endocrine responses to noise may be seen as part of a normal response to environmental stressors. The question is whether prolonged noise exposure can lead to elevation in hormones that remain elevated for long periods of time and that might have relevance for human health. This question requires further study.

Noise and mental health

- 6.19 Many studies have reported that noise exposure in industrial and occupational settings is related to individual psychological symptoms. However, noise exposure in occupational settings may be very much higher than that from environmental noise. In addition, many of these studies are difficult to interpret because workers are exposed to other stressors such as dust, heavy work, and physical danger in addition to excessive noise and will not be discussed further. However, some community studies are biased towards over-reporting of symptoms because of an explicit link between aircraft noise and symptoms in the questions inviting people to remember and report more symptoms because of concern about noise. Community surveys have found that a high proportion of people report 'headaches', 'restless nights' and being 'tense' and 'edgy' in high noise areas (Tarnopolsky *et al*, 1980).
- 6.20 From the lay perspective it has always seemed plausible that noise might cause psychiatric disorder. The empirical evidence has been less clear-cut. Early studies found associations between the level of aircraft noise and psychiatric hospital admission rates both in London and Los Angeles but this was not confirmed by further studies (Jenkins, 1979, 1981). In community studies, such as the West London Survey of Psychiatric Morbidity, aircraft noise was not related to the prevalence of psychiatric morbidity using various indices of noise exposure except in highly educated and professional subgroups (Tarnoplosky and Morton Williams, 1980). The results of these cross-sectional studies are potentially biased by people sensitive to noise moving out of noisy areas - this might leave people behind who are resilient to noise effects. Thus these studies are not a fair test of the effects of noise on mental health in the general population. In longitudinal analyses in men in the 'Caerphilly study', a longitudinal community study of risk factors for ischaemic heart disease based in South Wales, no association was found between road traffic noise and overall psychological distress, even after adjustment in the analyses for socio-demographic factors and baseline psychological distress. There was a small non-linear association of noise with increased

anxiety scores and, when men were grouped by noise sensitivity, an association between noise and psychological distress was found with road traffic noise exposure (Stansfeld *et al*, 1996; Stansfeld *et al*, 2002). However, some studies have found tentative dose-response associations: exposure to higher levels of military aircraft noise around Kadena airport in Japan was related in a dose-response relationship to 'depressiveness' and 'nervousness' (Hiramatsu *et al*, 1997). These studies have recently been criticised because of the long interval between the measurement of noise exposure and the mental outcomes and a reappraisal suggests that the evidence for dose-response associations is limited.

- 6.21 Road traffic noise has also been weakly associated with mental health symptoms in a multi-site study after adjusting for age, sex, income and length of residence (Halpern, 1995). A recent Sardinian study compared subjects living close to an airport with control subjects living in other areas matched by sex, age and employment status. This study showed that noise exposed subjects exhibited a higher frequency of 'generalised anxiety disorder' and 'anxiety disorder not otherwise specified' diagnosed using the Composite International Diagnostic Interview. This is one of the first studies finding an association between aircraft noise exposure and psychiatric diagnoses (Hardoy *et al*, 2005). This study, which did not measure sound levels and had a response rate of 64% is interesting and needs replication. Overall, environmental noise is linked to psychological symptoms and may be linked to clinical psychiatric disorder, especially at much higher sound levels, but this needs replication.

Children's cognition and health

- 6.22 Recent work suggests that children and adults may be equally susceptible to environmental noise effects on performance (Boman *et al*, 2005). Nevertheless, children may be more vulnerable to the effects of noise than adults because of lower ability to understand environmental issues and anticipate stressors and because they may be exposed to noise during a critical period of learning at school. The most consistent effects of noise in children are cognitive impairments (Cohen *et al*, 1980; Evans and Lepore, 1993). Tasks which involve central processing and language comprehension, such as reading, attention, problem solving and memory appear to be most affected by noise exposure. Complex tasks requiring high cognitive demands as opposed to simple tasks are most affected by environmental stressors such as noise (Smith and Broadbent, 1981).
- 6.23 Most research has been carried out in primary school children aged 5-12 years. Studies examining the effects of chronic aircraft, rail and road traffic noise on children's cognitive performance have found memory impairments for tasks that require high processing demands (Evans *et al*, 1995; Hygge *et al*, 1996), poorer reading ability and school performance on National Standardised Tests (Bronzaft, 1981; Green *et al* 1982; Evans *et al*, 1995, Haines *et al*, 2001; Stansfeld *et al*, 2005; Shield and Dockrell, 2008), deficits in sustained attention and visual attention (Haines *et al*, 2001), difficulties in concentration (Crook and Langdon 1974), and poorer auditory discrimination and speech perception (Cohen *et al*, 1973; Evans and Maxwell, 1997). Perhaps the most convincing evidence for noise related cognitive effects has

come from the prospective longitudinal natural experimental field research around Munich airport in children (Hygge *et al*, 2002). In 1992 the old airport in Munich closed and a new airport opened. The cross sectional results indicated an association between high noise exposure and poor long-term memory and reading comprehension (Evans *et al*, 1995). Longitudinal analysis, after three waves of testing, indicated improvements in long-term memory after closure of the old airport. Strikingly, these effects were paralleled by impairment of the same cognitive skills in a new group of children after the new airport opened (Hygge *et al*, 2002). In the RANCH (Road traffic and Aircraft Noise exposure and children's Cognition and Health) study dose-response associations were demonstrated between chronic aircraft noise exposure and reading comprehension and recognition memory in pooled analyses from three European countries (Stansfeld *et al*, 2005). The same effects were not observed for road traffic noise where, if anything, episodic memory showed better performance in high road traffic noise areas. External noise to school classrooms has also been associated with poorer performance on standardised assessment scores in London primary school children (Shield and Dockrell, 2008).

- 6.24 One possible cause for decrements in cognitive performance among children exposed to high levels of aircraft noise may relate to task motivation. Chronic exposure to aircraft noise in the field has been associated with decreased motivation in school children (Cohen *et al*, 1980; Evans *et al*, 1995) although the results have not been consistent (Haines *et al*, 2001). This motivation effect may either be independent or secondary to noise-related cognitive impairment or indeed, may contribute to noise-related cognitive impairment.
- 6.25 There has been rather little research on noise exposure and mental health in children. In the Munich study the children living in areas exposed to high aircraft noise had lower levels of psychological wellbeing than children living in quieter environments (Evans *et al*, 1995). The longitudinal data from this study show a significant decline in self reported quality of life after exposure to increased aircraft noise following the opening of the new airport (Evans *et al*, 1998). A recent Austrian study found that exposure to road and rail traffic noise was associated with poorer classroom behaviour and poor self reported child mental health derived from the Kindl Quality of Life Scale (Lercher *et al*, 2002). However, ambient noise was only associated with poorer mental health in children with low birth weight or pre-term birth. Overall, these studies suggest that, noise is probably not associated with serious disturbance of child mental health. However, it may affect child stress responses and sense of wellbeing and there is a need for further research. An intriguing finding in the West London Schools Study was that chronic aircraft noise exposure was associated with hyperactivity measured as a subscale in the Strength and Difficulties Questionnaire (Haines *et al*, 2001).
- 6.26 Furthermore, children have been shown to be annoyed by specific sources of environmental noise. In a questionnaire survey of over 2000 primary school children in London, children reported being annoyed both at home and at school by noise from sources such as trains, motorbikes, lorries and sirens (Dockrell and Shield, 2004).

6.27 A number of different mechanisms have been suggested for the effects of noise on reading and memory including interference in communication between teachers and children, narrowing the focus of attention excluding useful information as well as noise, effects on speech discrimination and speech perception. However there is no substantive evidence to favour one of these mechanisms over the others – this needs further investigation. Moreover, although aircraft noise exposure at school has been linked to impairment of reading there needs to be an investigation of whether cutting down aircraft noise exposure in the classroom through sound insulation reduces the impairments in reading.

Low frequency noise and health

6.28 Low frequency sound (10 Hz to 200 Hz) from sources such as transport or building ventilators, has been linked to changes in the respiratory rate, heart and gastro-intestinal functions (Maschke, 2004). In people with extreme exposure to low frequency noise such as aircraft technicians, vibroacoustic disease, consisting of heart wall thickening, depression and irritability has been described (Castelo Branco and Alves-Pereira, 2004). However, this diagnosis is considered controversial by many and has not been studied sufficiently in epidemiological studies. Recent work with Danish Air Force personnel who “*are standing directly beside the jet fighters during running up and shutting down the jet engine*” showed no effects on health, other than the potential for hearing loss. Overall levels were in the region of 115 to 120dB (Jensen *et al*, 2008). Jensen concluded: “*This study does not support the findings of the Portuguese researcher group*”.

6.29 The evidence on health effects of low frequency noise is ambiguous; there are suggestions that some people are more susceptible to this type of noise and there may be learned aversive responses to low frequency noise (Leventhall, 2004) and possibly sleep disturbance (Persson Waye, 2004). Effects of low frequency noise are discussed in more detail in Appendix A.

Positive effects of sound

6.30 Not all sound is noise; that is to say some sounds are welcomed, would not be seen as noise, and may increase wellbeing. For instance, positive soundscapes in urban and rural areas are often a familiar and pleasurable part of the environment, for instance the sound of fountains or bird song. This is a relatively novel area of research and has been little studied in terms of health. Quietness and tranquillity have been found to contribute to satisfying lives for older people (Lawton *et al*, 1980), ambient music has been found to have a positive effect on wellbeing in patients undergoing invasive cardiac procedures (Thorgaard *et al*, 2004) and the availability of restorative environments in which to relax and unwind has been associated with lower levels of annoyance in children exposed to chronic aircraft noise (Gunnarsson *et al*, 2003). Exposure to tranquil areas of nature is thought to be stress reducing and have positive effects on physical and mental health. These effects may be partly the result of exercise but also aspects of the environment may be important (Pretty *et al*, 2005) one of which may be quiet.

Conclusions

6.31 In summary, there is increasing evidence that environmental noise, from both aircraft and road traffic noise is associated with raised blood pressure and has small effects on the risk of coronary heart disease. Although the magnitude of the effects of environmental noise on blood pressure is small, the effects are still important as noise exposure is so widespread in the population. Environmental noise also impairs cognitive performance in children and adults and may be responsible for psychological symptoms. Noise exposure in children may have implications for education; it is not known if the effects persist or are temporary and further research is recommended.

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Chapter 7. Current policy context

Introduction

- 7.1 The main purpose of this Chapter is to discuss the current context of legislation and guidance relevant to noise and health in the UK. In particular the provisions of the WHO 'Guidelines for Community Noise' (WHO, 1999) will be discussed. The Environmental Noise Directive (END) (European Commission, 2002) which has already been discussed in earlier Chapters will also be briefly reviewed.
- 7.2 Various policy approaches are used to manage environmental noise, including
- placing limits on the noise emission of particular sources (vehicles, outdoor equipment)
 - placing restrictions on aircraft and traffic movements
 - providing schemes for sound insulation grants to properties subject to high noise levels (road, rail and air traffic)
 - limiting residential development in noisy areas, and/or mitigating its effects through planning conditions (PPG24, BS8233)
 - regulating some noise sources through nuisance legislation .
- 7.3 The framework for forming, implementing, monitoring and enforcing the various policies is highly complicated, involving a number of departments from national and European government agencies such as the Environment Agency, the police and local government.
- 7.4 There is a wide range of guidelines relating to noise and noise control applicable in the UK, running to hundreds of documents. However, many of these, especially standards, deal with how to quantify noise and do not concern themselves with the acceptability or otherwise of noise. Relatively few documents provide guidance on acceptable noise levels and fewer still actually give specific quantitative limits.
- 7.5 Two approaches have emerged to setting limits at receiver locations: relative and absolute limits. The former approach, which is employed in BS4142 (British Standards Institution, 1997) is to set limits relative to the pre-existing background sound levels. Such limits are generally set outside affected properties. Broadly speaking, the logic is that someone will not notice a new noise unless it exceeds the background noise. The alternative approach, employed primarily in the WHO guidelines (WHO, 1999), is to set absolute levels of noise for living spaces. Such limits include external limits for gardens, balconies and parks, and internal limits for bedrooms and living rooms. The absolute and relative approaches are not necessarily incompatible.
- 7.6 The various "rules" governing noise in the UK can be considered as having varying degrees of legal status: legislation, standards, guidelines, recommendations etc. It is important to be clear on the distinctions between these categories. Although there are various key

documents, for example the WHO Guidelines which cover many aspects of noise and health, it is fair to say that legislation in its strict sense only applies to two areas of health effects: hearing loss (which is not relevant for environmental noise), and annoyance (or closely related concepts such as nuisance, amenity etc). One of the definitions of statutory nuisance given in Section 17 of the Environmental Protection Act, 1990 is “noise emitted from premises so as to be prejudicial to health or a nuisance”. However, road, rail and aircraft noise are generally exempt. We could therefore argue that a health-based system for regulation of environmental noise is already in existence in the UK in the form of the statutory nuisance regime, but that it does not apply to many environmental noise sources.

- 7.7 Legislation in the UK on hearing loss comes under the umbrella of occupational health related to workers and is outside the scope of the report. The remainder of this Chapter will be on environmental noise and annoyance, and standards for noise *immission*, meaning “noise at the receiver” (as opposed to noise *emission* which refers to noise emitted by a source).

WHO Guidelines for Community Noise

Background

- 7.8 There is a considerable “history” behind the 1999 version of the WHO Community Noise Guidelines as summarised in Table 7-1.

Table 7-1 Ancestry of the WHO Community Noise Guidelines

1980	WHO report produced (WHO, 1980)
1992	Meeting of experts in Dusseldorf leading to a draft report
1993	External review draft prepared and circulated
1995	Update report published by editors (Berglund and Lindvall, 1995)
1999	Expert group meeting in London. WHO Community Noise Guidelines published

- 7.9 Noise guideline values were first made available in a WHO report published in 1980 (WHO, 1980). WHO later decided to revise the earlier publication with the aim of producing “a global document on community noise”. The first draft of what was to become the updated 1995 document was initially prepared by Berglund and Lindvall on behalf of the WHO and the Nordic Noise Group of the Nordic Council of Ministers, based on reviews of community noise effects published since the 1980 document (Berglund and Lindvall, 1995). This draft was reviewed by a WHO Task Force of invited international experts at a meeting held in Dusseldorf in late 1992. A series of revised guideline values were agreed upon by consensus at the Dusseldorf meeting and were included as a separate Chapter (Chapter 11). Berglund and Lindvall then prepared an external review draft for wider comment incorporating some additional contributions from members of the Dusseldorf Task Force. This draft was widely circulated in 1993. Many comments from different experts around the world were submitted

to the editors. The final published document was compiled by Berglund and Lindvall with some assistance from the WHO secretariat. As stated in the foreword of the final report (Berglund and Lindvall 1995), the editors decided how to deal with particular points where conflicting comments had been received, so the final report therefore includes an element of personal interpretation.

7.10 These 1995 Guidelines were further developed over the following years. Following an Expert Task Force Meeting convened in April 1999 in London, the Guidelines for Community Noise were extended to provide global coverage and applicability, and the issues of noise assessment and control were addressed in more detail. Thus the 1999 Guidelines were published (WHO, 1999).

Summary of WHO Guidelines 1999

7.11 The 1999 Guidelines for Community Noise were prepared as *“a practical response to the need for action on community noise at the local level, as well as the need for improved legislation, management and guidance at the national and regional levels.”*

7.12 The main topic areas covered in the Guidelines are noise sources and measurement and adverse health effects of noise, including:

- noise-induced hearing impairment
- interference with speech communication
- sleep disturbance
- cardiovascular and physiological effects
- mental health effects
- the effects of noise on performance
- effects of noise on residential behaviour and annoyance
- the effects of combined noise sources
- vulnerable groups.

7.13 Guideline values, for specific health effects of noise are given for the following specific environments:

- dwellings, including bedrooms and outdoor living areas.
- schools and preschools, including rooms for sleeping and outdoor playgrounds.
- hospitals, including ward and treatment rooms.
- industrial, commercial shopping and traffic areas, including public addresses, indoors and outdoors.
- ceremonies, festivals and entertainment events, indoors and outdoors.
- music and other sounds through headphones.
- impulse sound from toys, fireworks and firearms.
- outdoors in parkland and conservation areas.

- 7.14 Chapter 5 of the Guidelines is devoted to “noise management” with discussions of strategies and priorities in managing indoor noise levels; noise policies and legislation; the impact of environmental noise; and the enforcement of regulatory standards.
- 7.15 Table 7-2 below (which appears in WHO, 1999 as Table 4.1) presents the WHO guideline values arranged according to specific environments and critical health effects. The guideline values consider all identified adverse health effects for the specific environment. An adverse effect of noise refers to any temporary or long-term impairment of physical, psychological or social functioning that is associated with noise exposure. Specific noise guidelines have been set for each health effect, using the lowest sound level that produces an adverse health effect. Although the guideline values refer to sound levels impacting the most exposed receiver at the listed environments, they are applicable to the general population. The time base for L_{Aeq} is 16 hours for “daytime” and 8 hours for “night-time”. No time base is given for evenings, but typically the guideline value should be 5–10 dB lower than in the daytime. Other time bases are recommended for schools, preschools and playgrounds, depending on activity.

Table 7-2: Guideline values for community noise in specific environments (reproduced from WHO, 1999)

Specific environment	Critical health effect(s)	LAeq [dB]	Time base [hours]	LAmx, fast [dB]
Outdoor living area	Serious annoyance, daytime and evening	55	16	-
	Moderate annoyance, daytime and evening	50	16	-
Dwelling, indoors	Speech intelligibility and moderate annoyance, daytime and evening	35	16	
Inside bedrooms	Sleep disturbance, night-time	30	8	45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School class rooms and pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	during class	-
Pre-school Bedrooms, indoors	Sleep disturbance	30	sleeping -time	45
School, playground outdoor	Annoyance (external source)	55	during play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time	30	8	40
	Sleep disturbance, daytime and evenings	30	16	-
Hospitals, treatment rooms, indoors	Interference with rest and recovery	#1		
Industrial, commercial, shopping and traffic areas, indoors and Outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (patrons:<5 times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music through headphones/ Earphones	Hearing impairment (free-field value)	85 #4	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults)	-	-	140 #2
	Hearing impairment (children)	-	-	120 #2
Outdoors in parkland and conservation areas	Disruption of tranquillity	#3		

#1: as low as possible;

#2: peak sound pressure (not LAmx, fast), measured 100 mm from the ear;

#3: existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low;

#4: under headphones, adapted to free-field values

Comments on Guideline values, and comparisons

7.16 In September 1998, an NPL review report for the then Department of the Environment, Transport and the Regions, DETR (Porter *et al*, 1998) included a section on the “Interpretation

of the WHO Guidelines". Comparison was made between the recommendations made by the WHO in 1980 and 1995. Table 7-3 below is reproduced from that 1998 report.

Table 7-3: The WHO guideline values (from Porter *et al*, 1998)

Effect to be avoided	Effect criterion	1980	1995
speech interference	100% intelligibility	45 L _{Aeq}	35 dBA
	reasonable intelligibility		45 dBA
	loud speech understood		55 dBA
noise induced hearing loss	negligible risk	75 L _{Aeq,8hrs}	75 L _{Aeq,8hrs}
	increasing risk	140 dB	130-150 dB(peak)
sleep disturbance	electrophysiological effects	35 L _{Aeq}	30 L _{Aeq}
			45 L _{Amax}
cardiovascular disease		more research needed	more research needed
performance effects	cognitive tasks		no specific criteria
	startle effects		no specific criteria
	reading skills in children		no specific criteria
thresholds of reported annoyance	moderate annoyance		50 L _{Aeq}
	serious annoyance	50 L _{Aeq}	55 L _{Aeq}
social behaviour	reduced helping behaviour		80 dBA

7.17 The authors commented that there were differences in the definitions of the different effects of noise considered and the units in which the guideline values were specified. For example, the 1980 guidelines for steady background sound levels to support 100% speech intelligibility were given as 45 L_{Aeq}, whereas the equivalent guideline values for 1995 were given as 35 dBA. In fact, it is difficult to compare the two sets of guideline values because of differences in the way the noise and its effects were measured.

7.18 The authors further noted that the 1980 guideline value to avoid 'interference with the restorative process of sleep' by continuous noise was specified as 35 L_{Aeq} as measured in the bedroom, whereas the 1995 guideline value for continuous noise 'if negative effects on sleep are to be avoided' was specified as 30 L_{Aeq}, some 5 dB lower than in 1980. An additional L_{Amax} guideline of 45 dBA was specified in the 1995 document to avoid sleep disturbance caused by separate noise events. These changes were considered to represent a more conservative approach by the editors of the 1995 document rather than any fundamental changes in

human sensitivity to noise whilst asleep. For reported annoyance, the 1980 guideline was that:

'daytime noise levels of less than 50 dBA Leq cause little or no serious annoyance in the community' ... 'Taking into account other factors such as transport needs,, daytime noise limits in the region of 55 dBA Leq might be considered as a general environmental health goal for outdoor noise levels in residential areas'.

7.19 The 1995 document states that:

'the threshold of annoyance for steady-state, continuous noise is around 50 dB L_{Aeq}. Few people are seriously annoyed during the day time at noise levels below around 55 dB L_{Aeq}'.

7.20 For reported annoyance, close comparison of the precise specifications given in the 1980 and 1995 documents suggested that the guideline values were actually relaxed over this time. In 1980, 55 L_{Aeq} was suggested as a general environmental health goal, whereas in 1995, 55 L_{Aeq} was suggested as the threshold value below which few people are seriously annoyed.

Interpretation

7.21 It is important to bear in mind that the WHO guideline values, like other WHO guidelines are offered to policy makers as a contribution to policy development. They are not intended as standards in a formal sense but as a possible basis for the development of standards. By way of overall summary, the 1998 NPL Report noted:

The WHO guidelines represent a consensus view of international expert opinion on the lowest noise levels below which the occurrence rates of particular effects can be assumed to be negligible. Exceedances of the WHO guideline values do not necessarily imply significant noise impact and indeed, it may be that significant impacts do not occur until much higher degrees of noise exposure are reached. The guidelines form a starting point for policy development. However, it will clearly be important to consider the costs and benefits of reducing noise levels and, as in other areas, this should inform the setting of objectives.

7.22 In 2006 Berglund presented comparisons between the Guidelines of 1980 and the 1999 version (Berglund, 2006). Her tabulated comparison is reproduced as Table 7-4.

Table 7-4: Comparison of 1980 and 1999 WHO guidelines (from Berglund, 2006)

Environment	Health effects	1980 Guideline value	2000 Guideline value	Differ- ence
Any	Physical Injury	140 dB	140 dB	0 dB
Any	Acute Pain	230 dB	230 dB	0 dB
Any	Aural Discomfort	100-110 dB	100-110 dB	0 dB
Any	Hearing Loss	85 dB LAeq,8h	70 dB LAeq,24h	10 dB
Indoors	Speech Interference, daytime	45 dB LAeq,12h	35 dB LAeq,16h	5 dB
Outdoors	Annoyance, daytime	55 dB LAeq,12h	see below	
Dwellings, outside	Serious Annoyance, day & evening		55 dB LAeq,16h	1 dB
	Moderate Annoyance, day & evening		50 dB LAeq,16h	6 dB
Bedrooms, inside	Sleep disturbance, nighttime	35 dB LAeq	30 dB LAeq & 45 dB LAm _{ax}	5 dB

Footnote. If not indicated, the time interval of LAeq was not given explicitly.

7.23 Professor Berglund noted that *“The comparisons are not straightforward because different time constants have been proposed. The guideline values agreed upon were in terms of “noise dose” lower in 2000 than in 1980 for hearing loss (10 dB), speech interference (5 dB), serious annoyance (1 dB), moderate annoyance (6 dB), and sleep disturbance (5 dB). These decisions were mainly based on the results of research published in the 80’s and 90’s.”*

7.24 It should however be noted that the Guideline values for Serious Annoyance, Moderate Annoyance and Sleep disturbance are unchanged between 1995 and 1999.

The Environmental Noise Directive

7.25 In 1996, the European Commission published a Green Paper – Future Noise Policy. It put forward the view that action to reduce environmental noise had had a lower priority than that taken to address other environmental issues such as air and water pollution despite significant public concern about the issue. The Green Paper was the first step aimed to stimulate public discussion on the future approach to noise policy and led to the publication of Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise (often known as the “Environmental Noise Directive” (END)).

7.26 The aim of the END is to define a common approach across the European Union with the intention of avoiding, preventing or reducing on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise.

7.27 The END is implemented separately in England, Scotland, Wales and Northern Ireland. The Directive requires a noise mapping and action planning process to be taken forward on a five-year rolling programme.

7.28 The first round of mapping and action planning applies to agglomerations with more than 250,000 inhabitants; major roads with more than 6 million vehicle passages a year; major railways which have more than 60,000 train passages a year and major airports with more

than 50,000 movements a year. Airports falling within agglomerations also have to be mapped if they lead to a population exposure of more than 55 dB L_{den} or 50 dB L_{night} . Subsequent rounds will additionally address agglomerations with a population of more than 100,000 inhabitants; major roads and major railways with more than 30,000 train passages. The first round of mapping was submitted to the Commission by the end of 2007. The results for England, Scotland, Wales and Northern Ireland are available on the internet.

7.29 Action plans to manage noise for these areas will be developed, based on the mapping results. These will be drawn up in consultation with the public with a view to preventing and reducing environmental noise where necessary.

Conclusions

7.30 The structure of legislation in the UK with respect to environmental noise is highly complicated involving a wide range of separate departments and agencies and calling on a large number of legal and guidance documents. The WHO guidelines have evolved over more than two decades and have the status of guidance rather than law but are nevertheless highly influential. Guideline values are provided for the prevention of annoyance, sleep disturbance, speech interference, and hearing impairment but not for cardiovascular and psycho-physiological effects, mental health effects, effects on performance or the preservation of tranquillity. Annoyance is the main health effect of environmental noise to be covered by legislation in the UK. It can be argued that health effects are taken into account more broadly in the statutory nuisance regime but this, however, does not apply to transportation noise sources. There are as yet no strict limits on noise derived from considerations of effects such as cardiovascular disease in the UK.

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<http://www.who.int/docstore/peh/noise/guidelines2.html>

Chapter 8. Conclusions

- 8.1 Noise, often defined as 'unwanted sound', implies both the presence of sound as a purely physical phenomenon, and also a subjective response to that sound from the people for whom it is unwanted.
- 8.2 'Noise maps' are maps of objective sound levels measured in physical units. Mapping of the subjective response to environmental noise could, in theory, also be done but would require a different approach, for example by measuring public reaction with social surveys.
- 8.3 Dose-response curves have been established which relate the average annoyance and sleep disturbance of the population (of Europe and elsewhere) to measured sound levels. However, it should be appreciated that there is significant variation between individuals, and that the average response measures do not reveal local variations.
- 8.4 Surveys have shown that about half of the UK population live in areas where daytime sound levels exceed those recommended in the WHO Community Noise Guidelines. About two thirds of the population live in areas where the night-time guidelines recommended by WHO are exceeded.
- 8.5 Attitudes to noise are changing. The evidence we have examined, from surveys, shows that people are probably becoming less tolerant of noise. Complaints about noise are increasing, although in part this may be due to variations in reporting and recording mechanisms.
- 8.6 It is also clear that some sources of noise are more likely to lead to complaint than others for the same sound level. Broad surveys of responses to noise may not adequately reflect concerns in local areas.
- 8.7 Environmental levels of sound do not reach the intensities needed for damage to hearing.
- 8.8 In general terms, the likelihood, and strength, of annoyance is related to the level of sound to which people are exposed. This relationship can be expressed both mathematically and graphically. Such relationships, described as dose-response curves, could be used as a basis for policy development regarding noise control. Such dose-response curves need to be studied closely; a considerable scatter of individual responses occurs around the average response at any specified sound level. The reasons behind such variations are not well understood. We think it also likely that the nature of peoples' reactions to specified sound levels appears to be changing and one might expect the slope of dose-response relationships to be unstable. We conclude from this that repeated surveys to establish reliable dose-response curves for annoyance may be needed.

- 8.9 That sleep can be affected by noise is common knowledge. Defining a dose-response curve that describes the relationship between exposure to noise and sleep disturbance has, however, proved surprisingly difficult. Laboratory studies and field studies have generated different results. In part this is due to habituation to noise which, in the field, is common in many people.
- 8.10 Exposure to noise has been shown to be associated with increased levels of stress hormones in the blood. These include the adrenal corticosteroids and also adrenaline and noradrenaline which reflect activity of the sympathetic nervous system. Whether such increases in concentrations are harmful is uncertain but some authors have linked such changes with the possibility of long term effects on blood pressure and on cardiovascular disease.
- 8.11 Long-term exposure to high levels of noise in the occupational setting has been shown to be related to the likelihood of individuals developing cardiovascular disease. Recent studies suggest an association between environmental noise and high blood pressure and this is supportive evidence for an effect of environmental noise on cardiovascular disease. It is not currently possible to reach a firm conclusion on this point and further work is needed.
- 8.12 It has been suggested that exposure to environmental noise is associated with an increased likelihood of development of mental illness. This assertion has attracted some attention, but the evidence is by no means clear cut. In our view it has not been established that exposure to environmental noise causes mental illness. Further research is recommended.
- 8.13 Exposure to environmental noise has been shown to be linked with impairment of cognitive performance amongst children exposed to high sound levels whilst at school. Further work is required to establish whether this effect is short or long-term.
- 8.14 Low frequency noise is an increasing cause of complaint in the UK. There is no firm evidence that exposure to this type of sound causes damage to health, in the physical sense, but some people are certainly very sensitive to it. Often a source can be identified and controlled. For some who suffer from the effects of exposure to low frequency noise development of a coping strategy can be helpful.
- 8.15 A wide range of legislation applies to the control of environmental noise in the UK. It is our impression that people may be confused as to who regulates environmental noise and who can be expected to take action in specific circumstances.
- 8.16 Our examination of the evidence relating to the effects of environmental noise on health has demonstrated that this is a rapidly developing area. Any single report will therefore need to be revised within a few years. We conclude, and recommend, that an independent expert committee to address these issues on a long-term basis be established.

- 8.17 Environmental noise is a problem in the UK today and many people are concerned about its possible effects on health. In terms of wellbeing we have little doubt that a significant number of people are adversely affected by exposure to environmental noise. If it is accepted that health should be defined in such a way as to include wellbeing then these people can be said to suffer damage to their health as a result of exposure to environmental noise. There is increasing evidence that environmental noise, from both aircraft and road traffic noise is associated with raised blood pressure and with a small increased risk of coronary heart disease. Evidence that environmental noise damages mental health is, on the other hand, inconclusive.
- 8.18 Our examination of the evidence relating to the effects of environmental noise on health has led us to realise that there are many important, unanswered questions. We thus conclude that a programme of research is needed and we have set out our perceptions of what such a programme might contain in the following Chapter.

Chapter 9. Recommendations for research

The Committee recommends the following areas of further research:

- 9.1 The development of better parameters to reflect the response of people to noise
- 9.2 Further study of changing attitudes to noise
- 9.3 Development of techniques for mapping public response to noise
- 9.4 Improvements in the methods used to record complaints about noise
- 9.5 Longitudinal studies of environmental noise exposure and measurement of hormones as well as health outcomes to understand whether there are effects of prolonged noise exposure to which people do not habituate
- 9.6 Longitudinal community studies of aircraft and road traffic noise and mental health using diagnostic measures in settings of high noise exposure in order to be more certain of noise effects on mental health
- 9.7 Research to distinguish between annoyance-related and stress-related effects of noise
- 9.8 Research into the effects of chronic exposure to noise and its effects on sleep
- 9.9 Further research on the susceptibility of population groups to health effects of environmental noise
- 9.10 Further work on the effects of exposure to noise on the development of cardiovascular disease
- 9.11 Research on the mechanism by which environmental noise may increase blood pressure and lead to coronary heart disease, and the relative risks associated with air pollution and noise
- 9.12 Further field research on noise and sleep disturbance and the links between long-term sleep disturbance by noise and health outcomes, particularly increased risk of coronary heart disease
- 9.13 Further study of the relationship between exposure to noise and the release of stress hormones

- 9.14 Further study of the relationship between noise and psychological symptoms and clinical psychological disorders
- 9.15 Research into the effects of noise exposure on children, to understand the mechanisms of the effects of noise on reading and memory, whether the effects are temporary or persist, and whether they can be remedied by improved acoustic conditions in schools
- 9.16 Research into the positive, beneficial effects of sound
- 9.17 Research into the causes and possible treatment of disturbance caused by low frequency noise
- 9.18 Other research into the benefits of quiet areas for health.

Glossary

A-weighted sound level	the level of sound in decibels, dB, after filtering with an A-weighting filter which mimics the frequency response of the human ear. Most environmental noise measurements use A-weighted sound levels.
A-weighting	a way of filtering sounds to mimic the response of the human ear. It is used for almost all measurements of environmental noise. Its use is indicated by an uppercase 'A' in the measurement indicator, <i>e.g.</i> L_{Aeq} .
actigraph	A device used to detect movement during sleep.
adrenaline	see catecholamines.
attenuation	reduction in sound level expressed in decibels (dB).
blood viscosity	the resistance to flow caused by adhesion of components of the blood.
C-weighting	a way of filtering sounds to mimic the response of the human ear, similar to A-weighting, but associated with high intensity sound not generally found in the environment. It has an approximately level response over most of the hearing range.
cardiac dysrhythmias	states of abnormal heart rhythm.
cardiovascular	relating to the heart and circulation.
catecholamine secretion	the catecholamines, adrenaline and noradrenaline are hormones produced by the inner part of the adrenal glands. Noradrenaline also acts as a transmitter substance and is released by nerve terminals in the sympathetic nervous system.
cholesterol	a fat found in the blood and thought to be related to cardiovascular disease.
CI, confidence interval	limits defined around a sample mean that indicate the probability of the true mean lying within the defined

	range.
cognitive	relating to conceptualising thought.
cortisol	a steroid hormone secreted by the adrenal cortex.
dB	decibel (see Chapter 2).
dB _A , dB _C	A weighting and C weighting.
diastolic blood pressure	the lowest pressure measured in the arterial system at each beat of the heart.
dose-response relationships	mathematical or graphical representations of the relationships between exposure to noise, or a chemical, and the response, for example illness or annoyance.
EEG	electrocardiogram, a recording of the electrical activity of the heart.
endocrine	endocrine glands such as the thyroid, adrenal and parathyroid glands release chemicals called hormones directly into the blood stream.
epidemiological	epidemiological techniques are those used to study diseases in populations.
frequency	the frequency of a sound is the number of cycles per second; high frequency sounds are high pitched and low frequency sounds are low pitched.
glucose level	the concentration of the sugar, glucose, found in the blood.
habituate	grow accustomed to a stimulus through repetition.
hypertension	a disease characterised by higher than normal blood pressure.
IHD, Ischemic Heart Disease	damage to the muscle of the heart caused by impairment of its blood supply, generally as a result of obstruction of the coronary arteries.

ischaemic	lacking in blood supply, tissues may become ischaemic due to obstruction of their blood supply.
L_{A10}	the sound level exceeded for 10% of the measurement period. This gives an indication of the higher levels that occur over the measurement period, and is used in the assessment of road traffic noise.
L_{A90}	the sound level exceeded for 90% of the measurement period, or equivalently the level which is not exceeded for the quietest 10% of the measurement period. This corresponds approximately to the level of steady background noise, by excluding noisy events such as cars passing or aircraft flying over.
L_{Aeq} :	effectively the average sound level over a specified time. Formally it is the equivalent continuous A weighted sound level, i.e. the level which if maintained constant for the stated time period contains the same sound energy as the real, varying sound over the same period.
L_{Amax}	the maximum A weighted sound level occurring during a given period. Strictly speaking, the time constant of the instrument used for measurement should also be stated; normally this is 'F' (Fast), the other option (rarely used) being 'S' (Slow).
L_{den}	day-evening-night level, a descriptor of noise level based on energy equivalent noise level (L_{eq}) over a whole day with a penalty of 10 dBA for night time noise (23.00-7.00) and an additional penalty of 5 dBA for evening noise (i.e. 19.00-23.00).
L_{night}	the night-time noise indicator for self reported sleep disturbance; the A-weighted sound level averaged over the night time period (23.00-7.00), as defined in ISO 1996-2:1987. Note that although night time noise attracts a penalty of 10 dBA in L_{den} , the definition of L_{night} does not include an addition of 10 dB.
meta-analyses	a statistical technique used to combine, with suitable weighting, the results of individual studies.

morbidity	Illness.
motility	a capacity for movement.
myocardial infarction	death of a part of the muscle of the heart caused by obstruction of its blood supply.
noradrenaline	see catecholamines.
peripheral vascular resistance	the resistance to blood flow posed by peripheral blood vessels, for example, those of the skin.
peripheral vasoconstriction	a narrowing of the blood vessels in the skin and other superficial tissues.
platelet count	platelets are small cells found in the blood. They lack nuclei and are involved in blood clotting. A low platelet count is associated with impaired clotting processes.
relative risk	the ratio of the risk of an adverse event in an observed sample compared with the background risk of the same event.
sociodemographic	techniques that focus on age and sociological distributions in the population.
sound level	the sound pressure level in dB or dBA at a given location.
sound power level	quantifies the sound output of a sound source and is given in dB or dBA.
systolic blood pressure	the peak of hydrostatic pressure measured in the arterial system at each beat of the heart.
triglycerides	other fats found in the blood.

Appendix A: Low Frequency Noise

Low frequency noise covers the range from about 10 Hz to 200 Hz, although the limit frequencies are not rigidly fixed (Leventhall *et al.*, 2003). Low frequency noise has been recognised by the World Health Organisation as meriting special attention, requiring lower environmental limits than those of other noises, as it presents particular problems to those people who are sensitive to its effects (WHO, 1999). For example:

"If the noise includes a large proportion of low frequency components, values even lower than the guideline values will be needed, because low frequency components in noise may increase the adverse effects considerably. When prominent low frequency components are present, measures based on A-weighting are inappropriate" (WHO, 1999).

A separate category of "low frequency noise sufferer", or "Hum Sufferer" has been recognised, although a "low frequency noise syndrome" has not yet been defined. The publicity which infrasound and low frequency noise have received over the past 40 years has led them to occupy a special place in the communal mind, such that a result of the publicity may be that descriptions by sufferers of their perceptions of the noise, and its effects on them, have been conditioned by external influences. However, this does not detract from the fact that there are low frequency noise (Hum) sufferers in the community who urgently, and rightly, plead for a solution to their problems.

The number is not known, but a review in 1989 suggested that local authorities in the UK might receive over 500 complaints of low frequency noise a year, for which nearly 90% of the complaint noises were identified (Tempest, 1989). In recent work on a small sample of complaints, only about a third were resolved by technical means, whilst the sources of the remainder could not be found, the noise could not be measured, or measurements of noise did not correlate with the complainant's perception of it (Moorhouse *et al.*, 2004). There is, of course, a good possibility that those low frequency sources which are at a relatively high, and easily measurable level, will be detected and controlled. But often the low frequency noise complained of is of very low level and, perhaps, cannot be measured separately from general environmental low frequency noise, which is always present. It then becomes difficult to distinguish between an external low frequency noise and low frequency tinnitus, so that tinnitus is often used as an explanation of last resort, after noise measurements have failed to detect a source.

Failure to detect and control the source leads to a group of long term complainants, either surviving on their own or joining together for mutual help, which has been given in the UK by the Low Frequency Noise Sufferers Association and the Low Frequency Noise Helpline. There is also an international Yahoo Group "Hum Forum".

There is no evidence that those low levels of low frequency noise and infrasound which are difficult to measure, and which occur in most environmental noises, will have a direct physiological effect on the body. As far as is known, the ear is the most sensitive body receptor for sounds at all frequencies, including infrasound (Yamada *et al*, 1983). The effects of low frequency noise on health follow from the stress and frustration which sufferers experience in attempting to find a solution to their problem, which is often worse at night and affects sleep. Claims that their lives "have been ruined" by their persistent low frequency noise, which cannot be traced to a source, are valid. Increasing exposure to the low frequency sound may lead to development of a general decrease in tolerance to sounds. Sufferers may be offered sleeping pills and anti-psychotic drugs to give them relief. However, some drug free improvement might be achieved by a change in attitude to the noise.

Many sufferers are, understandably, resentful of the noise and of whoever might be responsible for the source, developing aggressive feelings towards anybody whom they suspect, often their neighbours. They become tremendously stressed and aggrieved by their situation. However, whilst sourcing and controlling the noise must have top priority, it has been shown that established techniques of stress management may have an ameliorating effect on sufferers' reactions, so leading to an improved quality of life. (Leventhall *et. al.* 2008).

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Appendix B: Dose-response functions: association or causality?

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1. The study of the effects on health of environmental factors such as noise, air pollution or ambient temperature, is characterised by attempts to observe associations between ambient levels of these factors and changes in indices of ill-health. The levels of the factors, for example sound level expressed in decibels or pollutant concentration exposed as μg per m^3 , may be measured over short or long time periods. Studies may, for example, focus on “long-term” average sound levels or on short-lived “peaks” of sound intensity. To study effects, variations in levels tend to be examined. If the time period considered is long we tend to think not in terms of variation in the intensity of exposure but, rather, to say that exposure is constant. Variation is provided in studies of long-term average levels by comparing one location with another: for example, a noisy and a quiet location or, better, a series of locations providing a graded series of exposures. Though the word “exposure” has already been used, it might be better to begin by thinking in terms of ambient levels of the factor. Exposure is discussed below. Indices of ill-health include, again for example, self-reported levels of annoyance or daily admissions to hospital, daily deaths or the relative risk of death at a specified age when one location is compared with another.
2. In principle then, studies are made of the effects of variations in factors that are believed to affect health. Such studies are rather more complicated than laboratory studies where the experimenter has close control over the factor (or factors) which he/she seeks to vary and is able to measure a well-defined response. In toxicology, such studies are referred to as dose-response studies and the results, when plotted on, for example, graph paper lead to dose-response curves. A number of mathematical methods to convert such curves into essentially linear relationships have been developed and, of course, the associations can be expressed mathematically as equations. Two types of dose-response study are described: (A) the quantal assay in which the proportion of subjects (animals, people or cells) showing a specified level of response is plotted against dose and (B) the graded response assay in which the average response amongst a group of subjects is plotted against dose. Both approaches have been used in the noise field.
3. In toxicological studies, dose is the independent variable and is easily quantified, for example as x mg of some drug per kg body weight. In some studies dose is difficult to determine and tends to be replaced by measures of exposure, for example, volunteers were exposed to sulphur dioxide at a concentration of y mg per m^3 for 10 minutes. In epidemiological studies exposures is sometimes measured (personal exposure studies) but ambient concentration is often used as a surrogate for exposure.
4. If ambient concentration of a pollutant (or ambient sound level) is used as a surrogate for exposure and if the responses of people living in different areas are to be compared, then factors

which affect the relationship between ambient levels and personal exposure need to be constant or, at least, known and allowed for. Consider a study of the effects of noise from an airport: for a constant level of sound one might expect a greater response in summer when people are, perhaps, sitting in their gardens than in winter when they will be more likely to be indoors and shielded from the ambient (outdoor) conditions.

5. Studies of associations between environmental factors and effects on health also need to take into account confounding factors. These are factors that vary in the same way (for example, in time or space) as the factor being studied. For example, if the effects of noise were being studied across a variety of locations and it were to be found that levels of air pollutants also varied, similarly, across these locations, it might be difficult to say how much of a measured response was actually due to noise. The effect of noise would, perhaps, be confounded by that of air pollution. More difficult yet are the possibilities of effect modification: we might discover that the slope of the dose-response curve for one factor was increased or decreased by a second factor. Statistical techniques for dealing with confounding factors and effect-modifying factors have been developed.

6. Confounding factors can operate at both a personal and non-personal level. Imagine that the prevalence of heart disease was found to be significantly higher in a noisy part of a town than in a quiet area. This effect might be due to noise or perhaps due to the fact that house prices tend to be lower in noisy areas encouraging poorer people to live in such areas and cigarette smoking, a certain cause of heart disease, is more common amongst the poor. Adjusting for confounding factors is an important part of the structure of the statistical analysis used in such studies.

7. Associations can occur by chance, may be due to confounding factors or bias in the study design or may be causal. Adequate study design and appropriate analysis eliminate, as far as possible, bias and confounding and define the likelihood of the association being due to chance. But even after this has been done deciding on whether an association is truly causal (ie, B is found to be associated with A and A is taken as causing B) is not easy. The simplest, but perhaps most intractable, cause for error is the problem of the unidentified confounding factor. A classical example is provided by the clear association between the number of licences issued for radio sets in the 1920's and the number of people admitted to asylums for the mentally ill. Was this a causal association? On a priori grounds we might think not. In fact, the rapid expansion of building of psychiatric hospitals at the same time as radios were becoming popular explains the association.

8. Despite all efforts an association could always be due to chance or to an unidentified confounding factor. We may feel confident that an association is unlikely to be due to chance and we may think that all confounding factors and biases have been taken into account, but proof, absolute and irrefutable proof, of causality is exceptionally difficult to obtain. Most scientists do not pursue this objective (irrefutable proof) and rely on "guides" that experience has shown to be useful in distinguishing causal from non-causal associations.

9. A much used source of such guidance is the work of the medical statistician Sir Austin Bradford Hill who, in a seminal paper in 1965, described a number of “features” of causal associations (Hill, 1965). These are sometimes regarded as “lists” or “criteria”: this is quite wrong and is a misinterpretation of Bradford Hill’s work. Bradford Hill listed nine features of association that tended to increase confidence in causality: strength of association; consistency; specificity; temporality (horse must precede cart); biological gradient (dose/exposure/concentration-response relationship); biological plausibility; coherence; experimental evidence; and, reasoning by analogy. A detailed discussion may be found in Bradford Hill’s *Principles of Medical Statistics* (Hill, 1971). Of these nine features only temporality can be seen as a necessary attribute of causality.

10. In recent years attention has focused on multiple-causality. This explains that few effects, such as death from heart disease, or reaching a specified level of annoyance, are likely to be caused by one factor alone. This concept is very important to explaining the lack of an apparent threshold of effect, a finding which is common in studies in environmental epidemiology. In the air pollution field this has led to a move away from defining “safe” levels of exposure to pollutants and a move towards expressing results in terms of probabilities of occurrence of a specified effect at a specified level of exposure. It seems likely that such an approach is also applicable in the environmental noise field.

References

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