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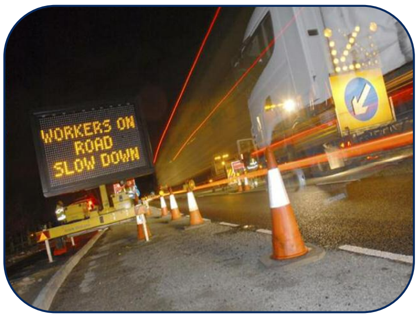

CLIENT PROJECT REPORT CPR1080

Estimating the productivity impacts of noise

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Executive Summary

Noise can have a number of important impacts on human health, productivity, amenity and ecosystems. Assessments of the impacts of noise in the UK have estimated the annual cost of noise as being of the order of £7-10 billion.

Whilst the impacts of noise on health are relatively well understood, less is known about the precise impact that noise has on productivity and the scale of this relationship. There are potential economic impacts from noise exposure due to reduced productivity at work caused by factors such as sleep loss/disturbance and workplace distractions; such impacts are not currently considered within UK policy appraisal.

In order to assist the development of a comprehensive understanding of the range of impacts included in government appraisal of policies affecting noise, this work looks to investigate the evidence on potential mechanisms through which noise exposure might be linked to productivity.

The identification of mechanisms has been addressed in terms of impact pathways. It was considered that productivity within the workplace can potentially be affected by different mechanisms resulting from noise experienced both during and outside of working hours. Mechanisms were grouped accordingly into these categories. As a separate consideration, mechanisms based on potential impacts on individuals in education that might result in reduced skills and reduced lifetime earnings were also assessed.

The level to which these were then investigated further was prioritised based on the potential for progress in the available evidence, the importance of the area and links to other ongoing work.

As a consequence of this assessment, the primary focus of this report is on those mechanisms associated with sleep disturbance and academic performance. Health effects were not pursued as they are covered in depth in previous work by the Interdepartmental Group on Costs and Benefits, noise subject group (IGCB(N)). Workplace distraction was not investigated in detail as the role for government intervention in this area was seen to be relatively weak.

Whilst it is clear that noise can impact on sleep and that sleep loss can have a significant economic cost providing an appropriate mechanism is problematic. Firstly much of the evidence linking noise to sleep disturbance is based around subjective self-reports which may not correlate with other objective measures of sleep quality. Secondly, while studies can identify distinct control groups, when considering the whole population it may be difficult to discriminate between noise-induced sleep disturbance and disruption caused from other factors such as lifestyle, physiology and lighting. It may be possible to make estimates based on L_{night} noise values since some studies show a correlation, however noise events have been shown to be a more accurate measure of awakenings. Thirdly measuring productivity in terms of efficiency in the workplace is difficult to do objectively and as such most studies rely on either subjective assessments or accident rates and absence only.

While recognising the importance of these uncertainties, IGCB(N) guidance provides an approach to quantify sleep disturbance from environmental noise. Work in Australia and Japan has demonstrated that the economic impacts of sleep disturbance can be derived. It is suggested that a monetary value for the UK could potentially be determined using a method similar to that in the Australian study, although this would require a robust estimate of the

proportion of the population suffering from a sleep disorder or awoken at night due to noise. The determination of this population value may be achievable using the IGCB(N) guidance in combination with appropriate population density information.

In terms of the mechanism linking the effects of noise exposure in an academic environment to productivity in the workplace, no studies have been identified which address the complete mechanism. However, there is evidence of work on components of the mechanism.

Much of the literature associated with the link between noise and academic performance focused only on the performance of primary school children. In contrast, literature associated with the link between academic performance and GDP focussed on secondary school children, with an emphasis on the effects of increased time in school or improvements in academic qualifications.

It is therefore considered that to make the link between these different components, further evidence is required to relate impacts on learning at a young age to academic achievement later in education.

In terms of links between noise exposure in the workplace and productivity, only disturbance by noise sources that are unlikely to exceed exposure action values within the Control of Noise at Work Regulations 2005 has been considered. There is evidence to suggest that office noise can cause disturbance and adversely affect productivity. However, the control and mitigation of such sources is the responsibility of employers who have sufficient incentives to address this. Developing appraisal tools for these mechanisms would be difficult and the role of government in assessing the impacts of environmental noise is perceived as limited.

In terms of mechanisms linking noise-induced health effects to productivity, no evidence has been found linking loss of productivity to health while in the workplace. One potential approach would be to focus on health-related absence. Monetised values associated with health-related absence take into account a wide range of factors and disaggregating the effects of noise is not considered possible with the evidence available in the associated published surveys. However, if the health effects considered can be correlated with those addressed by IGCB(N), it may be possible to use IGCB(N) estimates of the number of cases due to noise in combination with the absence figures to estimate the effect from noise.

1 Introduction

Noise can have a number of impacts which can affect human health, productivity, amenity and ecosystems. In order to allow governments to make informed decisions and implement policies for the management and control of noise, suitable appraisal and evaluation tools must be available which allow both the scale of the problem and the impacts of such policies in terms of affordability, value for money and meeting objectives to be assessed.

Cost benefit analysis is one such tool which plays a key role in the development and assessment of UK Government policy by quantifying the likely costs and the tangible and intangible benefits of proposed policies. Appraisal is undertaken in accordance with guidance set out in the HM Treasury's Green Book (HM Treasury, 2008). This defines the key stages of the appraisal and evaluation process, from inception of a proposal through to its final implementation.

In carrying out an appraisal it is important to consider the lifecycle, or whole life, costs and benefits that would result from the different policies being appraised. By 'discounting' the value of future costs and benefits, as per the guidance set out in the Green Book, the net impact of different policies over an appropriate timeframe (analysis period) can be determined and compared on an equitable basis. Whole life costing requires that all relevant costs and benefits be monetised. The objective of this study is to investigate the link between noise and productivity, which would allow the effects of noise to be monetised in terms of changes in productivity.

The Interdepartmental Group on Costs and Benefits (IGCB) is a group of government analysts, led by Defra, which provides analysis and advice on the quantification and valuation of local environmental impacts. Within IGCB, a noise subject group, IGCB(N), has been established to provide advice on the economic evaluation of the noise impacts of government policy and plays an important role in helping the government develop its understanding of the costs and benefits of reducing noise pollution.

IGCB(N) is working to develop and improve appraisal methodologies for polices having noise impacts and seeks to expand the range of noise sources and impacts considered.

In order to achieve this, it is necessary to understand what is categorised as 'noise'. The Noise Policy Statement for England (NPSE; Defra, 2010), which applies to all types of noise apart from noise in the workplace (occupational noise)[1], considers that noise includes the following categories:

- **Environmental noise**, which includes noise from transportation sources
- **Neighbour noise**, which includes noise from inside and outside people's homes
- **Neighbourhood noise**, which includes noise arising from within the community such as industrial and entertainment premises, trade and business premises, construction sites and noise in the street

[1] Noise in the workplace is regulated by the Health and Safety Executive (HSE).

The definition of environmental noise in Directive 2002/49/EC (END; European Commission, 2002) on the management and assessment of environmental noise is broader, defining it as "*unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity.*" This is in order to take account of countries in the EU where there is less specific national regulation on individual sources of noise such as industrial noise.

Environmental noise is managed through policies and regulations at both national and European level. Examples of these include:

- **At national level:** NPSE, the 2006 Environmental Noise (England) Regulations 2006 (as amended), the Environmental Noise (Wales) Regulations (2006) (as amended), the Environmental Noise (Scotland) Regulations (2006) (as amended) and the Environmental Noise (Northern Ireland) Regulations (2006) (as amended)
- **At European level:** END, Directive 70/157/EEC (European Communities, 1970) and its subsequent amendments on vehicle noise type approval, Regulation 51.02 (European Commission, 2007b) which sets out uniform provisions for the type approval of motor vehicles in relation to permitted noise levels when the vehicles are in operation, and Directive 2001/43/EC on vehicle tyre noise (European Commission, 2001)

Neighbourhood noise and neighbour noise (using the definitions from NPSE) are addressed through noise and statutory nuisance legislation including the Anti-social Behaviour Act 2003, the Clean Neighbourhoods and Environment Act 2005, the Noise and Statutory Nuisance Act 1993 and the Control of Noise (Codes of Practice for Construction and Open Sites) (England) Order 2002 and similar legislation for the devolved administrations.

Assessments of the impacts of environmental noise in the UK conducted by IGCB(N) split the range of impacts into four broad groups of health impacts, effects on amenity, effects on productivity and impacts on ecosystems. It was estimated that the annual cost of noise was of the order of £7-10 billion, being made up of between £3-5 billion in annoyance costs, £2-3 billion of adverse health costs and productivity losses (based on sleep disturbance) of £2 billion[2] (IGCB(N), 2008).

One of the areas where a relative lack of robust evidence was identified was the link between noise and productivity. Increased productivity is a key determinant of economic growth and, together with higher employment, is a primary route to higher living standards (Office for National Statistics [ONS], 2007). Understanding the link between noise and productivity is therefore beneficial since there are potential economic impacts from noise exposure due to reduced productivity at work caused by factors such as sleep loss/disturbance, adverse health effects and workplace distractions; such impacts are not currently considered within UK policy appraisal.

While IGCB(N) identified two routes in which noise disturbance could lead to a loss of productivity, namely through loss of sleep and noise in the workplace, only a single study

[2] This figure was derived by assuming that sleep disturbance causes 1% lower productivity per day for 2% of the population

was identified (Wicke, 1986)[3], which estimated that productivity losses in Germany due to noise were estimated to be 0.2% of GDP (Gross Domestic Product), equivalent to £3 billion at 2007 prices.

The work presented in this report serves as a first step towards the potential development of appraisal tools linking noise to changes in productivity.

1.1 Objectives of the project and methodology

TRL was commissioned by Defra, on behalf of IGCB(N), to identify potential mechanisms through which noise affects productivity and to conduct a literature review to scope the validity and relevance of each mechanism.

The methodology used to achieve this objective was as follows:

- **Stage 1:** Defining productivity and its relation to economic performance (presented in Section 1.2)
- **Stage 2:** Identification of potential mechanisms linking noise exposure to changes in productivity, based upon discussion and a preliminary literature review. These mechanisms were discussed with Defra to clarify which would be taken forward for further investigation, based on the likelihood of suitable evidence, importance and the potential for/value of developing appraisal tools for monetary quantification
- **Stage 3:** A detailed literature review into the identified mechanisms or components thereof. This included sourcing literature from a range of topic areas that might consider productivity such as occupational health, psychology and medicine, economics, sleep and education, as well as acoustics

The long term ambition was identified as being a high-level assessment of the total and marginal impact on productivity of noise, i.e. to estimate the annual cost of productivity across England and Wales from noise. The effects of environmental noise might, for example, be taken into account using data from the noise maps produced under the requirements of the END. However, the level of impact of potential mechanisms associated with other categories of noise may be dependent upon the personality of the individual exposed, the nature of their employment, the distance between their home and workplace, and the location of their home. It was expected therefore that not all of the mechanisms identified in Stage 2 would necessarily be carried forward into Stage 3 or be suitable for inclusion in appraisal tools for monetary assessment.

1.2 Defining of productivity and the link to economic performance

Productivity is a key driver of prosperity and is considered a key parameter in measuring the efficiency and competitiveness of national economies. As noted previously, it is a primary route to higher living standards. A number of different definitions exist for productivity. For example, the ONS Productivity handbook (ONS, 2007) defines general productivity as "*the ratio between what is obtained (output) and what was put in to obtain it (input).*"

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[3] This report was cited by IGCB(N). However the reference was incomplete and the TRL authors have been unable to locate the report.

Increasing productivity therefore means greater efficiency in producing output of goods and services from labour, capital, materials and any other necessary inputs, i.e. an increase in output with input remaining unchanged or even decreasing.

One of the ways in which efficiency can be measured is through labour productivity. The Organisation for Economic Cooperation and Development (OECD) defines labour productivity as "*GDP per hour worked*" (OECD, undated), where GDP is Gross Domestic Product.

GDP is also used as a measure of prosperity, and thereby indirectly productivity. This can be measured in 4 ways: *Production* (as the sum of all the gross value added (GVA)[4] by all producers in the economy), *Income* (as the total of the income generated through this productive activity), *Expenditure* (as the expenditure on goods and services produced) (ONS, 2007), and *Average Output* (total output divided by the number of workers. It is a key indicator of national economic performance, i.e. the health of the economy, and one of the most commonly used measures of output in the determination of productivity estimates. It is used by HM Treasury in planning economic policy, by financial bodies such as OECD, IMF, and the World Bank to compare the performance of different economies, and by the European Union as a basis for determining different countries' contributions to the EU budget (BBC, 2010).

1.3 Structure of the report

This report is structured as follows:

- Chapter 2 addresses Stage 2 of the project, i.e. the identification of potential mechanisms linking noise exposure to changes in productivity. Information from the preliminary literature review carried out as part of that process is included in Chapters 3-6
- Chapters 3-6 present the findings from Stage 3 of the project, i.e. the literature review associated with mechanisms taken forward from Stage 2. Each chapter addresses one of the 4 topic groups of sleep disturbance, academic performance, noise disturbance in the workplace and noise-induced adverse health effects
- Chapter 7 presents a summary and the conclusions of the work, together with gaps/limitations in the research and associated further work

[4] Gross Value Added, GVA = total output - intermediate consumption

2 Identification of potential mechanisms

Sources of annoyance and disturbance over which individuals have no direct control will, for the most part, result in mechanisms which might have adverse effects on productivity. However some mechanisms may allow individuals to reduce the level of these impacts, although it is unlikely that they will be fully negated. These have also been considered in this stage of the project.

In order to identify potential mechanisms, the approach adopted was to consider the mechanisms in terms of impact pathways. This approach follows the logical progression from the source of the disturbance, to its initial effect, through to its anticipated impact on productivity be that adverse or positive.

It was considered that productivity within the work place can potentially be affected by different mechanisms resulting from noise experienced both during and outside of working hours. Mechanisms have therefore been grouped accordingly into those two categories and sources of disturbance have been considered irrespective of who is responsible for regulating or legislating on their impacts.

- **For noise experienced during work hours (including home working)**, potential sources of disturbance fall into the three categories of noise to which NPSE applies (environmental noise, neighbour noise and neighbourhood noise) as well as into the category of occupational noise unlikely to exceed exposure action values within the Control of Noise at Work Regulations 2005 (e.g. person generated noise, PC/printer noise, background office noise, etc.). The level of neighbour and neighbourhood noise experienced will be dependent upon the location where an individual is working
- **For noise experienced outside of working hours**, potential sources of disturbance fall only into the three categories of noise to which NPSE applies, and could potentially be experienced in the home, on the journey to/from work and during recreational activities

The impact of each mechanism has been categorised in terms of either immediate effect (generally increased task duration), short-term effects or long-term effects.

Figure 2.1 presents those mechanisms linking noise experienced during working hours to the likely impacts on productivity. Figure 2.2 presents those mechanisms which link noise experienced outside of working hours to the likely impacts on productivity. The Figures illustrate the complexity of the issue and the large, but not exhaustive, number of potential mechanisms.

It is noted that these mechanisms only apply to individuals of employable age. However, since the work force changes over time as individuals pass from the education system through to employment, it was considered that it would be beneficial to assess whether there were any potential impacts that might affect individuals during their years in education, resulting in reduced qualifications/skill levels which might thereby reduce their lifetime earnings and influence their productivity in later life.

Figure 2.3 presents those mechanisms linking noise experienced in academic environments to changes in productivity once in employment.

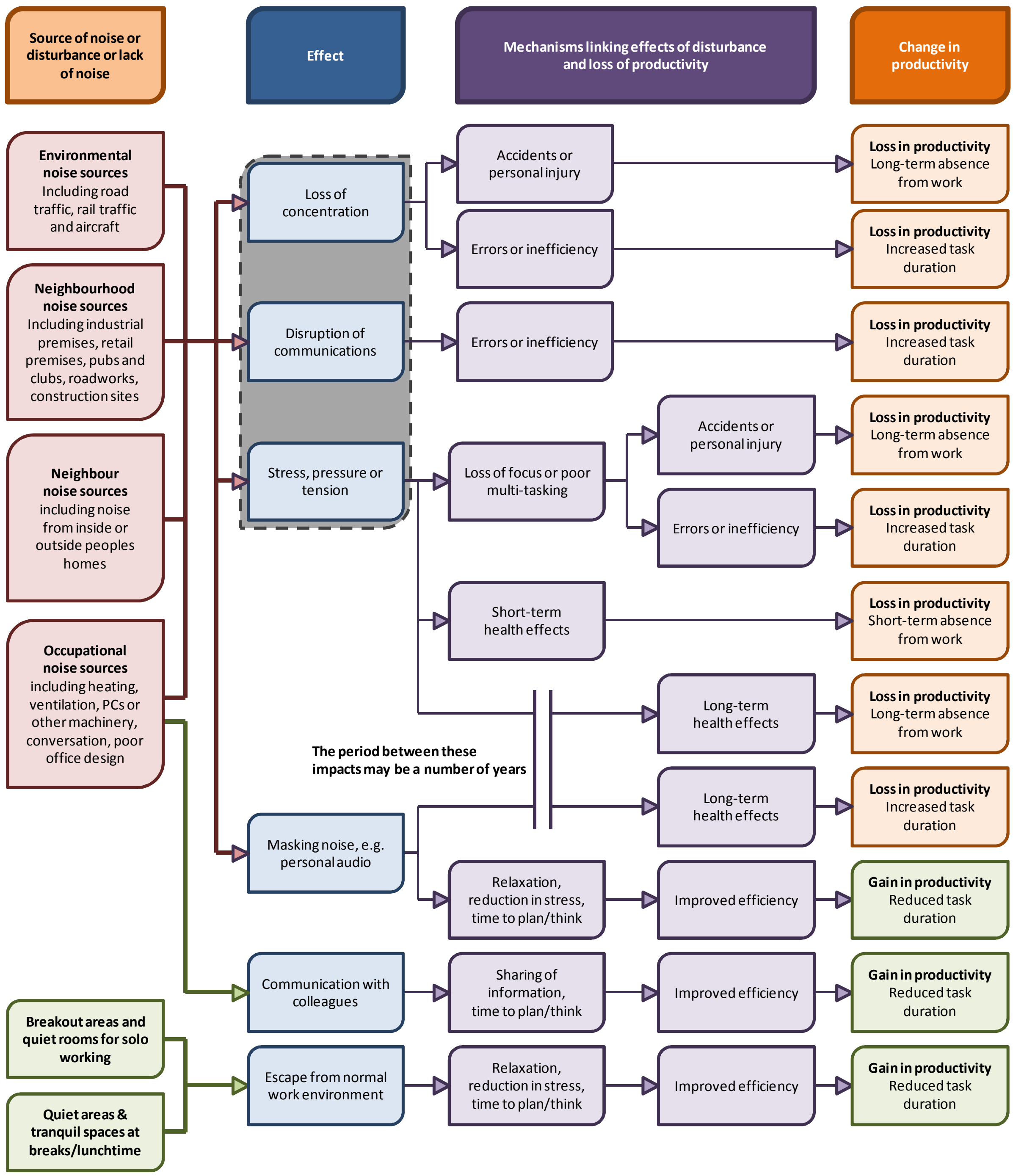

Figure 2.1: Potential mechanisms linking noise experienced during working hours to productivity (Dotted lines indicate those effects investigated further within the report)

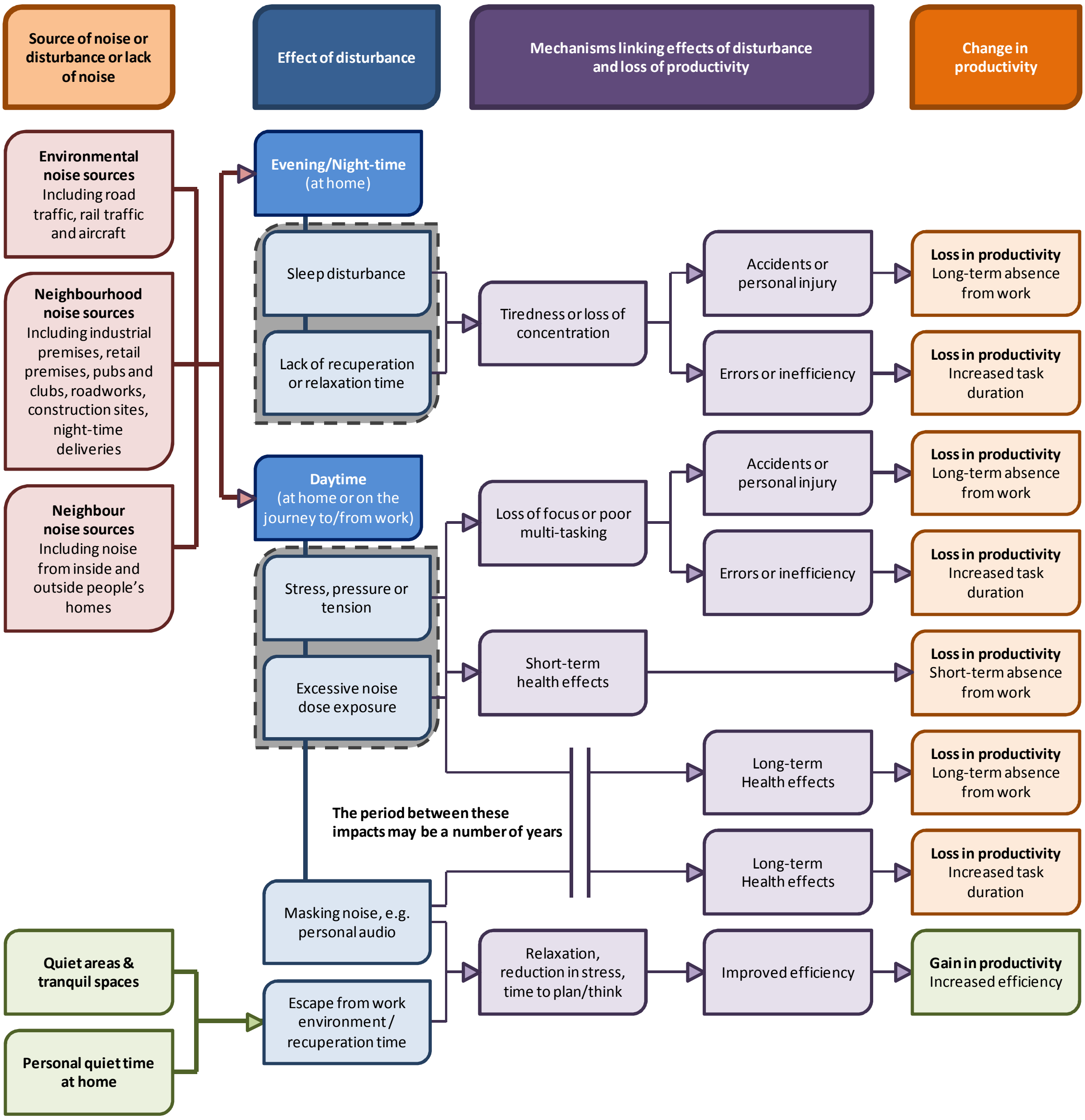

Figure 2.2: Potential mechanisms linking noise experienced outside of working hours to productivity (Dotted lines indicate those effects investigated further within the report)

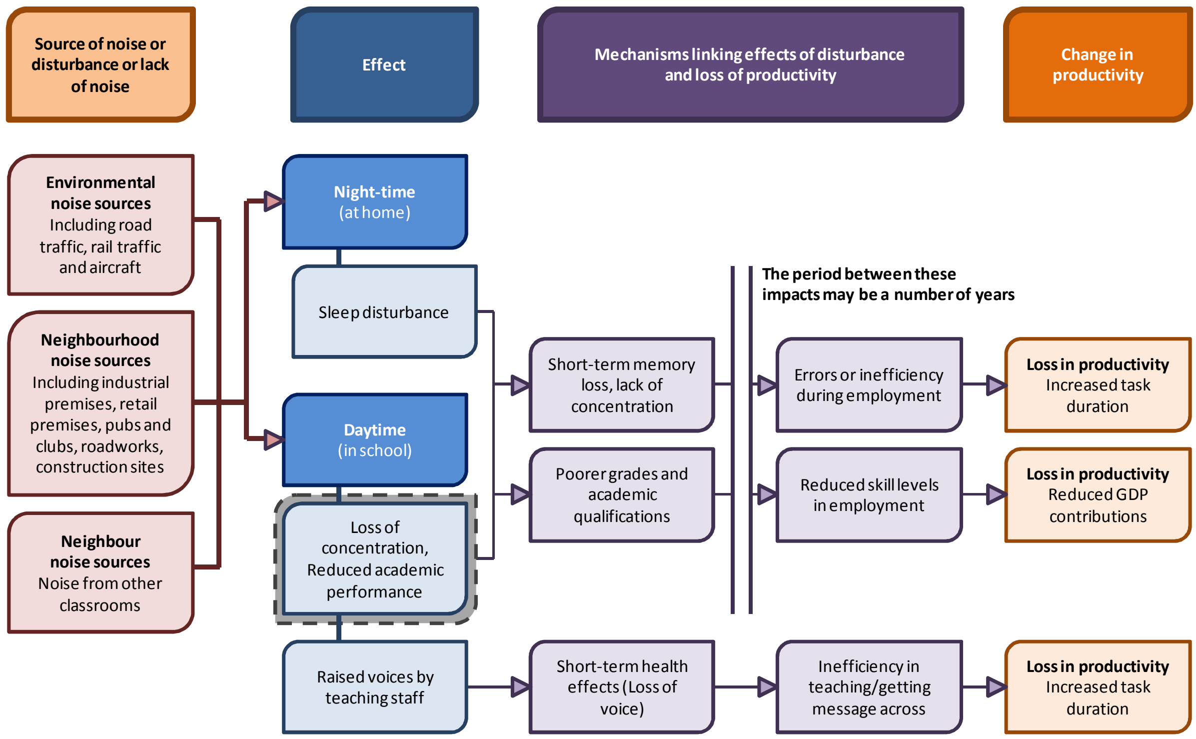

Figure 2.3: Potential mechanisms linking noise impacts on academic performance to later-in-life productivity (Dotted lines indicate those effects investigated further within the report)

Having identified these potential mechanisms linking noise impacts to changes in productivity, a preliminary literature review was undertaken to assess the likely scale of evidence available in terms or either the complete mechanisms or components thereof. This highlighted that work in the subject area could be broadly classified into four groups:

- The role of residential and transport noise in sleep disturbance and the resulting effect on productivity
- The role of office design and interior noise on productivity
- The effects of noise on long-term health, e.g. high blood pressure, and the resultant loss of days at work
- The effects of transport noise on academic performance and short-term memory (with a potential future impact on lifetime earnings/productivity).

The mechanisms presented in Figure 2.1-Figure 2.3 and the findings from the preliminary literature review were discussed and reviewed with the project board to assess the mechanisms that should be taken forward for further study.

Based on the timescale of the project and the number of potential mechanisms, it was concluded that

- There was sufficient evidence associated with noise and sleep disturbance to warrant further review with a view to making recommendations for the development of appraisal tools

- Much of the evidence on the effects of noise experienced during work hours was focussed on office noise as the source of disturbance. Such impacts would be the responsibility of employers who already have the incentives to address this. As such, the role of government in addressing this is limited and incorporation into appraisal tools would be difficult as it is highly dependent upon an individual's sensitivity to the situation. It was also concluded that the review would not address work environments where noise impacts were likely to exceed the exposure action values within the Control of Noise at Work Regulations 2005 since employers already would be required to take mitigating action to reduce noise
- There is already extensive literature on the health impacts of noise and Defra has existing commissioned further work on health effects[5]. Where possible, further investigation would focus only on links between health and productivity
- It was considered that there was sufficient evidence of the effects of noise on academic performance to warrant further investigation of potential links to later-in-life impacts

Mechanisms whereby adverse impacts on productivity might be mitigated and mechanisms associated with the impacts of journeys to/from work would not be pursued further based on limited evidence and the limited value that might therefore be gained from incorporating these into an appraisal framework. Defra also has existing commissioned work related to 'quiet areas'[6]. Mechanisms associated with recreational noise would also not be pursued since these are potentially less intrusive because of the nature of the activities.

The dotted lines in each of the Figures indicate the initial effects of the mechanisms investigated.

The remaining sections of this report present the findings from both the preliminary and more detailed literature reviews.

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[5] The project on health aims to identify the key health outcomes of hypertension, and evaluate these links between health outcomes and hypertension. The project will, where possible, produce a methodology for valuing these health outcomes.

[6] The project on 'quiet areas' aims to produce a methodology for calculating potential quantitative links between consumer satisfaction and quiet areas.

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3 Noise, sleep disturbance and productivity

Sleep disturbance, as shown in Figure 2.2, is potentially one of the most common factors linking noise exposure to changes in productivity at work. It is already well known that sleep can be disrupted through noise exposure (WHO, 2009) and there are a number of studies indicating that sleep disturbance can have detrimental impacts on productivity, e.g. (Rosekind et al., 2010) and a significant economic impact (Uchiyama, 2003).

This chapter looks at the evidence for linking environmental noise to productivity through the assessment of the problems that can be caused by sleep disturbance.

Section 3.1 reviews links between environmental noise and sleep loss. Section **Error! Reference source not found.** looks at studies showing how sleep disturbance can impact cognitive function and productivity. Section **Error! Reference source not found.** summarises the work that has been conducted to quantify the economic impact of sleep disturbance through associated productivity loss and health care costs. Section **Error! Reference source not found.** considers the likelihood of being able to quantify mechanisms linking noise to productivity through sleep disturbance.

3.1 The effects of noise on sleep

A large body of research has been conducted to investigate the link between noise and sleep disturbance. Berry and Flindell (2009) carried out a review of the available research and techniques for quantifying sleep disturbance. They concluded that much of the research was representative of 'acute responses' (awakenings) to noise and there was not a standardised approach to measuring this, with researchers choosing between wrist actigraphy, EEG (electroencephalograph arousal response) and behaviourally confirmed awakenings, and disagreeing which method provides the best results. They also reported that subjective evaluations of sleep disturbance were affected by multiple modifying factors, and did not correlate well with more objective measures.

In their literature review, Berry and Flindell concluded that the dose-response curves published in a European Commission paper (2004) provided the best quantitative link between noise and sleep disturbance, and IGCB(N) (2010) identified using this link for policy appraisal as best practice.

A review of the research on links between noise and sleep disturbance was conducted by the World Health Organisation (WHO) in 2005 as part of a wider ranging consultation on quantifying the burden of disease related to environmental noise (WHO, 2007). As part of this review it is mentioned that dose-effect curves are largely based on subjective surveys and behavioural. The comment is made that while L_{den}[7] is a good metric for assessing global noise exposure, event indices are a more accurate measure in predicting sleep disturbance.

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[7] L_{den} is a noise indicator of annoyance from long-term exposure to noise, and is a long-term average A-weighted equivalent noise level. It is derived from three other levels, L_{day}, $L_{evening}$ and L_{night}, as specified in Annex 2 of the EU Directive on the Assessment of Environmental Noise, 2002/49/EC.

Ldn is an average A-weighted equivalent noise level derived from two other levels, Ld (the day equivalent level from 07:00-22:00) and Ln (the night equivalent level from 22:00-07:00)

However a study not mentioned in the WHO review reports strong discomfort expressed by 50% of subjects living in an area with an L_{dn} of 75 dB(A) in the case of air traffic noise and 80-90 dB(A) in the case of road traffic noise, where 'strong discomfort' is measured through behaviours such as closing windows and staying indoors due to noise (Pichot, 1992).

An earlier piece of work for predicting the level of sleep disturbance from noise levels was reported by Miedema et al. (2003). This work presented a relationship between the noise index L_{night} and the percentage of people highly sleep disturbed (%HSD); indeed, it is this (and associated relationships for other levels of sleep disturbance) which is reported in the 2004 European Commission paper cited previously and recommended for use in policy appraisal by IGCB(N). Such an equation could, with appropriate population density data, potentially be used in combination with the Defra night-time noise maps produced in accordance with the requirements of Directive 2002/49/EC (transposed into English law in the Environmental Noise England Regulations 2006 (as amended), and into corresponding Regulations for the devolved administrations) to estimate the number of people affected. Ainge et al. (2007) used such an approach to give an example of how sleep disturbance maps might be used for controlling the night-time movement of freight traffic in urban areas.

Since the time of the WHO review, a number of other studies and reviews have been conducted. Schapkin, Falkenstein, Marks and Griefahn (2006) looked at cognitive performance in subjects with disrupted sleep from railway noise; it was found that a decreased blink rate suggested increased mental effort in maintaining performance and concentration. Muzet (2007) reported that sleep disturbance is more annoying in the early evening and just before awakening.

Ohrstrom, Hadzibajramovic, Holmes and Svensson (2006) conducted studies to evaluate exposure effect relationships between road traffic noise and sleep quality in Sweden. The study concluded that children had better perceived sleep quality and fewer awakenings than adults but both groups showed a significant exposure effect relationship between noise levels and sleep quality and awakenings.

Lee, Shim and Jeon (2010) looked at disturbance caused by road traffic noise and a combination of road traffic and construction or neighbour noise (using noise from an action film to replicate noise from a neighbour) through the use of a questionnaire given to twenty participants over a period of two weeks. Premature awakenings and difficulties in falling asleep were reported by participants exposed to road traffic and construction noise. A decrease in next day performance was also reported by those participants who had been sleep disturbed.

The WHO night noise guidelines (WHO, 2009) contain a further comprehensive review of the effects of night time noise on sleep. As well as reporting in some detail the mechanisms used to measure sleep and sleep disturbance the review also refers to a dose-response relationship relating aircraft noise to noise-induced awakenings (Passchier-Vermeer, 2003). This relationship predicts over 100 awakenings per year for L_{night} values over 60 dB.

3.2 The impact of sleep disturbance on performance

IGCB(N) (2010) identified that the key link from sleep disturbance to productivity is fatigue or 'next day sleepiness'. It was recommended that research was required considering the impacts of sleep disturbance on next-day productivity. Such work may enable a monetary value to be placed on the sleep impacts of noise.

A number of studies have looked at how sleep disturbance and sleep deprivation affect productivity the next day. Snyder (2003) reports productivity measured for participants who had had different amounts of sleep with the highest levels being reported for participants who had had more than 9 hours sleep. Those who slept for less than 5 hours however were found to have the second highest productivity level followed by those who slept for 8 to 9 hours and lastly those who slept for between 6 and 8 hours. However, it is noted that the study was interrupted during its duration by external factors which may have affected the results.

Decreased next day productivity has also been reported for insufficient-sleep syndrome groups[8] (Rosekind et al., 2010) and shift workers (Yovich, 2009; Ansiau, Wild, Niezborola, Rouch and Marquie, 2008). These studies involved participants completing self-assessment questionnaires and, in the case of the latter study, participating in cognitive tests with assessment by occupational health doctors.

Furthermore, there are studies showing that sleep loss may impact upon cognitive activity. In a study investigating procedural memory, it was concluded that sleep was required for improved consolidation of procedural memory and subsequent improved performance in the future when required to recall this information (Maquet, 2001). This was determined from the results of several studies using a finger tapping exercise to investigate the role of sleep on motor skills (Walker, Brakefield, Morgan, Hobson and Stickgold, 2002; Fischer, Hallschmid, Elsner and Born, 2002).

Impaired procedural memory can be linked to academic performance. Research has been conducted showing that deficiencies in procedural memory associated with sleep loss were linked with the learning capacity and therefore the academic performance of students at all stages of the education system (Curcio, Ferrara and De Gennaro, 2006).

3.3 The economic cost of sleep disturbance

Some studies have managed to quantify the cost to society economically due to sleep deprivation and the estimates vary in terms of the factors affecting productivity that were included and the population of the country of interest.

In 1999, the National Sleep Foundation[9] estimated that lower productivity and accidents cost US$150 billion per year in America. More recently, a US$30.7 billion loss to the

[8] Participants were considered to have insufficient sleep syndrome based on criteria published by the American Psychiatric Association (2000) and the American Academy of Sleep Medicine (2001).

[9] This work was cited by Snyder (2003); however the reference was incomplete. The TRL Information Centre has been unsuccessful in sourcing a copy of this report. No information on this cost was arrived at is available.

Japanese economy has been estimated due to productivity loss caused by sleep deprivation, based on a survey of over 3000 employees of a chemical company (Uchiyama, 2003)[10].

Research was undertaken that evaluated the direct and indirect economic costs of sleep disorders to the Australian economy in 2004 (Hillman, Murphy, Antic and Pezzullo, 2006). The overall cost was estimated at US$4524 million, which was equivalent to 0.8% Australian GDP. The overall economic cost included the following:

- US$459 million for direct health costs, comprising US$ 146 million for sleep disorders and $313 million for medical conditions associated with sleep disorders. The direct health costs of sleeping disorders were extrapolated from 2000-2001 Australian health system data, while the direct health costs for medical conditions associated with sleep disorders were based on odds ratios[11] for various health conditions, i.e. the odds ratio of having the health impact with (relative to without) disturbed sleep
- US$1956 million for the indirect financial costs of work-related injuries due to sleep disorders[12]. This figure, which excludes health costs, assumes that sleep disorders are linked to 9.1% accidents at work (assuming an annual probability of a workplace accident of 4.5%[13] and an odds ratio of accident with disordered sleep of 3.0[14]) and that workplace accidents in 2004 were estimated to be US$21.5 billion
- US$808 million for the indirect financial costs of motor vehicle accidents due to sleep disorders[15]. This figure, which excludes health costs, assumes that sleep disorders are linked to 7.6% motor vehicle accidents (Assuming an annual probability of an injury from an MVA of 1.3%[16] and an odds ratio of MVA with disordered sleep of 2.52[17]), which was used when calculating the cost in 2004 from 1996 data

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[10] Only an abstract for this report has been located. In spite of the availability of a full reference, the TRL Information Centre has been unsuccessful in sourcing a copy of this report. No information on how this cost was arrived at is available.

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

[12] This figure consists of costs incurred from production disturbance, human capital, travel, caregivers, investigation, legal, funerals, aids and modification.

[13] Australian Bureau of Statistics (2000). *Work-related injuries.* Canberra, Australia: Australian Bureau of Statistics.

[14] Lindberg, E., Carter, N., Gislason, T. and Janson, C. (2001). Role of snoring and daytime sleepiness in occupational accidents. *Am J Respir Crit Care Med*, 164, 2031-5.

[15] This figure consists of costs incurred from long-term care, workplace labour and disruption, household labour, quality of life, emergency and rescue services, vehicle repairs, travel delays, insurance administration and non-vehicle property damage.

[16] Bureau of Transport and Regional Economics (2000). *Road crash costs in Australia.* Canberra, Australia: Bureau of Transport and Regional Economics

- US$1201 million for 'other' productivity losses (which are unspecified). This was derived from findings by the Australian Bureau of Statistics (2001) suggesting that "*people with cardiovascular disease are employed in the workforce 3% less than the age-standardised average.*" It was assumed that this proportion was the same for all other illnesses, giving a population of 40,091 sufferers of sleep disorders and related conditions, from which the loss of earnings was calculated. Added to this was a 5% loss due to lower productivity at work and absenteeism
- US$100 million for the administrative costs of raising alternative tax revenue and welfare payments

An investigation into productivity losses associated with insomnia was conducted in Québec, which estimated an annual cost of absenteeism of approximately Cdn$970.6 million with productivity losses of Cdn$5 billion (Daley, LeBlanc, Grégoire, and Savard, 2009). This was based on a series of questionnaires assessing subjective sleep quality, use of medicinal sleeping aids, and productivity. Lost working time was calculated using the 'human capital approach' to costing staff time, and was corrected based on the trial participant's perception of insomnia affecting their productivity.

Other estimates have been derived on an employee basis. Rosekind et al. (2010) estimated that productivity losses in 2007 due to fatigue range from US$1298 to US$3156 per employee each year (US$1967 average), based on survey results from 4 companies which were selected to represent different industries (transportation, healthcare and manufacturing). The survey included a work limitations questionnaire (WLQ) which is a statistical tool used to measure the impact of health problems on productivity and performance in the workplace. The range of values represents different sleeping behaviours that the employees typically exhibited, which were insomnia, insufficient sleep syndrome, 'at-risk' and good sleep. These classifications were based on criteria in the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association [APA], 2000) and the International Classification of Sleep Disorders (American Academy of Sleep Medicine, 2001). Those categorised as suffering from insomnia or insufficient sleep syndrome had a lower performance and greater productivity losses.

Similar results have been found in other studies. Research in France by Godet-Cayré et al. (2006) reported higher levels of absenteeism for employees suffering insomnia, causing productivity losses of €1813 ± €356 per employee per year, compared with productivity losses of €752 ± €156 per employee per year for good sleepers. This figure represented the cost incurred by the employer, employee and French Health Service. Insomnia was defined based on criteria in the Diagnostic and Statistical Manual of Mental Disorders (APA, 2000) and participants were required to complete a survey using the Pittsburg Sleep Quality Index Scale and the Spiegel Sleep Inventory.

Máca, Melichar and Ščasný (2008) report estimated productivity loses due to sleep disturbance for employees in 27 EU nations based on insomnia-associated work absenteeism. Results for the UK indicate average loses of €1010 per employee per year, based on an assumed absence of 3.5 days. An upper estimate of €1278 per employee per

[17] Sassani, A., Findley, L. J., Kryger, M., Goldlust, E., George, C. and Davidson, T. M. (2004). Reducing motor-vehicle collisions, costs, and fatalities by treating obstructive sleep apnea syndrome. *Sleep*, 27:453-8.

year was also estimated assuming that the cost of sleep disturbance was 2% of GDP per employee.

Considering the health impacts from noise outlined by WHO, a report by IGCB(N) (2008) estimated the monetised impact for the UK. In terms of severe sleep disturbance, no figure was reported. A figure for the UK could potentially be determined using a method similar to that of Hillman et al. (2004), although further research would be required to calculate a robust estimate of the proportion of the population suffering from a sleep disorder.

3.4 Relating noise to productivity loss through sleep disturbance

Whilst it is clear that noise can impact on sleep and that sleep loss can have a significant economic cost, providing an appropriate mechanism is challenging.

Firstly much of the evidence linking noise to sleep disturbance is based around objective studies but without a direct link to productivity, or subjective self-reports which may not correlate with other objective measures of sleep quality (Berry and Flindell, 2009). The evidence identified linking sleep disturbance to next-day productivity also used self-reported assessments.

Secondly, while studies can identify distinct control groups, when considering the whole population it may be difficult to discriminate between noise-induced sleep disturbance and disruption caused from other factors such as lifestyle, physiology and lighting. It may be possible to make estimates based on L_{dn} noise values since some studies show a correlation, or L_{night} values. However, it is noted that noise events have been shown to be a more accurate measure of awakenings (WHO, 2007).

Thirdly measuring productivity in terms of efficiency in the workplace is difficult to do objectively and as such most studies rely on either subjective assessments or accident rates and absence only.

Nevertheless if environmental noise can be attributed to a defined proportion of people suffering sleep disturbance there are a number of studies showing how certain economic impacts can be derived, e.g. from Australia and Japan.

Estimates of productivity loss caused by sleep disturbance have been produced using a variety of methods, including WLQ questionnaires and assumptions about the proportion of the population likely to suffer from a sleep disorder. In some cases the results have been weighted to reflect perceived performance.

It is suggested that a monetary value for the UK could potentially be determined using a method similar to that of Hillman et al. (2004), although further research would be required to calculate a robust estimate of the proportion of the population suffering from a sleep disorder or awoken at night due to noise. An estimate of the sleep disturbed population to input into the methodology used by Hillman et al. (2004) may be achievable by using dose-response relationships as suggested by IGCB(N), e.g. the relationships developed by Miedema et al. (2003), in conjunction with the L_{night} noise maps produced in accordance with END and appropriate population density data.

4 Noise, academic performance and productivity

Establishing links between the effects of noise on academic performance and the resulting effects on productivity is a more complex issue than for many of the other factors considered elsewhere in this report since, as shown by the flow chart presented in Figure 2.3, there may be a significant time period between the noise impacts being experienced by the individual and the potential impacts on productivity in the workplace.

It is assumed that the impact of noise exposure experienced by a pupil in an academic environment will be such that their educational levels do not necessarily match their true capabilities. This may be as a result of dropping out of education early or simply achieving lower academic grades. On entering the workforce, such individuals are therefore likely to have fewer skills and as a result their lifetime earnings will be reduced. While an employee might be perceived to be working equally hard (in terms of effort/hours worked) regardless of whether they are in semi-skilled or skilled employment, their reduced productivity due to reduced skills will potentially result in lower output than would have been the case had their level of academic achievement been greater. This potentially leads to slower economic growth if less-skilled employees continually enter the market and therefore lower GDP.

Section 4.1 reviews the effects of noise upon academic performance. Section 4.2 examines the relationship between language acquisition /literary skills and academic performance. Section 4.3 considers the relationship between academic performance and lifetime earnings. Section 4.4 considers the likelihood of being able to quantify mechanisms linking noise to productivity through reduced academic performance.

4.1 The effects of internal and external noise on academic performance

In general, a number of studies have been conducted to assess how noise affects the academic performance of children in terms of literacy, language acquisition and long-term memory, e.g. Shield and Dockrell (2008b), Westman and Walters (1981). Exposure to noise can affect concentration, attention span, problem solving skills and motivation (Institute for Environment and Health, 1997).

Work has addressed disturbance by noise originating from within the school building/ classroom as well as disturbance by noise originating from outside of the school premises. This is illustrated as follows:

Noise within the school building/classroom can have an adverse effect on academic performance. A review of 140 classrooms across 16 primary schools in London (Shield and Dockrell, 2004) found that the average internal background noise levels exceeded those recommended in current guidelines[18] and that noise levels within classrooms were dependent upon the activities in which children were engaged, with a difference of 20 dB L_{Aeq} between the 'quietest' and 'noisiest' activities. This suggests that management of internal noise is of particular significance. A further study by the same authors (Shield and Dockrell, 2008a) demonstrated that background noise and classroom chatter had a 'detrimental' impact on task performance for primary school children.

[18] These included WHO Guidelines on Community Noise (1999) and Building Bulletin 93: Acoustic Design for Schools (2003).

In terms of the effects of distraction by external noise sources, Shield and Dockrell (2004) reported that both subjective assessment and correlation analysis indicated external noise had little effect on the internal noise environment. It was concluded that external noise was only thought to affect internal noise levels while children are participating in 'quiet' activities such as working in silence, doing a test or silent reading, thereby potentially affecting concentration. In a study of primary school children performing verbal and non-verbal tests, Shield and Dockrell (2008b) established that the performance of older children was more affected by external noise, such as vehicle sirens, than when exposed to internal noise.

Considerable research has been performed to investigate how transportation noise affects performance at school. Transportation noise in general has been shown to affect memory (Stansfeld et al., 2005) and reading comprehension in children (Passchier-Vermeer and Passchier, 2000). In the latter study, it was considered that there is sufficient evidence to suggest that noise exposure and performance at school are related.

Haines, Stansfeld, Job, Berglund and Head (2001) investigated the effects of aircraft noise exposure on school children in the vicinity of London Heathrow airport. They compared the cognitive performance and health of 340 children, aged between 8-11, attending four schools in high aircraft noise areas with children attending four similar schools exposed to lower levels of aircraft noise. The results indicated that high levels of exposure to aircraft noise were associated with higher levels of noise annoyance and poorer reading comprehension although there was no association with mental health problems.

Hygge (2003) performed a series of experiments involving 1358 Swedish school children aged from 12-14, whereby the children read tests in either noisy or quiet conditions. Ten different scenarios were designed where the noisy scenarios looked at different combinations of road, rail and aircraft noise and speech, with levels of either 55 dB L_{Aeq} or 65 dB L_{Aeq} (the former being recommended as a maximum outdoor level for 24 hour exposure and the latter based on preliminary trials within the same work). The children's recognition and recall was tested a week later. A strong noise effect on recall was observed with a lesser but still significant effect on recognition. Where only one noise source was present, aircraft and road traffic noise impaired recall at both noise levels while train noise and speech did not affect either recognition or recall. Some of the paired noise combinations (aircraft noise with train or road traffic, with one or the other as the dominant source), were found to interfere with recall and recognition.

Findings from the RANCH[19] project involving studies of 2100 children aged from 9-10 from 89 schools around Amsterdam, Madrid and London Heathrow airports (Clark et al., 2005; Stansfeld et al., 2005) found that there was a linear relationship between aircraft noise exposure and impaired reading comprehension. It is noted that aircraft noise estimates for Spain and the UK were based on aircraft noise contour data in the period July-September 1999 and July-September 2000 whilst in the Netherlands, contours were used from October 1999 to November 2000. For the former countries, it is therefore feasible that noise levels might have been affected by higher flight volumes than in normal school periods, thereby

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[19] Road Traffic and Aircraft Noise and Children's Cognition and Health (http://www.wolfson.qmul.ac.uk/RANCH_Project).

overestimating the level of aircraft noise that children might have been exposed to. There was no relationship associated with road traffic noise either in the absence or presence of aircraft noise; the second paper reports that exposure to road traffic noise was linearly associated with increases (improvements) in episodic memory although the reasons for this were unclear. The findings were consistent in all three countries.

One of the key findings from the various studies was that aircraft noise could be a factor impairing cognitive development, i.e. long-term memory, concentration and language development in children (Institute for Health and Environment, 1997; Stansfeld et al., 2005).

WHO guidelines on community noise (Berglund, Lindvall and Schwela, 1999) suggest that outdoor noise levels greater than 55 dB $L_{Aeq,16hr}$ could cause annoyance during play. A level of 35 dB $L_{Aeq,16hr}$ is reported as a guideline internal level for classrooms above which speech intelligibility, message communication and information extraction can be affected. Green schools, which aim to be located away from areas with high external noise levels, could be beneficial in improving both learning and the productivity of teachers (Spengler and Loftness, 2007).

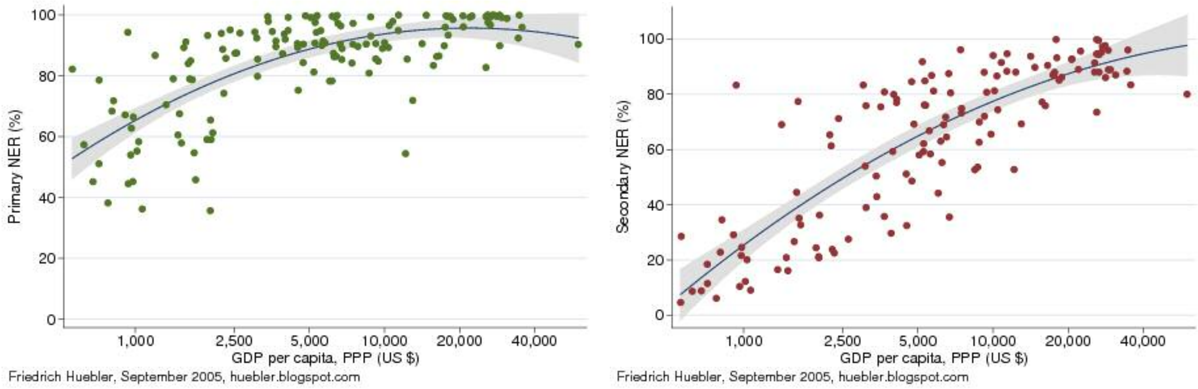
4.2 The relationship between language acquisition/literary skills and performance

Language acquisition and literacy are key elements for progressing through the education system and performing well in exams. Although no information has been identified which directly links literacy, memory and language acquisition to academic performance, it has been shown that there is a positive correlation between academic performance and fluency in English of bilingual students who have learned English as a second language (Demie and Strand, 2006). No information has been identified which demonstrates how noise affects the academic performance of secondary school students.

4.3 The relationship between academic performance and lifetime earnings

The relationship between academic performance and salary, lifetime earnings or occupational performance has been examined. Oreopoulos (2007) states that teenagers who do not ‘drop out’ of compulsory schooling are likely to increase their lifetime earnings by 15% for one additional year of education, and are less likely to be unemployed, thereby having a positive impact upon GDP. Tyler (2004) investigated the relationship between the performance of 16-18 year old dropouts and earnings by means of a maths test, and it was found that those who achieved results one standard deviation above the mean enjoyed an average increase in salary of approximately 6.5% in their first three years in employment. Similarly, Bishop (1992) found that test results from a military database were linked positively to job performance and stated that “the market rewards competencies signalled by credentials”.

Huebler (2006) reported the link between school enrolment and GDP per capita. Figure 4.1 presents net enrolment ratios for both primary and secondary schools. It was observed that low income countries have significantly lower levels of primary school enrolment. Countries with a GDP per capita of US$2,500 or less have Net Enrolment Ratios (NERs) below 80%. Almost all countries above this level of GDP have NER values of more than 80%. The link between national wealth and school enrolment is even more evident at secondary school level. Virtually all countries with a secondary school NER below 60% have a GDP per capita of less than US$10,000. In contrast, all countries with a per capita income of more than US$15,000 have NER levels near or above 80%.



(a) Primary schools (b) Secondary schools

Figure 4.1: School net enrolment ratio vs. GDP per Capita, 2002 (Huebler, 2005)

(Figure reproduced with the permission of Friedrich Huebler, huebler.blogspot.com)

However, care must be taken reviewing this type of relationship on the basis that the effect can work either way, i.e. high levels of GDP encourage investment in schools/education which may potentially lead to an increase in secondary school enrolment, while an increase in secondary school enrolment potentially means a higher qualified workforce in the longer term and thereby potentially increased GDP.

A report for the UK Commission for Employment and Skills (Garrett, Campbell and Mason, 2010) collated information on the value of skills, reviewing a number of independent studies of skill value at national level as part of the report.

The report cites a number of papers which demonstrate the benefits of an improved education, as follows. Bassini and Scarpett (2001) found, in a study of 21 OECD countries from 1921-1998, that on average, one additional year in education is associated with a long-run increase in output of 6%. Sianesi and Van Reenen (2003) found that such an increase in education has an impact of 3- 6% on the level of output and of over 1% on the growth rate. Blundell et al. (1999) reported that the impact is greatest for higher levels of education since while primary and secondary education skills are related to growth in developing countries, tertiary education skills are most important for growth in OECD countries. Jenkins (reported in Blundell et al., 1999) suggested that for the UK a 1% increase in the proportion of workers with higher qualifications raised output over the period 1971-92 by between 0.42% and 0.63% per annum.

4.4 Relating noise to productivity loss through academic performance

There have been a significant number of studies undertaken looking at the impacts of noise on academic performance and the impacts of academic performance on GDP. However no studies have been identified where a direct link between the three factors has been examined or established.

Much of the literature associated with the link between noise and academic performance focuses on primary school children. As such there is no evidence relating to the effect of noise on academic qualifications. Literature associated with the link between academic performance and GDP focussed primarily on secondary school children.

Evidence of the links between improved academic performance and GDP is available, although much of this appears to focus on increased time in school, or upskilling in terms of academic qualifications.

It is considered that it will be difficult with the current information to define a robust relationship to quantify the link between noise and changes in productivity through reduced academic performance.

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5 Noise in the workplace and productivity

The flow chart presented in Figure 2.1 identifies a wide range of potential mechanisms linking noise exposure in the workplace to adverse productivity.

During the discussions with Defra it was concluded that the literature review would not address work environments where noise impacts were likely to exceed the exposure action values within the Control of Noise at Work Regulations 2005 since employers would already be required to take mitigating action to reduce noise.

Much of the literature identified and reviewed in the following sections addresses the effects of occupational noise, i.e. noise within the workplace on disturbance rather than the effects of external (e.g. environmental) noise, with a particular focus on offices rather than other workplaces such as factories. Occupational noise is an 'internalised externality' in that it is the employer's responsibility to control and, if necessary, mitigate these noise impacts. In addition to the Control of Noise at Work Regulations 2005, in the context of both employee satisfaction and productivity, there are sufficient incentives for employers to provide a pleasant working environment.

Section 5.1 addresses the sources of annoyance experienced in an office environment. Section 5.2 looks at the influence of office design on office noise. Section 5.3 analyses the characteristics of workplace noise. Section 5.4 looks at the effects of noise in the workplace on health. Section 5.5 considers the likelihood of being able to quantify mechanisms linking noise exposure in the workplace to productivity.

5.1 Sources of noise annoyance in the office environment

The typical types of noise encountered in office environments are as follows:

- **Person generated noise**, e.g. conversation, including conversation on the telephone
- **Machine generated noise**, e.g. printers, copiers, shredders and ringing telephones
- **Impact noise**, e.g. opening and closing doors, walking on hard surfaces
- **Background noise**, e.g. heating, ventilation and air conditioning (HVAC) systems
- **External noise sources**, e.g. environmental and neighbourhood noise

The level to which these will cause disturbance and impact upon productivity will depend on office design, office size, number of employees within a workspace, etc.

Office noise can cause annoyance, distract people from tasks and alter decisions or strategic choices, ultimately having an adverse impact on employees' productivity (Institute for Environment and Health, 1997; Bowden and Wang, 2005). However, it can also have positive impacts on productivity, by making people more alert (Institute for Environment and Health, 1997) and allowing improved communication and knowledge sharing.

Many of these sources can potentially be controlled by the use of best practice or appropriate working guidelines, with education of the work force to encourage respect for and consideration of fellow employees.

Not all sources of annoyance in an office environment are noise related and these can all have an adverse effect on productivity. Based on a review of a studies looking at the workplace-related effects on well being and productivity, Bergs (2002) estimated that 15% of Dutch employees (the scale of the sample group is not stated) report that building-related grievances such as air quality, temperature and lighting conditions have an adverse effect on their productivity.

5.2 The influence of office design on office noise

In terms of office design, the most immediate comparison is between open-plan workspace, cubicles and fully enclosed offices. Appropriate design influences social interaction, perceived concentration and annoyance. Many sources of annoyance are more likely to be apparent within cubicles and, particularly, in open-plan workspaces.

Perception studies reported by Nyunling and Cheung Chan (2007) and Cherow (1991) indicated, as might be expected, that people in enclosed offices perceive their productivity to be high, whereas those in open-plan offices perceive their level of productivity to be lower. A study by Leaman (1994), based on a review of collated complaints from workers in 25 buildings, estimated that noise reduced productivity by 8%.

Office design and layout can also have a significant effect upon speech intelligibility and privacy. Overhearing other people's conversations is a source of distraction and potential annoyance. Noise sources such as heating/air conditioning and ventilation (HVAC) can mask conversation and thereby potentially improve privacy. However, as technology has improved, so the noise levels resulting from these systems have reduced and the masking effects have reduced accordingly.

Statistics collated by Screen Solutions Ltd (undated) from a range of different (primarily American) studies suggested that 64% of office workers are interrupted up to 20 times a day, 72% of workers are dissatisfied with their speech privacy, 59% of employee time is spent trying to do quiet, focused work in one's own workspace and 70% of office workers said that they could be more productive in a less noisy office environment. Other studies indicate that approximately 80% of office workers believe that their productivity would increase if their working environment was more acoustically private (American Society of Interior Designer, 2005).

A review by Sykes (2004) found that when conversation noise was reduced and speech privacy increased, the office workers' ability to focus on tasks improved by 48%, conversational distractions decreased by 51%, error rates improved by 10% and the physical symptoms of stress reduced by 27%.

Jensen, Arens and Zagreus (2005) conducted a large-scale survey of 23,450 office staff from 450 buildings. It was found that speech privacy was a greater concern than the overall noise level. Employees working in private offices were found to be significantly more satisfied with the acoustics than those working in cubicles, although 30% with private offices considered that the acoustics interfered with their ability to work productively; this may be due to noise from adjacent offices, conference rooms, etc. Surprisingly, employees working in open plan offices were more satisfied by noise levels and speech privacy than those in cubicles; possible explanations for this are that private conversations are more readily possible in an open plan workspace since the presence of colleagues can easily be visually checked, and that where visual contact between colleagues is possible (due to low or absent partitions/screens), people adapt their listening and speaking habits accordingly.

5.3 The characteristics of workplace noise

Whilst louder noises cause more annoyance (Kjellberg, Landstrom, Tesarz, Soderberg and Akerlund, 1996), the evidence linking general workplace noise and annoyance is contradictory, with some studies suggesting that there is no link (Health Council of the Netherlands, 1994) and others suggesting the opposite (Occupational Safety and Health Service, 1996). The Dutch report stated that the there are five factors more important than noise level which cause annoyance in the workplace, namely the meaningfulness of the noise, its predictability, the attitude of the employees to the noise, task demand and susceptibility.

The characteristics of noises in the workplace are likely to affect distraction and annoyance. Subjective laboratory trials reported by Bowden and Wang (2005) suggest that mid-high frequency noise is more likely to be disturbing, while excessive low frequency noise is linked to decreased productivity.

Work by Errett, Bowden, Choiniere and Wang (2006) found that while there was no significant correlation between exposure time to background noise (from HVAC) and task performance, there is indicative evidence suggesting that perception of background noise affects task performance. Similarly, Passchier-Vermeer and Passchier (2000) state that not enough evidence exists to prove that performance in a work environment and noise exposure are related. The spectral content of the noise is important when examining effects on productivity (Holmberg, Landström, Kjellberg , 1993).

Bowden and Wang (2005) reported that productivity, measured in terms of typing performance, decreased if the source of distraction had rumbly, roaring or hissy characteristics. Telephones ringing are thought to be the biggest distraction although there is an element of self-control, where a person allows themself to become annoyed or distracted (Kjellberg, Landström, Tesarz, Soderberg and Akerlund, 1996).

Only two studies were identified looking at the impacts of external noise, e.g. environmental and neighbourhood noise sources, on productivity and these both addressed only the effects of road traffic noise exposure. Whilst there is a large amount of literature looking at the impacts of external noise on academic performance (Chapter 4), this is generally related to children considerably below school leaving age; this factor combined with the differing nature of activities between the age groups prevents any transfer of relationships.

Sandrock, Schütte and Griefahn (2010) reported experiments investigating annoyance and mental strain due to different road traffic noise scenarios. One hundred and two individuals, aged 18-31, were exposed to one of five different traffic conditions (based on flow and composition) whilst performing grammatical reasoning and mathematical processing tasks. A reference condition comprised background traffic noise at of level of 44 dB L_{Aeq} where the passage of individual vehicles could not be distinguished, while the other 4 conditions were representative of real road traffic scenarios. The results showed that performance and mental strain were not affected by any of the five noisy conditions. It is noted that the mathematical task caused slightly higher mental strain than the grammatical task; it was considered that this could be a result of the different cognitive and memory skills required for each task. Individuals with high noise sensitivity were partially more annoyed and performed less well than persons with low sensitivity.

A study by Sakuma and Kaminao (2010) involving controlled studies where 16 participants undertook a number of tasks while being exposed to HVAC noise, road traffic noise (assuming a road outside the test room), telephone speech and background music. Considering the nature of the sounds, road traffic noise caused the most discomfort to the participants. However, in terms of their abilities to complete the tasks in the presence of the different sounds, all of the different sounds had a negligible effect averaged across the participants on their performance.

5.4 Noise in the workplace and health

Although health issues are addressed in Chapter 6 of this report, several studies have been identified which specifically addressed the health effects of noise exposure in the workplace.

Generally, it appears inconclusive as to whether noise in the workplace that does not invoke the Control of Noise at Work Regulations 2005 is linked to the health of employees. Some studies categorically state that there is no evidence linking physical health to office noise, e.g. Nyunling and Cheung Chan (2007), although it can cause annoyance or stress which in turn contributes to high blood pressure (Lercher, Hörtnagl and Kofler, 1993), fatigue, headaches and irritation that could lead to decrease performance (Occupational Safety and Health Service, 1996; Persson Waye, 2001). However, annoyance and stress could be caused by other factors such as workload or work pattern.

The research does not seem to agree whether office noise affects stress levels. For example, a study of 40 female clerical workers randomly assigned to either quiet or simulated open-plan office noise levels was reported by Evans and Johnson (2000). The workers in the noisier environment perceived the work setting as being noisier than those in the quiet environment, but the groups did not differ in perceived stress. In contrast, the American Society of Interior Designers (2005) reported on work which showed that low-level office noise can increase stress hormones and worsen high blood pressure and diabetes, whilst other reports, e.g. (Occupational Safety and Health Service, 1996; Sykes, 2004), also claim that noise causes stress at work or that reducing noise can reduce the physical symptoms of stress.

5.5 Relating noise disturbance in the workplace to productivity loss

There have been a significant number of studies undertaken looking at disturbance in the office and productivity. Whilst the literature reviewed has not identified any specific quantification of mechanisms linking noise in the workplace to productivity, there is evidence to suggest that noise occurring within the workplace potentially causes annoyance and disturbance and that productivity can be adversely affected as a result. The studies reviewed are generally based on subjective responses from workers, making the definition of relationships difficult.

No significant evidence has been found looking at links between external noise sources and productivity in the workplace.

It is considered that the occupational noise sources considered in these studies are potentially unavoidable characteristics associated with the work environment. Quantifying the effect of disturbance on productivity for inclusion in appraisal tools would therefore be difficult, especially in view of the aim to predict the cost to productivity at a national level, and potentially of limited benefit. Furthermore, as already noted, mitigating such sources is the responsibility of employers who already have the incentives to address this. As such, it is perceived that the role of government in assessing the impacts of occupational noise is limited.

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6 Noise-induced health effects and productivity

Noise is recognised as a serious threat to public health by the WHO. It is reported that traffic noise alone is harming the health of one in three people within the WHO European region and that one in five Europeans is regularly exposed to noise levels at night that could significantly damage health (WHO, undated). Exposure to excessive noise can lead to an increase in the risk of diseases such as acute myocardial infarction (heart attack), hypertension (high blood pressure), hearing impairment, memory loss and mental illness (IGCB(N), 2008).

The flowcharts shown in Figure 2.1-Figure 2.3 all include mechanisms which potentially link noise exposure to ill-health and, as a consequence, adverse impacts on productivity. Loss of productivity due to either accidents or absence from the work place as a result of noise-induced health issues are perhaps the most visible mechanisms.

There has been considerable work looking at the health effects of noise and evidence of the links between noise and adverse health impacts are widely accepted. However there is continued uncertainty over the quantification of these relationships, and work in this area is ongoing. Other Defra projects are investigating noise and health, so the focus was aimed more on the link between health and productivity. The evidence identified focuses on the cost of absence from work rather than reduced productivity due to illness whilst in the workplace.

Section 6.1 provides, for completeness, a short overview of noise-induced health effects (excluding sleep disturbance, which has been considered separately in Chapter 3. Section 6.2 reviews information associated with the link between health effects and productivity, from the perspective of the costs of ill-health to the employer. Section 6.3 considers the likelihood of being able to quantify mechanisms linking noise to productivity through health impacts.

6.1 Overview of the effects of noise on health

IGCB(N) (2008) mentions health impacts as a potential pathway for monetisation of the impacts of noise. Noise can affect the health of adults and children and has been identified in Dutch and Flemish studies as the second most important environmental cause of loss of healthy years of life, being more dangerous than both passive smoking and NO_x pollution (WHGSEA, 2005; MIRA, 2005), suggesting that noise can therefore affect long-term productivity.

Noise can cause stress (Maschke et al., 2002; Pichot, 1992; Health and Welfare Canada, 1989), psychological problems (Pichot, 1992; Staples, 1996) and elevated blood pressure (Cohen, Evans, Krantz, and Stokols, 1980; Talbott and Thompson, 1995; Health Council of the Netherlands, 1996; Belojevic, Jakovljevic, Paunovic, Stojanov and Ilic, 2008; van Kempen et al, 2006; Lercher et al., 2006), which may lead to cardiovascular illness. This could be as a result of exposure to excessive levels of environmental, neighbourhood or neighbour noise. However, a large focus has been given to investigating the impact of aircraft noise on health. Pichot (1992) reported an increase in prevalence of health problems with the noise level near airports, which is mirrored in research conducted in the 1980s suggesting that increased use of medicine and healthcare services was linked to aircraft noise (Hemingway and Dickinson, 1981; Tarnopolsky and Clark, 1984).

Much research has been carried out regarding the relationship between noise and cardiovascular illness. A WHO report (2007) indicated that no cardiovascular differences were observed between noise sensitive and non-sensitive groups of people whilst asleep. An extensive literature review studying the impact of noise on health was conducted by Berry and Flindell (2009) and concluded that robust dose-response relationships exist between cardiovascular illness and noise for use as monetisation tool. Work by Babisch (2006) on the link between myocardial infarction and L_{day} was considered of particular significance for economic appraisal.

For adults, exposure to noise levels of 85 dB(A) for lengthy time periods is shown to increase blood pressure (Health Council of the Netherlands, 1996), and situations where people are likely to be exposed to such noise levels are controlled in the UK by the Control of Noise at Work Regulations 2005 to prevent noise-induced hearing loss. In these Regulations, 85 dB(A) is the upper exposure action value for an 8 hour exposure to noise over a working day. A report by enHealth (a subcommittee of the Australian Health protection Committee) (enHealth, 2004) cites WHO (1999) guidelines and research by Passchier-Vermeer (1993) reviewing noise levels below which health effects would not be expected. Here, an outside $L_{Aeq,16h}$ for 06:00 to 22:00 of 65-70 dB is suggested as a value by Passchier-Vermeer (1993) as a starting point for ischaemic heart disease[20] and 70 dB for hypertension.

International literature studies and evaluations carried out in conjunction with the development of the Danish road noise strategy (Danish Environmental Protection Agency, 2003) suggested a relationship between road traffic noise and incidences of high blood pressure and heart disease. The work estimated that around 800-2200 people in Denmark are admitted to hospital each year with high blood pressure or heart disease due, in the opinion of the study authors, to additional risk brought about by traffic noise. It was also estimated that between 200-500 people in Demark die prematurely as a result of exposure to high levels of traffic noise. It was estimated that the health costs of traffic noise alone are €80-450 million per year. Recent research in Denmark suggests that exposure to noise from road traffic can increase the risk of a first stroke in the over 65s. It was found that for every 10 dB increase in noise, the risk of stroke increases by more than a quarter (27%). However, the study has highlighted a link rather than identified a specific cause (Sørensen, et al., 2011).

Exposure to noisy environments can not only cause high blood pressure in adults but in children too. It has been shown that noise exposure at home or at school is related to the systolic blood pressure of children aged between 3 and 7 years old (Belojevic, Jakovljevic, Paunovic, Stojanov and Ilic, 2008; Thompson, 1996), and is lower when exposed to quieter environments. However, raised blood pressure due to noisy environments has a temporary effect on children (Health Council of the Netherlands, 1996), whose blood pressure changed per 5 dB(A) increase in noise (van Kempen et al., 2006).

Some work has been carried out under the RANCH project to determine whether exposure to different sources of noise affect the blood pressure of children (van Kempen et al., 2006). It was found that exposure to aircraft noise at home (including at night) was linked to a significant increase in blood pressure. Unexplained negative associations were found

[20] A disease characterized by ischaemia (reduced blood supply) to the heart muscle.

between road traffic noise and blood pressure and no conclusions could be drawn with regards to the effect of community noise.

Work reported by Niemann and Maschke (2004) looked at the effects of both environmental and neighbourhood noise on health effects in adults, children and the elderly. The health effects of neighbourhood noise induced annoyance were in the same range as those for traffic noise induced annoyance. The results illustrated the necessity of sound insulation in residential buildings.

Very little work has been identified on the health benefits of recuperation either after work or between the workplace and home. Nylén, Melin and Laflamme (2007) found that allowing for relaxation and/or 'unwinding' time in between the workplace and home helped to improve sleep patterns, while negative work-to-home transition interference was found to have the potential for adverse effects on sleep quality. It was considered that adequate rest between work periods and workdays may help to increase the effects of 'unwinding' and have beneficial effects on sleep quality

6.2 The economic cost of health issues

The most common way of assessing the economic cost of health issues is to examine the cost in terms of Quality Adjusted Life Years (QALY) or lost productivity caused by sick leave absence from work. No specific evidence has been found of the cost of reduced productivity due to illness whilst in the workplace.

In 1996, the EC estimated that the annual cost of excessive noise on public health was approximately 500 million ECU dollars to 1900 million ECU per year for road noise, and 100 million ECU per year for rail noise in Germany. However, the report did not identify the methods by which this was assessed or the health effects considered. The research does not go as far as linking this to productivity although it can be inferred that a workforce with health complaints would be less productive due to increased sick leave (European Commission, 1996).

IGCB(N) (2008) reported that the initial estimates of the costs of noise pollution were £7-10 billion per annum. This estimate is made up of between £3 - £5 billion in annoyance costs, an adverse health cost of around £2-3 billion and productivity losses of another £2 billion. Considering the health impacts from noise outlined by the WHO, IGCB(N) also estimated the monetised impacts for the UK (IGCB(N), 2008). The impact of heart disease due to exposure to daytime traffic noise was £1,183 million per annum; the impact of severe annoyance due to 24 hour background noise was estimated at an impact of £1,571 million per annum; the impact of tinnitus due to exposure to traffic or leisure noise was estimated at £52 million per annum; the impact of reduced learning in children due to daytime and night-time noise was estimated as £252 million per annum and hearing loss due to leisure noise (particularly loud music) was estimated at £38 million per annum.

The most recent IGCB(N) report looking at valuing the health impacts of environmental noise exposure (IGCB(N), 2010) identified that some evidence was found between noise and other health effects, including annoyance, mental health, hypertension (high blood pressure), sleep disturbance, cognitive development in children and hearing impairment. It concluded that acute myocardial infarction can already be applied into the monetary valuation of noise. A methodology was presented linking noise exposure to an increase in hypertension. However there was insufficient evidence available to allow the impact to be assessed in monetary terms. Similarly, while the use of EC dose-response functions was considered a suitable for use in appraisal to illustrate the scale of sleep disturbance, there was again insufficient evidence for monetisation of the impacts.

Considering the costs of absence from work, figures reported by ACAS[21] (undated) suggest that on average people are absent from work for 7.4 days a year. The annual cost of absence to the UK economy is £10-12 billion. The national average per employee is £666. No information is given as to how these numbers were derived or whether they were derived by ACAS.

Barham and Begum (2005) summarised findings from a number of different sources including the Chartered Institute of Personnel and Development (CIPD), who reported in July 2004 that average sickness absence was 9.1 working days (based on a 228 day working year) with the average annual cost of absence per employee being estimated at £588, and the Confederation of British Industry (CBI) who reported in 2003 that average sickness absence was 6.8 working days with the average annual cost of absence per employee being estimated at £476. However it is noted that the response rates for the former survey was only 16%; for the latter, the public sector accounted for 12% of responses received, the service sector 50% and manufacturing 38%.

The CBI reported that in 2007, absence from work cost the UK economy £13.2 billion as the average employee took 6.7 days of sick (Confederation of British Industry, 2007). These figures were based on survey where 503 private sector companies and public sector organisations responded, employing more than one million employees - equivalent to 3.6% of the UK workforce. In 2009, the rate of absence had decreased slightly to 6.4 days with a cost to the economy of £16.8 billion, based on a survey with 241 respondent organisations employing 1.28 million people, representing 5.12% of the UK workforce (Confederation of British Industry, 2010).

The 2010 Absence Management Report produced by the CIPD (Chartered Institute of Personnel and Development, 2010) compiled data from 573 organisations across the UK for the period 1st January 2009 to 31st December 2009. The average level of employee absence was found to be 7.7 days per employee (based on 9.6 days in the public sector, 8.3 days in the non-profit sector and 6.6-6.9 days in the private sector depending on organisation type). The median cost of absence was £600 per employee (the median cost per employee in the public sector was £889, more than twice that in the manufacturing and production sector (£400) and substantially higher than in private sector services organisations (£600) or non-profit organisations (£600)). Minor illnesses were the most common cause of short-term absence, followed by stress. The most common causes of long-term absence were acute medical conditions.

While the CIPD survey included a breakdown of absence in terms of individual health effects, it is noted that it did not specifically identify absence due to noise-induced health effects. Unless this level of breakdown can be achieved, it is considered unlikely that it will be possible to assign a monetary value to this type of absence.

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[21] Advisory, Conciliation and Arbitration Service

Monetisation of the health impacts on productivity caused by neighbourhood and neighbour noise exposure is likely to be complicated based on the limited available evidence, particularly for the latter. Noise and statutory nuisance legislation may potentially mean that noise impacts that are likely to cause adverse health effects can be quickly addressed.

6.3 Relating noise-induced health effects to productivity loss

There is already significant evidence linking noise exposure to adverse health effects. While the evidence suggests that relationships exist for predicting the monetary impact of health-related absence, no evidence has been identified of relationships linking loss of productivity due to poor/ill health while at work. Evidence from annual employer surveys in the UK goes as far as identifying absence due to individual types of health effect, but there is insufficient detail to attribute any of these effects as being brought-on/caused by noise exposure.

It is therefore considered that quantification of mechanisms linking noise-induced health effects to loss of productivity is only achievable in part with the information that is available from published health-related absence surveys. However, if the health effects considered in these surveys can be correlated with those addressed by IGCB(N), it may be possible to use IGCB(N) estimates of the number of cases due to noise in combination with the absence figures to estimate the effect from noise.

Any quantification involving all aspects of lost productivity would need to make an estimate of the number of workers who are ill but still active in the workplace and the scale of loss of productivity, taking into account the skill mix and nature of the work being undertaken.

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7 Summary and Conclusions

As part of the implementation of policies to manage environmental noise, the quantification and valuation of the impacts of noise enable policy makers to make informed decisions on noise. TRL was commissioned by Defra, on behalf of the noise subject group of the Interdepartmental Group on Costs and Benefits, IGCB(N), to identify potential mechanisms through which noise affects productivity and conduct a literature review to scope the validity and relevance of each mechanism.

An extensive literature survey of potential mechanisms linking noise exposure to changes in productivity has been carried out. The published literature has been obtained from a wide range of fields such as occupational health, psychology and medicine, economics, sleep and education, as well as acoustics.

The review has, for the most part, not identified any existing complete mechanisms linking noise exposure or disturbance directly to changes in productivity. The exceptions to this were mechanisms linking sleep disturbance to loss of productivity, although the ability to use such mechanisms is dependent upon available background information, such as the size and demographics of the sleep-disturbed population.

In other cases, evidence has been found addressing components of mechanisms. In such cases, further work is required to link these separate components together in order to form a complete mechanism that could be developed into a monetary appraisal tool. For example, research has been found linking noise disturbance to learning capacity and linking qualifications/time in school to national economic output. However there is no evidence of research connecting these different aspects together.

The number of potential noise-related mechanisms affecting productivity makes the determination of a high-level assessment of the cost of productivity due to noise, i.e. estimation of the annual cost of productivity across the UK, a complex issue.

Once such a cost has been determined, any subsequent implementation of practical measures to reduce the adverse impacts of noise on productivity may have a knock-on effect elsewhere. By way of example, if there was a need to reduce traffic levels to reduce night-time disturbance to local residents, then controls such as restrictions on night-time deliveries or curfews on the movement of heavy goods vehicles could be implemented. Whilst this might potentially have benefits on the work productivity of the local residents, such measures might have an adverse effect on the productivity of road users and businesses associated with transport, deliveries etc. Any implementation of noise reduction measures would therefore need to consider the wider implications.

7.1 Implications of the findings

The implications of the findings are as follows:

Relating noise to productivity loss through sleep disturbance: Whilst it is clear that noise can impact on sleep and that sleep loss can have a significant economic cost, providing an appropriate mechanism is complicated. Firstly much of the evidence linking noise to sleep disturbance is based around subjective self-reports which may not correlate with other objective measures of sleep quality (Passchier-Vermeer, 2003). Secondly, while studies can identify distinct control groups, when considering the whole population it may be difficult to discriminate between noise-induced sleep disturbance and disruption caused from other factors such as lifestyle, physiology and lighting. It may be possible to make estimates of the number of people sleep disturbed based on L_{dn} noise values, since some studies show a correlation (Pichot, 1992), or L_{night} values (from the Defra noise maps) using the relationships developed by Miedema et al. (2003); indeed, IGCB(N) have recommended the use of dose-response relationships in policy appraisals. However noise events have been shown to be a more accurate measure of awakenings (WHO, 2007). Thirdly measuring productivity in terms of efficiency in the workplace is difficult to do objectively and as such most studies rely on either subjective assessments or accident rates and absence only.

Nevertheless if environmental noise can be attributed as the cause for a defined proportion of people suffering sleep disturbance, studies in other countries have illustrated that it is possible to quantify the monetary impact on productivity. For example, Australian studies in 2004 estimated the cost of lost productivity due to sleep disturbance at a national level as being equivalent to 0.8% GDP. Similarly, Japanese research in 2003 estimated the cost of lost productivity as being US$30.7 billion. These studies suggest the potential for a high level UK assessment of the associated cost of productivity to be derived.

It is suggested that a value for the UK could potentially be determined using a method similar to that of Hillman et al. (2004), although further research would be required to calculate a robust estimate of the proportion of the population suffering from a sleep disorder or awoken at night due to noise. This may be achievable using the approaches outlined above.

Relating noise to productivity loss through academic performance: The review has identified that a significant number of studies have been undertaken looking at the impacts of noise on academic performance and the impacts of academic performance on GDP. However no studies have been identified where a direct link between the three factors has been examined or established.

Much of the literature associated with noise exposure and academic performance focuses on primary school children, and demonstrates a link between increased environmental noise exposure and reduced performance. No work was identified looking at the eventual outcome of those impacts on final qualifications or the time spent in education. The studies linking academic performance to GDP have focussed on the impact of spending additional time in education, particularly secondary school children. There is evidence of a positive link between improved academic performance and increased GDP.

Based on the evidence collected, it is considered that developing a robust mechanism for quantifying the link between noise and changes in productivity through reduced academic performance, and therefore the cost to productivity in the UK, cannot be achieved without further work linking learning and memory issues caused by noise exposure to time spent in education.

Relating noise disturbance in the workplace to productivity loss: The focus has been on disturbance by workplace noise sources that are unlikely to exceed exposure action values within the Control of Noise at Work Regulations 2005. There have been a significant number of studies looking at disturbance in the office and its effect on productivity. There is evidence to suggest that noise occurring *within the workplace* potentially causes annoyance and disturbance and that productivity can be adversely affected as a result. The studies reviewed are generally based on subjective responses from workers, making the definition of accurate relationships quantifying these effects more difficult. No evidence was found applying a monetary value to any of these effects.

The limited evidence looking at links between *external noise sources* and productivity in the workplace suggests that disturbance due to road traffic noise is negligible.

The sources of disturbance to office workers that have been identified are potentially unavoidable characteristics associated with the work environment. These would be best controlled through the implementation of best practice, and it is considered that attempts to assess their cost impact on productivity would be of limited benefit, on the basis that it is difficult to make a widespread assumption on whether some of the sources, e.g. conversation, are for the most part disruptive or beneficial.

Relating noise-induced health effects to productivity loss: There is significant evidence linking noise exposure to adverse health effects. While the evidence suggests that relationships exist for predicting the monetary impact of health-related absence, no evidence has been identified of relationships linking loss of productivity due to poor/ill health while at work. Evidence from annual employer surveys in the UK goes as far as identifying absence due to individual types of health effect, but there is insufficient detail in these studies to attribute any of these effects as being brought-on/caused by noise exposure. However, if the considered health effects can be correlated with those addressed by IGCB(N) it may be possible to use IGCB(N) estimates of the number of cases due to noise in combination with the absence figures to estimate the effect from noise.

Any quantification involving all aspects of lost productivity would need to make an estimate of the number of workers who are ill but still active in the workplace and the scale of the resulting loss of productivity, taking into account the skill mix and nature of the work being undertaken.

It is therefore considered that the monetisation of mechanisms linking noise-induced health effects to loss of productivity, with the objective of assessing the cost to productivity in the UK, can only be achieved in part.

7.2 Recommendations for further work

Based on the literature reviewed, there is generally a lack of evidence linking noise disturbance to productivity in the workplace when considering the different types of mechanisms. Most commonly, research has been undertaken addressing components of the mechanisms. Additional work is therefore required to allow the links between these individual components to be addressed. The following areas are identified where it is considered that further effort would be of benefit.

Sleep disturbance: It has been identified that the use of methodologies similar to those used in Australian studies might form the basis of an appraisal tool which uses estimates of the proportion of the population suffering from sleep disturbance/disorders. It is suggested that the suitability of using L_{night} noise maps to derive this information be reviewed.

For assessments of the effects of sleep disturbance on productivity, the use of more objective laboratory studies rather than subjective (self-assessment) studies is recommended. Within these objective tests, the use of specific activities to assess productivity should be considered. Ideally, as is often the case in studies involving assessments of the capabilities of school children (Section 4.1), these activities should assess a range of different cognitive skills representative of those used in the workplace. This type of study would allow the use of controlled environments and noise sources, which would lead potentially to robust dose response relationships that could be used for monetisation purposes. Investigations of this type into the effects of sleep disturbance on next-day or short-term impacts on productivity are considered to be of particular value.

Academic performance: The research reviewed has focussed on the performance of primary school children, while work linking school performance to earnings/GDP focussed largely on secondary school children. It is considered that evidence in relating impacts on learning at a young age to academic achievement later on is crucial in order to quantify the relationship between noise and productivity through academic performance.

Noise disturbance in the workplace: The evidence identified suggested that the main focus of previous research has been on occupational noise and its effects in office environments. It is considered that the development of appraisal tools for this type of disturbance is complex and the role of government in its assessment is limited.

Whilst evidence was found assessing the performance of school children due to environmental noise sources (particularly aircraft), further work to investigate the potential impacts of environmental noise on workplace performance would build confidence in the existing, limited studies which suggest the impact of environmental noise sources is negligible. It is noted that building design and sound insulation play an important part in the scale of the impacts, so the impacts might be expected to be lower in newer buildings.

Noise-induced health effects: While some of the studies reviewed used surveys to assess absence from work in terms of individual health effects, disaggregating these in terms of noise as the source of the problem is likely to be complex, particularly since the percentage of the national workforce on which these surveys are based is small.

At the moment, there is no means of assessing the impact on productivity of poor/ill health while actually at work. Further work is required to identify an appropriate methodology that might allow monetisation of the effects.

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