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ENNAH – European Network on Noise and Health

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Editors:
Jurgita Lekaviciute, Stylianos Kephalopoulos,
Stephen Stansfeld, Charlotte Clark

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Institute for Health and Consumer Protection

Contact information
Stylianos Kephalopoulos
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 281, 21027 Ispra (VA), Italy
E-mail: stylianos.kephalopoulos@jrc.ec.europa.eu
Tel.: +39 0332 78 9871
Fax: +39 0332 78 5867

http://ihcp.jrc.ec.europa.eu/
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With contributions from ENNAH WP leading teams:

WP1 *Stephen Stansfeld, Charlotte Clark* (Queen Mary, University of London, UK)

WP2 *Anna Hansell, Helga Elvira Laszlo, Sarah Floud* (Imperial College, London, UK)

WP3 *Danny Houthuijs, Wim Swart* (RIVM, The Netherlands)

WP4 *Göran Pershagen, Charlotta Eriksson, Johanna Penell* (Karolinska Institute, Sweden)

WP5 *Francesco Forastiere, Carla Ancona, Francesca Mataloni* (ASL, Rome, Italy)

Laura Perez, Nino Kuenzli (Swiss Tropical Institute, Basel, Switzerland)

WP6 *Stephen Stansfeld, Charlotte Clark* (Queen Mary, University of London, UK)

WP7 *Stylianos Kephalopoulos, Jurgita Lekaviciute* (European Commission, JRC)

ENNAH coordinator:

Professor Stephen A. Stansfeld and Dr Charlotte Clark
Centre for Psychiatry
Barts & the London School of Medicine
Queen Mary, University of London, UK
E-mail: s.a.stansfeld@qmul.ac.uk / c.clark@qmul.ac.uk

ENNAH homepage: www.ennah.eu

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EXECUTIVE SUMMARY

The ENNAH project (The European Network on Noise and Health) was funded by the European Union's 7th Framework Program (FP7-ENV-2008-1, project no.226442) to establish a research network of experts on noise and health in Europe. The network brought together 33 European research centres from 16 countries to establish future research directions and policy needs for noise and health in Europe. ENNAH focused on the study of environmental noise sources, in particular transport noise. This network facilitated high level scientific communication and encouraged productive interdisciplinary discussion and exchange through a series of workshops and reports.

The ENNAH Network has identified gaps in noise and health research while at the same time assessing, prioritizing and integrating the future research orientation into policy development for a more efficient investment of resources in this research area. Noise maps produced under the direction of the Environmental Noise Directive (2002/49/EC) are potentially a very useful resource for noise and health research. We have reviewed the advantages and disadvantages of current noise maps and recommended changes that would make them more appropriate for public health research purposes. We have also considered possible new methods for acoustic measurement and modelling which will help to develop innovative exposure measurement techniques in future noise and health studies.

One important development has been the involvement in ENNAH of researchers mainly working on air pollution. The aim was to jointly consider the impact of both transport noise and air pollution on health. The ENNAH meetings have provided a fruitful exchange of views on how air pollution and noise can be further studied jointly and the underlying mechanisms elucidated. The European Union (EU) has made a substantial investment in funding cohort studies on the effects of air pollution on health. ENNAH provided an important opportunity to begin to exploit the existing cohort data in Europe having good information on air pollution and adding in data on noise exposure, some of which can be derived from existing noise maps. This may have direct relevance for transport and environmental policy in terms of deciding the priorities for a reduction in air pollution or noise or both when developing new mitigation actions.

An exciting part of ENNAH has been the opportunity for young researchers to be involved in an exchange program between EU countries and academic disciplines on noise and health with the aim of establishing research partnerships among a new generation of noise and health researchers.

Another important aspect of ENNAH research has been to contribute to increasing the information relevant for noise burden of disease calculations. The project fed into the important publications from World Health Organization (WHO) and European Commision's Joint Research Centre (JRC) on 'Burden of Disease from Environmental Noise'. Additionally, ENNAH included sessions on skilling up in health impact assessment (HIA). HIA is an important methodology for evaluating the health impacts of policy scenarios or actions aimed at reducing exposures to various environmental stressors such as noise and their associated health effects in relation to transport and infrastructure developments in Europe.

ENNAH focused on outlining new priorities and recommendations for research on environmental noise and related negative effects on health, such as: cardiovascular disease, mental health, children's cognitive performance, annoyance, sleep and hearing loss, as well as on some cross-cutting health related themes. Some of the most important recommendations are:

- To strengthen the evidence on existing exposure effect relationships and to use more robust methods such as longitudinal rather than cross sectional studies. It is particularly relevant to the research on environmental noise and hypertension and coronary heart disease and on studies of noise and children's learning.

- To encourage new research increasingly relevant for policy that will test whether interventions to reduce noise are effective and cost optimized and also whether they have a measurable impact on health.

- To assess where new investment in noise research should be placed, whether this relates to previously non- or poorly studied health outcomes or improvements in the noise and health methodological framework.

Exploitation of the ENNAH Network findings was aimed at having an impact on research-based policy-making. Interaction has been established with policy makers and EC services to communicate the ENNAH recommendations concerning needs for new research strategies on noise and related health effects in the EU. Policy makers have acknowledged the helpfulness of ENNAH in providing ideas where future thinking on noise and health issues should focus. A greater understanding of the adverse effects of noise can be used for better informed policy making and for prioritising key gaps for future research.

1 INTRODUCTION AND POLICY BACKGROUND

Environmental noise, caused by traffic, industrial and recreational activities is considered to be a significant local environmental problem in Europe. According to the recently published WHO-JRC report (2011), environmental noise leads to a disease burden that is second in magnitude only to that from air pollution.

Whereas the direct consequences of noise pollution lead to permanent hearing loss and impairments, the indirect health effects encompass a wide range of health problems resulting from increased anxiety, annoyance, sleep disturbance, psychological distress, and communication problems. In chronic cases this can result in cardiovascular problems. The WHO-JRC report highlighted that:

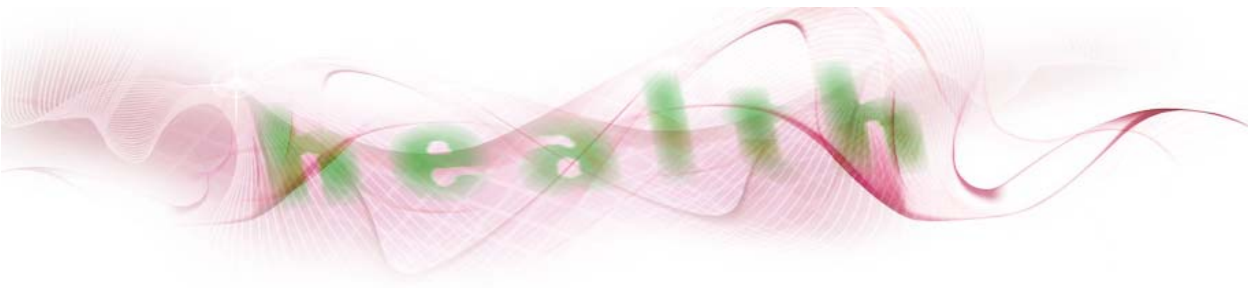
- One in three Europeans experience annoyance during the daytime and one in five has disturbed sleep at night because of noise from roads, railways and airports.
- Traffic-related noise accounts for over 1 million healthy years of life lost annually to ill health, disability or early death in the western countries in the WHO European Region.

The Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise (often known as the “Environmental Noise Directive” [END]) aims to define a common approach across the European Union with the intention of avoiding, preventing or reducing, on a prioritised basis, the harmful effects, including annoyance, due to exposure to environmental noise. To this end, the directive sets two instruments, noise maps and action plans, respectively, to describe the exposure of population to noise from relevant sources (aircraft, road, railway and industry) and to preserve quality areas or reduce noise pollution when necessary. The enormous undertaking of developing noise maps across Europe according to the END and action plans associated with these maps, has highlighted the importance of having reliable and replicated evidence on whether and how environmental noise exposure influences human health and wellbeing.

The ENNAH project (European Network on Noise and Health) was funded by the European Commission’s 7th Framework Program (EU Project FP7-ENV-2008-1, project no.226442) and established a research network of European scientists working on environmental noise exposure and health with the aim of producing information that is useful for the future development of the Environmental Noise Directive by developing and refining knowledge about the relationship between noise exposure and health outcomes. ENNAH has been the largest network on noise and health ever established in Europe and included in total 33 partners from 16 countries.

2 ENNAH OBJECTIVES

The initial objective of ENNAH was to review the existing literature on environmental noise exposure and health focusing on consolidation of existing knowledge and the identification of gaps in the evidence and future research needs. A further objective was to ensure that the most up-to-date measures of noise exposure assessment are applied to health studies. The network also assessed complex analytical models of noise and health effects that take into account moderating factors such as the joint effects of air pollution and noise. Furthermore, ENNAH helped to improve the measurement of health outcomes relevant to noise research taking examples from other areas of biomedicine and extending analyses of existing large studies of noise and health. It also helped to enhance communication between researchers working on noise and researchers working on air quality issues. Ultimately, it aimed to develop new designs for research on noise and health and to provide the EU with a new strategic outlook on noise and health for future noise and health related policies. An important element of the network was the exchange programme for junior researchers in noise and health designed to increase expertise among junior researchers in this important area. Throughout the 24 months duration of ENNAH efforts were also dedicated to disseminating the results to a wide range of stakeholders and potential end-users across Europe. This included EU Institutions, national governments, fellow researchers, research councils and the general public.



WP 1: ENNAH MANAGEMENT

3 ENNAH MANAGEMENT (WP1)

Network co-ordination

The overall co-ordination of the ENNAH network was carried out by Queen Mary University of London (QMUL), UK.

Co-ordinating committee

The individual ENNAH activities were planned and managed by the ENNAH co-ordinator in liaison with the ENNAH Co-ordinating Committee which was composed from the ENNAH work package leaders.

Advisory board

An advisory board of policy makers and other stakeholders was established at the start of the project, to advise the ENNAH network about the policy implications of the networks' work, findings and conclusions.

Champions

The discussions for each of the health outcomes studied in the context of ENNAH were led by a designated topic leader (champion).

3.1 ENNAH structure and description of work packages

ENNAH's activities were organised across seven Work Packages (WPs) and developed through a series of international workshops associated with these work packages. The main outcome of each work package is reported in the various chapters of this report. The workshops were arranged so as to maximise the collaboration of relevant expertise but also to bring together noise researchers with key experts from cross-cutting or adjoining research fields that could inform future noise research.

Figure 1 illustrates the management structure of ENNAH and the objectives of each WP are briefly outlined below:

Work package 1 - Management of the ENNAH network. The main aim of this work package was the management and coordination of the network to ensure that the network's main objectives were realised on schedule and within the budgetary limits and to ensure a quick and smooth communication and decision making process within the network and with the Commission.

Work package 2 – Review of the evidence of environmental noise effects on health. The aim of WP 2 was to assess critically previous reviews and identify new studies to provide a state of the art summary of knowledge and to make recommendations for further research on environmental noise and its health effects (other than those on hearing, which are already well-documented).

Work package 3 - Noise exposure assessment for health studies. The objectives of WP 3 were twofold: (a) to investigate the current practice of noise exposure assessment and of strategic noise mapping in Europe and its potential use for epidemiological health studies; (b) to identify novel methods and advanced measurement and modelling techniques for exposure assessment in future studies.

Work package 4 - Confounding and effect modifying factors in noise related health research. The main objective of WP 4 was to investigate the potentially important confounders and effect modifiers in noise related health research. These included exposure modifying factors, such room orientation to the noise source and effect modfying factors such as noise sensitivity.

Work package 5 - Measurements of health outcomes in epidemiological studies on noise and European Health Impact Assessment. The two main objectives of WP 5 were: (a) to discuss the improvement of measurement of health outcomes in epidemiological studies on noise and get a consensus on standardized methodologies to be used in future studies on health effects of noise; (b) to compare approaches and methods currently used in Health Impact Assessment (HIA) to promote common criteria for conducting a European-wide evaluation.

Work package 6 - New strategies for noise and health research in Europe. WP 6 focused on the development of new strategies and priorities for noise and health as the primary outcome of the ENNAH Network taking into account the existing state of knowledge and gaps in understanding on noise and health.

Work package 7 - Information strategy plan and dissemination of the ENNAH findings. The objective of WP 7 was to develop an information strategy plan and dissemination of the scientific findings of ENNAH through dedicated actions aimed at promoting and communicating the ENNAH results to various target groups of end-users (i.e., scientific community, policy makers in EC and member states, NGOs, industries and general public).

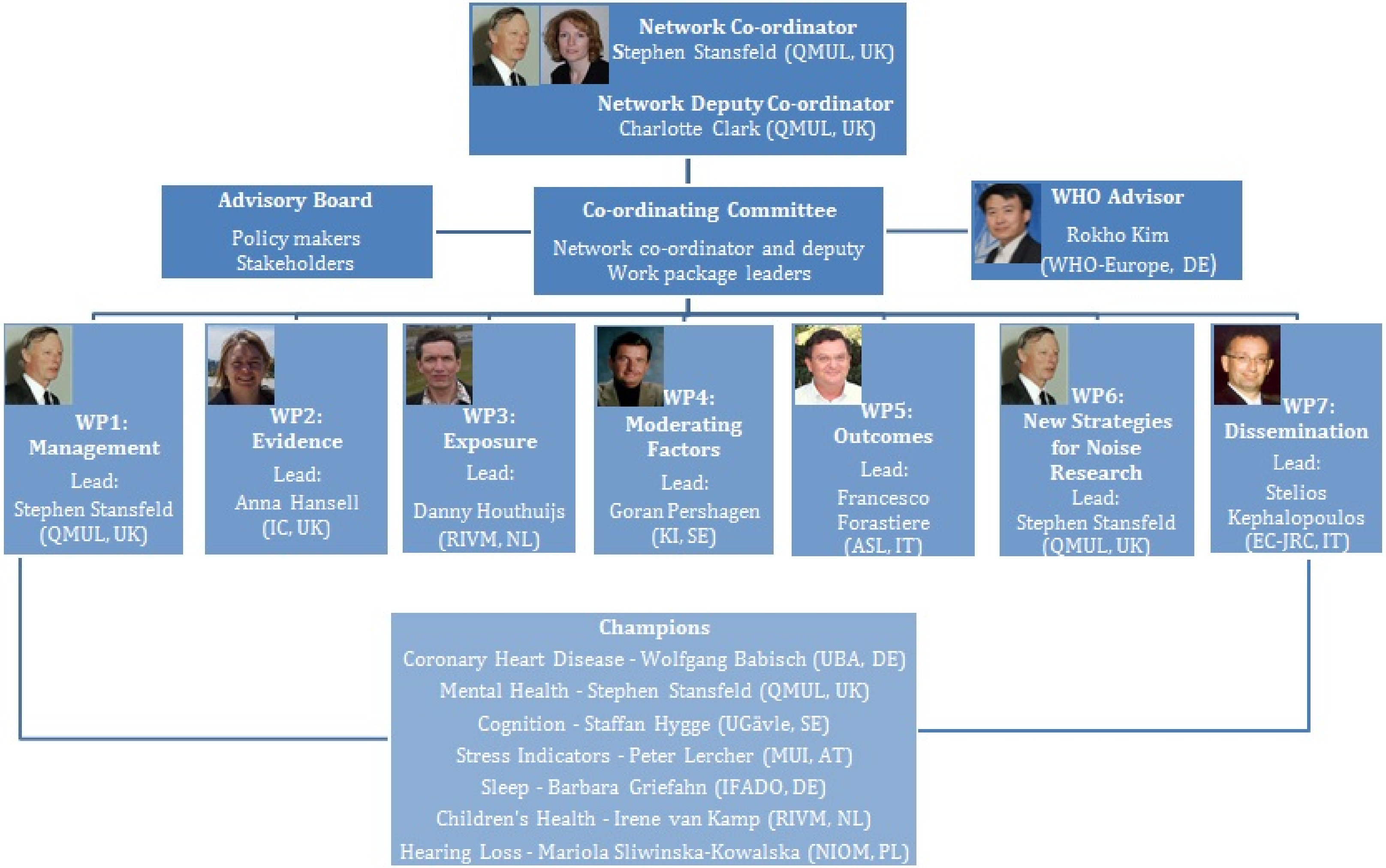


Figure 1. The management structure of ENNAH

3.2 ENNAH deliverables and milestones

D=deliverable; M=milestone

Work package (WP)	No. of deliverable	Description
WP 1	D1.1	Launch meeting
	D1.2	Launch network website
	D1.3	Report on student exchange activities
	D1.4	Annual report to EU
	D1.5	Final project report
	D1.6	Lay summary report
	M1.1	Young researcher exchange programme organised
	M1.2	Review of progress meeting
WP 2	D2.1	Hosting workshop on the evidence of noise-related health effects (workshop 2a)
	D2.2	Hosting update workshop on the evidence of noise-related health effects (workshop 2b)
	D2.3	Review of the evidence workshop report
	D2.4	Update website with review of evidence findings
	D2.5	Publication of main findings of workshop in peer-reviewed journal
	M2.1	Identification of gaps in knowledge and prioritization for policy needs
WP 3	D3.1	Hosting workshop on noise exposure assessment
	D3.2	Noise exposure assessment workshop report
	D3.3	Update website with review of noise exposure assessment
	M3.1	Identification of policy related relevant analyses of existing datasets concerning noise exposure assessment

	M3.2	Exchange of doctoral and post-doctoral researchers between centres
	M3.3	Identification of new and novel methods of exposure assessment
	M3.4	Standardisation of methods for measuring noise exposure for single and combined sources
	M3.5	Recommendations for noise exposure assessment in health studies
WP 4	D4.1	Hosting workshop on moderating factors
	D4.2	Moderating factors workshop report
	D4.3	Update website with review of moderating factors
	D4.4	Peer-reviewed paper on how the combined exposure to air pollution and noise may affect the risk of cardiovascular disease
	M4.1	Identification of policy related relevant analyses of existing datasets concerning moderating factors
	M4.2	Exchange of doctoral and post-doctoral researchers between centres
	M4.3	Identification of relevant moderating factors
	M4.4	Innovative methods for the measurement of moderating factors
	M4.5	Standardisation of methods for measuring moderating/confounding factors
WP 5	D5.1	Hosting workshop on health outcomes (workshop 5a)
	D5.2	Review of health outcomes workshop report (workshop 5b)
	D5.3	Review of health outcomes workshop report
	D5.4	Update website with review of health outcomes
	D5.5	Peer reviewed paper on measurements of health outcomes in noise research

	M5.1	Exchange of doctoral and post-doctoral researchers between centres
	M5.2	Innovative methods of measurement of health outcomes
	M5.3	Standardisation of measurement of health outcomes
WP 6	D6.1	Hosting of workshop to derive new noise research strategies
	D6.2	Review of new strategies for noise and health research in Europe workshop report
	D6.3	Update website with review of new strategies for noise and health research in Europe
	D6.4	Leaflet for policy makers and stakeholders
	D6.5	Peer reviewed journal papers summarising state of art of the field
	M6.1	Optimum study designs for different exposure and outcome combinations
	M6.2	Research strategies for assessing mechanisms for noise effects on health
WP 7	D7.1	Updating website
	D7.2	Newsletter
	D7.3	Platform of end users
	D7.4	Summary brochures (Leaflets)
	D7.5	Publications in peer-reviewed journals and conferences
	D7.6	Final meeting/workshop
	D7.7	Final report to EU
	M7.1	Publication and dissemination of new strategies for noise

WP 2: REVIEW OF EVIDENCE OF NOISE RELATED HEALTH EFFECTS

4 ENNAH RESULTS

4.1 Review of evidence of noise related health effects (WP 2)

ENNAH's work package 2 was led by Imperial College London by Anna Hansell with the participation of Helga Elvira Laszlo.

The aim of ENNAH WP 2 was to assess critically previous reviews and identify new studies to provide a state of the art summary of knowledge and to make recommendations for further research on environmental noise and its health effects (other than those on hearing, which are already well-documented).

4.1.1 Methodology used for the review

The first stage of the literature review was achieved through a workshop (WP 2a) organised immediately after the ENNAH launch meeting (September 2009, London). This workshop concluded that the literature review should build on several authoritative reviews already published or in preparation (as can be seen from Table 1) and also include literature published not only in English. This extensive review was greatly facilitated by the multi-national and multi-lingual membership of the ENNAH network.

Specific topics were identified for potential further follow-up and for discussion at the second workshop (WP 2b) organised in June 2010 in London:

1. *Interaction between noise and air pollution effects and possible issue of mutual confounding*
2. *Vulnerable groups in relation to the effects of noise and health*

   Groups such as children, elderly, people with existing illness or with high self-reported noise sensitivity may be more vulnerable to health effects of noise than the general population.
3. *Sources of noise*

   Research literature considering health effects relating to the following noise sources and their combination were actively sought (except for road and railway traffic for which much research has been already conducted):

   - Industrial
   - Neighbourhood noise
   - Entertainment
   - Railways – freight trains and high speed trains
   - Shipping and ports

- Wind turbines

4. *Acute vs. long-term effects of noise*
5. *Noise as a cause of accidents*
6. *Exposure issues*

   Prediction models, dosimeter indoor sound levels, effects of opening windows and window sound insulation, time-activity data - moving beyond residential address as an estimate of exposure (and impact of personal exposures, occupational exposures and protective factors e.g. deafness), distance from source, microenvironment models, similarities between inputs in models for noise and air pollution exposure estimates making comparisons of effects difficult, average noise levels vs. noise events above a certain noise threshold, habituation effects.

7. *Low frequency noise and associated health effects*
8. *Positive effects of noise and soundscaping*
9. *Health benefits of noise mitigation and intervention studies*

   For example, sound insulation of buildings.

10. *Health outcomes not or poorly studied to date*

   For example, respiratory health, developmental effects including birth outcomes (birth weight, miscarriages), stress mediators (cortisol, insulin resistance, abdominal obesity, blood lipids), sleep disturbance in infants, immune system dysfunction and health status.

Following the workshop WP 2a in September 2009, literature searches were performed on the specific topic areas identified and agreed upon using a number of electronic databases (PubMed, Web of Science and EMBASE) and other internet search engines. The searches included peer-reviewed papers published in English and/or German between 1980 and September 2012. The following subjects were covered:

- Environmental noise and physiological effects (for example cardiovascular disease or effects on the endocrine system)
- Environmental noise and psychological effects (for example sleep disturbance, effects on cognitive function, annoyance, noise sensitivity)
- Environmental noise and psychosocial effects (for example social adaptability, depression, general well-being)

Studies on hearing impairment were not considered in the literature search. While occupational noise was not included in the noise sources that ENNAH focused on, health studies related to noise at work were reviewed as a potential information source relevant to environmental noise effects.

The selection for relevant studies was made on the basis of comprehensive previous reviews, the number of citations and the quality assessment of papers completed within the work package 2. Recommendations made by the ENNAH partners were used to identify national reports, grey literature, especially non-English studies in press or in progress and relevant conference proceedings (e.g., Internoise and ICBEN).

The aim of the second workshop (WP 2b) was to identify literature relevant to the research gap areas which had been identified in the first stage of the literature review and to provide recommendations for future noise and health studies. Topic areas identified were: sources of noise, occupational noise, noise and co-exposures, vulnerable groups, noise characteristics, acute vs. long term effects of noise, stress and social impacts, positive effects of noise and noise reduction interventions. As a conclusion of this workshop several gaps were identified in the current knowledge about noise and health effects.

It was agreed that the two most important topics to focus most of the new literature review activity on were:

1. Noise and co-exposures (including air pollution) and
2. The relationship between noise annoyance, noise sensitivity and health outcomes.

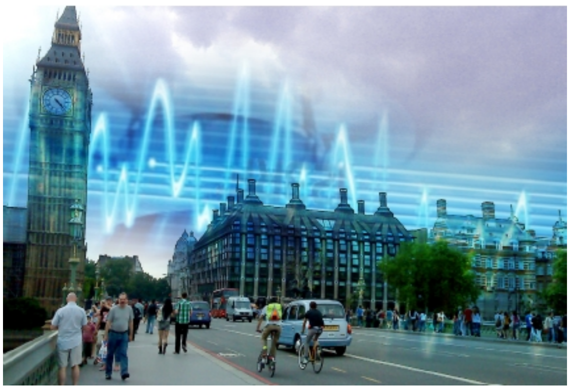
The agenda of the Workshops 2a and 2b can be found in Appendix A of this report.

4.1.2 Summary of literature reviews on noise and health research

Increasingly more information is becoming available about the health impacts of noise. The latest publication of the WHO and the European Commission's Joint Research Centre shows that traffic-related noise may account for over 1 million healthy years of life lost annually in the EU Member States and other Western European countries (WHO-JRC, 2011).

The evidence of hearing impairment due to high level noise exposure is well known. However, while the literature on non-auditory health effects of environmental noise is extensive, the scientific evidence of the relationship between noise and non-auditory effects is still contradictory. The WHO (1995) states that:

"The main negative effects of such noise on people are disturbances of communication, rest and sleep, and general annoyance. Over long periods of time these effects have a detrimental influence on wellbeing and perceived quality of life."



However, more recent studies have suggested that exposure to environmental noise is associated with physiological health effects such as cardiovascular disease or increased blood pressure, socio-physiological responses like annoyance or sleep disturbance and also mental health and cognitive performance. In a recent CE Delft report (den Boer and Schroten, 2007), noise from rail and road transport was estimated to be linked to 50,000 fatal heart attacks every year and 245.000 cases of ischemic heart disease in the EU25. The estimation of the probability of heart disease was based on the annual count of people suffering a fatal heart attack due to traffic noise published in

Babisch (2006), Ohm and Jensen (2003) and van Kempen et al. (2005) and the number of people exposed to noise levels over 60 dB(A) in the relevant countries.

The study of den Boer and Schroten in 2007 also estimated that the full costs to society of traffic noise pollution in EU27 (except Cyprus, Estonia, Latvia, Lithuania and Malta), including costs to health services, were at least EUR 40 billion per year.

Part of the work of WP 2 has been to identify the authoritative general reviews of the health effects of environmental noise. Authoritative reviews were identified by the following means: emailing ENNAH WP 2 workshop attendees, citation by other papers or reports, used in the WHO Night Noise Guidelines for Europe (WHO, 2009) or reports for governmental bodies (Berry, 2008; Berry and Flindell, 2009a, b).

The literature search led to 145 reviews published after 1980 from which 43 reviews were grey literature. The list of these reviews can be found in Annex B of the present report. The quality assessment of the peer-reviewed journal papers (see Annex C) showed that only 10 papers were classified as high quality, while 9 and 83 papers were medium and low quality, respectively. Most of the review papers were of narrative type – in part, because studies were too heterogeneous to permit a statistical synthesis of results in a meta-analysis. Although narrative reviews are considered lower quality compared to systematic reviews and meta-analyses they can contain useful information. However, for risk assessment, high quality meta-analysis is preferred as this contains the most detail on dose-response.

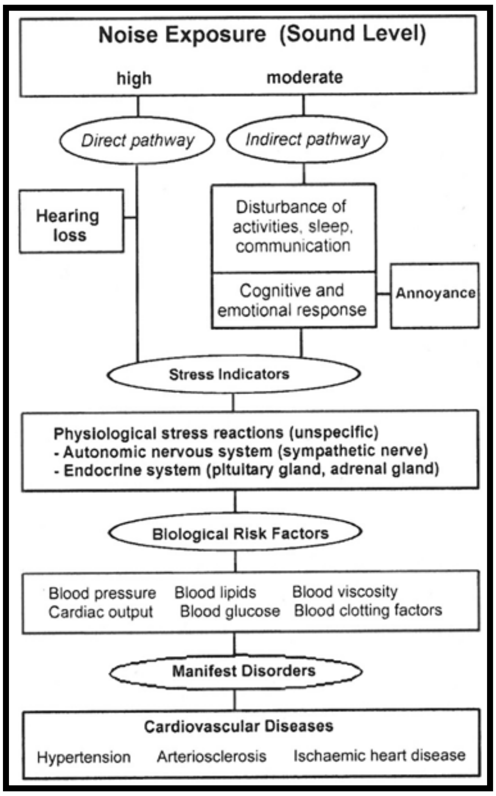
In the following section, the current knowledge and conclusions of the literature review performed are briefly summarized in order to highlight the key points in noise and health research which were identified.

The mechanism of noise induced health effects

Several theories and mechanisms have been put forward to understand the relationship between noise and non-auditory health effects (Babisch, 2004; den Boer and Schroten, 2007; Jones, 2010; Lercher, 1996; Passchier-Vermeer and Passchier, 2000; Prasher, 2009). The general stress model summarized by Lercher (1996) is widely accepted. In this model, noise is conceptualized as a stressor that activates the central nervous system generating a typical stress response. This model has several limitations. First of all, it focuses on the direct effects which result in a 'hard' medical health outcome such as increased blood pressure. Furthermore, difficulties arise from lack of specification of the expected response set. This early model does not take into account the individual differences in human responses to stressors.

The individual or situational difference models takes into account situational or personal modifiers for example noise sensitivity or interference with activities that jointly influence the noise-health relationship. Coping styles may also be an important element in the noise-health interaction (Lercher, 1996).

Two examples for direct and indirect pathways for non-auditory effects of environmental noise are shown in Figure 2. Acute noise exposure directly causes a number of predictable short-term physiological responses such as increased heart rate, blood pressure, and endocrine outputs. Chronic noise exposure may cause longer-term activation of these responses and subsequent symptoms and illness (Clark and Stansfeld, 2007). It is still unclear whether annoyance is a consequence of the noise affecting on the human body or whether the indirect pathway to ill-health might be mediated by annoyance. In addition, the role of noise sensitivity with regards to environmental noise and annoyance is unconfirmed. There has been evidence that other factors such as socioeconomic status, age, gender or other environmental factors like air-pollution also confound or moderate health outcomes (Campo et al., 2009; Cary et al., 1997; Hancock and Pierce, 2010; Ljungberg, 2009; Ljungberg and Parmentier, 2010), but their role in these interactions is unclear to date.



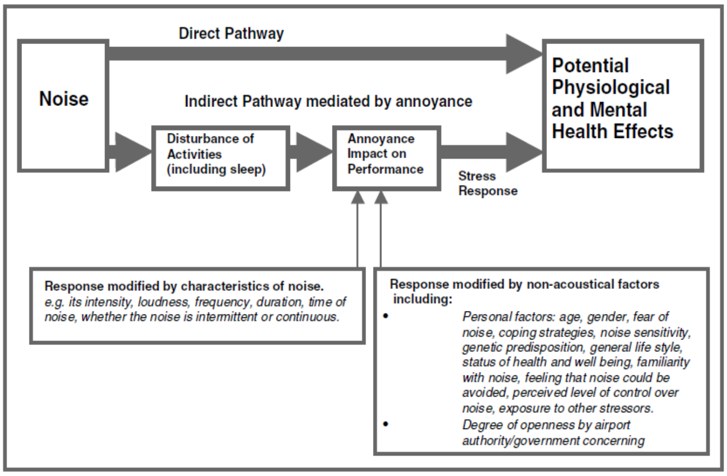


Figure 2. Possible mechanism of noise-induced health effects (left-Babisch, 2004, right-Jones, 2010)

Health outcomes

Environmental noise related health outcomes (excluding hearing impairment) have been extensively reviewed (Babisch, 2004; Berglund and Lindvall, 1995; Berglund et al., 1999; Berry, 2008; Berry and Flindell, 2009; Borg, 1981; den Boer and Schroten, 2007; Jones, 2010; Kaltenbach et al., 2008; Kawada, 2004; Knipschild, 1977; Kryter, 1972; Passchier-Vermeer and Passchier, 2000; Porter et al., 1998; Prasher, 2009; Schneider et al., 2005; Stansfeld et al., 1997; Stansfeld and Matheson, 2003). Similar to environmental noise, occupational noise effects on health have been studied (Babisch, 2004; Berry and Porter, 2004; Butler et al., 1999; Smith and Broadbent, 1991; Tomei et al., 2010; van Dijk, 1986; van Kempen et al., 2002) and the results could be used to suggest or support findings in relation to environmental noise.

Potential non-auditory health effects of environmental noise are:

- **Cardiovascular disease including hypertension, coronary heart disease and myocardial infarction** (reviewed in Babisch, 1998, 2000, 2003, 2006a,b, 2008; Babisch and van Kamp, 2009; Clark and Stansfeld, 2007; Davies and van Kamp, 2008; Hoffmann et al., 2009; Ising and Kruppa, 2004; van Kempen and Babisch, 2012; van Kempen et al., 2002)
- **Annoyance** (reviewed in Brown and van Kamp, 2009,a,b; Job, 1988; Miedema and Vos, 2003; Ouis, 2001)
- **Sleep disturbance** (reviewed in Griefahn, 1991; Hume, 2010; Jones, 2009; Lukas, 1975; Maschke and Hecht, 2004; Michaud et al., 2007; Muzet, 2007, 2011; Ouis, 1999; Pirrera et al., 2010; Raschke, 2004; Zaharna and Guilleminault, 2010)
- **Endocrine effects** (reviewed in Babisch, 2003; Ising and Braun, 2000; Maschke and Heckt, 2004; Maschke et al., 2000)
- **Mental health and cognitive development** (reviewed in Clark et al., 2006; Clark and Stansfeld, 2007; Kujala and Bratico, 2009; Lambert and Hafner, 1979; Matheson et al., 2003; McLean and Tarnopolsky, 1977; Smith, 1990; Stansfeld, 1992; Stansfeld and Clark, 2011; Stansfeld et al., 2000)

Despite the extensive number of review articles mentioned above on health outcomes related to environmental noise, the scientific evidence base is limited. Therefore several papers rate the evidence as follows (e.g. Babisch, 2004):

- Sufficient evidence is given if the positive relationship in observed between exposure to the agent and the health outcome, in studies in which chance, bias and confounding can be ruled out with reasonable confidence.
- Limited evidence is given if a positive association is observed between exposure to the agent and the health outcome. For which a causal interpretation is considered by a Working Group (experts) to be credible, but chance, bias or confounding could not be ruled out with reasonable confidence.
- Inadequate evidence is given if the available studies are insufficient in quality, consistency or statistical power to permit a conclusion regarding the presence or absence of a causal association.

Babisch (2004) reviewed the evidence of association between traffic noise and cardiovascular disease and states that the evidence for ischemic heart diseases is limited/sufficient, for hypertension it is inadequate/limited, and for biochemical changes of risk factors the evidence is limited. Recent studies, however, have suggested that different groups, especially children might show different responses to environmental noise (Clark and Stansfeld, 2007; Kawada, 2004; Matheson et al., 2003; Niemann and Maschke, 2004). Therefore, future noise and health research needs to include consideration of vulnerability and separate investigation of vulnerable groups.

It should also be noted that studies generally describe health outcomes according to the noise source (Babisch, 2008; Bly et al., 2001; Jones, 2009; Kaltenbach et al., 2008; Mestre, 2008; Morrell et al., 1997; Ouis, 1999, 2001; Raschke, 2004). Limited knowledge exists about the non-auditory health effects of the combination of aircraft, road traffic or rail noise.

Recent research clearly links exposure to night noise with harm to health through sleep disturbance and annoyance (WHO, 2009), but it is difficult to conclude at which time of the day the noise is most harmful (i.e. sensitive periods) and how the 24 hour noise dose is related to health outcomes.

Very few studies have investigated the effect of noise characteristics beyond noise level for example frequency or noise spectrum on health outcomes (Berglund et al., 1996; Colby et al., 2009; Leventhall, 2003, 2004; Roberts and Roberts, 2009; Schust, 2004). Those studies conducted mainly focus on low frequency noise and annoyance and sleep. Leventhall (2003) states that in the published studies there is little or no agreement about biological activity following exposure to infrasound and yet the primary effect of infrasound appears to be annoyance.

Table 1. Effects of noise on health and wellbeing

Effect	Passchier-Vermeer & Passchier (2000)			Babisch (2004, 2006) Babisch & Van Kamp (2009)	WHO (2009)			EEA (2010)		
	Acoustic indicator	Threshold	Classification of the evidence	Classification of the evidence	Acoustic indicator	Threshold	Classification of the evidence	Acoustic indicator	Threshold	Classification of the evidence
Annoyance	L_{dn}	42	sufficient		L_{den}		sufficient	L_{den}	42	sufficient
Hypertension	L_{dn}	70	sufficient	(inadequate) / limited / sufficient (aircraft)	$L_{night,outside}$	50	limited	L_{den}	50	sufficient
Cardiovascular disease (inc. ischaemic heart disease and myocardial infarction)	L_{dn}	70	sufficient	(limited) / sufficient	$L_{Aeq,24h}$ $L_{night,outside}$ (myocard.)	50 (myocard.)	limited	L_{den}	60	sufficient
Self reported sleepdisturbance	$L_{Aeq,night}$	40	sufficient		$L_{night,outside}$	42	sufficient	L_{night}	42	sufficient
Awakening	SEL	55	sufficient		$L_{Amax,inside}$	42	sufficient	$SEL_{indoors}$	53	sufficient
Sleep (arousal, motility, sleep quality)	($L_{Aeq,night}$) SEL	(< 60), 35	sufficient		$L_{Amax,inside}$	35, 42	sufficient	$L_{max,indoors}$	32	sufficient
Heart rate, body movements during sleep	SEL	40	sufficient				sufficient			
Hormonal changes during sleep			limited	limited			limited			
Performance, fatigue next day			limited				limited			
Stress hormones			limited				limited	L_{max}, L_{eq}	NA	sufficient
Learning, memory, performance	$L_{Aeq,school}$	70	sufficient					L_{eq}	50	sufficient
Immune effect			limited							
Birth weight			limited							
Well being			limited				limited	L_{den}	50	sufficient

The classification categories for the evidence (sufficient / limited / inadequate) are based on Babisch (2004)

4.1.3 Identified gaps in the literature on noise related health effects

The identified gaps in the current knowledge were:

- The effect of *combined noise sources* especially the contribution of neighbourhood noise.
- The effect of *changing noise characteristics*, particularly frequency on annoyance, sleep disturbance and health outcomes. No comparison has been made between low and high frequency noise effects.
- The mechanism and pathway of *co-exposures* in particular air-pollution and chemicals.
- The importance of *noise sensitivity* in annoyance, sleep disturbance and other health outcomes.
- It is unclear *which factors (i.e. age, gender, sensitivity, chronic disease as a precondition, etc.) can be used to define a vulnerable group*. Do these factors modify the effect of noise?
- Distinguishing between the effects of *short and long-term noise exposure*.
- The *relationship between sleep disturbance and stress* as a pre-condition or as an outcome. It is also unknown whether long term sleep disturbance has an adverse health effect.
- The role of *annoyance in health outcomes*. Annoyance can be the result of noise exposure, but also a mediator.
- Effects of *noise on social behaviour*.
- *Habituation and its effects* on health outcomes and annoyance.
- *Positive effects of sound*.
- The effect of *noise intervention on health outcomes*.

The lack of definition of noise sensitivity and vulnerable groups was noted as well as the need for a standardized method to measure or categorize these possible effect modifier factors. Since there are many factors potentially interacting with the measured and perceived sound, the purpose of noise management policy needs to be clarified – is it to manage sound levels or to manage effects?

4.1.4 Survey

A web based survey was developed and circulated among ENNAH partners in order to gain a better insight into emerging research topics and research needs. We asked the participants to rate the strength of evidence for road-, aircraft- and railway related health endpoints. We also asked to indicate whether the sufficient evidence could provide quantitative risk assessment or support some policy decisions. Limited/inconclusive evidence for noise related health effects could be due to lacking or old studies and methodological issues that could result in considerable heterogeneity in study conclusions. Additional recommendations about research needs for each noise source were collected within this survey. In the second part we asked ENNAH partners to rank the most important health outcomes that need further research as well as select the three most important principles that are applied by the scientific community and policy makers during decision making. Participants selected three topics that should get highest attention among scientists and policy makers.

We sent 42 invitations from which we got 25 completed surveys. The strength of evidence for various health outcomes was judged against the three main noise sources. The evidence was rated to be sufficient for annoyance, blood pressure and sleep disturbance (Figure 3). However for blood pressure the evidence was rated inconclusive to almost the same extent. The evidence was rated inconclusive for cardiovascular disease, stress and hormonal changes, cognitive development while mental health and effect on vulnerable groups were judged as being inconclusive / lacking. It is worth noting that the ratings varied depending on the noise source. In general, the evidence was lacking in case of railway noise while road traffic noise related health outcomes are well studied.

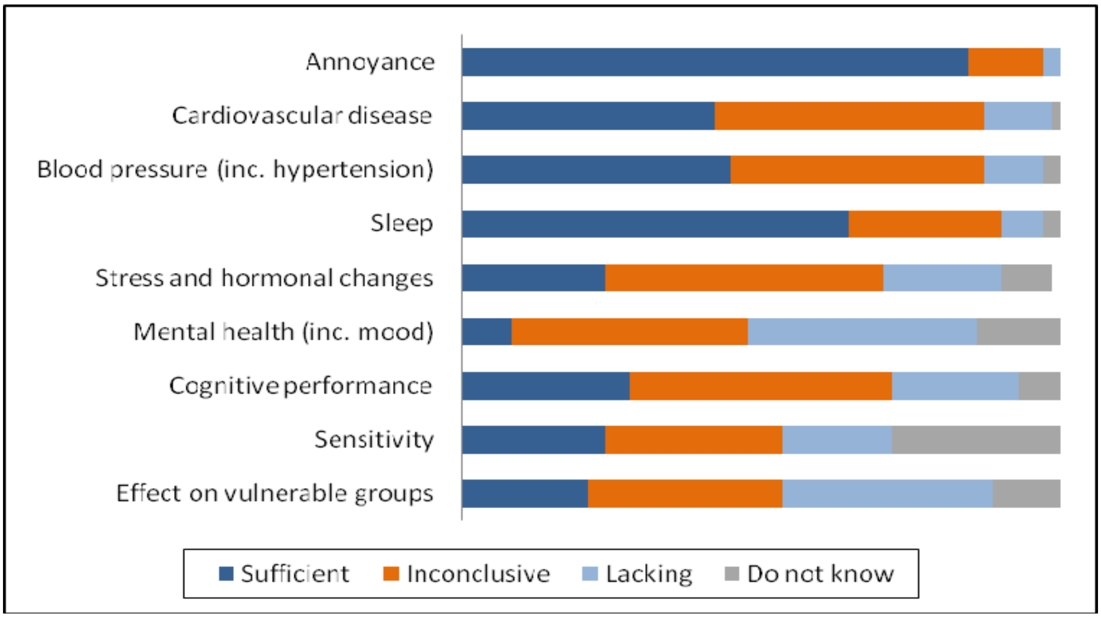


Figure 3. Judging the strength of evidence for environmental noise related health effects based on ratings from 25 experts

Generally half of the expert group indicated that sufficient evidence could provide quantitative risk assessment while the other half suggested that it could be used to provide support for policy decisions. The main reason for inconclusive evidence was methodological issues and substantial heterogeneity between studies in relation to aircraft noise and road traffic noise, while studies are lacking for most health outcomes in relation to railway noise.

The survey participants suggested that the scientific community and policy makers have different priority areas and they apply different principles to select these areas (Table 2). While researchers focus on areas where the evidence is inconclusive / lacking, policy makers may select topics according to the number of people who are affected by noise or who could benefit from noise intervention.

Table 2. Applied principles when prioritising research areas

	Scientific community	**Policy makers**
1st principle	Research focuses on areas where evidence is inconclusive/lacking	How many people are affected
2nd principle	Research on effect models to understand causality	Cost efficiency
3rd principle	How many people are affected	Harmonisation with other EU members

Similar differences have been found for priority areas among the two groups (Table 3).

Table 3. Priority research areas for scientific community and policy makers suggested by the 25 participants of the survey

	Scientific community	**Policy makers**
1st most important	Cardiovascular disease Health effects of combined noise sources Relationship between noise induced sleep disturbance and stress Vulnerable groups Role of annoyance and noise sensitivity Habituation and coping	Dose-effect curves
2nd most important	New endpoints (i.e. stroke, perinatal outcomes)	Vulnerable groups
3rd most important	Mechanism and pathway of co-exposures Effect modifiers	Noise interventions and health

The experts suggested that policy makers should emphases noise reduction at the source in order to minimise noise related health effects rather than focusing on noise mitigation interventions, reducing noise annoyance or using other tools.

4.1.5 Conclusions and recommendations

The major gaps identified in the literature discussed were:

- *Effects of combined sources of noise*. The effects of separate noise sources have been studied but there is no information relating to how noise exposure from combined sources changes the response.
- *Mental health, physical health other than cardiovascular disease, reproductive outcomes*. Most studies to date investigating health effects of environmental noise have been conducted on cardiovascular system outcomes.
- *Annoyance and noise sensitivity*. Relatively few studies have looked annoyance and noise sensitivity in relation to health outcomes including cardiovascular disease.
- *Appropriate exposure measures*. Modelled average A-weighted dB-based noise exposures may not be the best measure and other metrics e.g. L_{max}, C-weighting, or other noise characteristics should be investigated.

The most important topics to perform future investigations are:

- Noise and co-exposures (including air pollution).
- The relationship between noise annoyance and health outcomes, also including noise sensitivity and a discussion of causes and mechanisms.

For a full overview on ENNAH WP 2 see deliverable D2.3 in the ENNAH's website.

List of identified reviews can be found in the Annex B of the present report.

Figure 4. ENNAH workshop on WP 2, 28-29 September 2009, London

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WP 3: NOISE EXPOSURE ASSESSMENT FOR HEALTH STUDIES

4.2 Noise exposure assessment for health studies (WP 3)


ENNAH's work package 3 leader was Danny Houthuijs from National Institute for Public Health and the Environment in Netherlands. He was working on ENNAH with his collaborator Wim Swart. The objectives of WP 3 were to: (a) discuss current practice of noise exposure assessment and of strategic noise mapping in Europe and its potential use for epidemiological health studies; (b) to identify novel methods and advanced measurement techniques for noise exposure assessment in future studies.

4.2.1 Introduction and objectives

The Commission's Green Paper on Future Noise Policy indicated in 1996 that the available data on noise exposure in Europe are generally poor in comparison with data collected for other environmental factors and often difficult to compare due to different assessment methods. Since the European Noise Directive (END) asked for strategic noise maps and noise action plans for major roads, railways and airports in agglomerations in 2007 and 2008, substantial efforts have been made in recent years to improve the assessment of noise through developing and harmonising methods for the modelling of transport noise (EC-JRC, 2011). Thanks to the requirement of strategic noise maps, an enormous amount of potentially useful information has become available for use in exposure assessment within health studies. Before the data generated in the framework of END can be applied in health studies, it is essential to consider the necessary requirements for exposure indicators since a reliable and valid assessment of noise exposure is essential for the interpretation of any study findings in relation to health outcomes. This was the reason why the ENNAH workshop 3 on "Noise Exposure Assessment for Health Studies" was organised.

4.2.2 ENNAH WP 3 topics

4.2.2.1 Assessment of the usefulness and limitations of strategic noise maps for health studies

Lessons from EU noise mapping

According to the European Topic Centre Land Use and Spatial Information (2008), 67 million people in Europe are exposed to level of road traffic noise higher than 55 dB L_{den} (day-evening-night equivalent sound level). This corresponds with about 55 % of the population in agglomerations with more than 250 000 inhabitants.

Limitations of the current practices start with general issues, such as the definitions of agglomerations, relevant year and the quality of data. Various methods are used in all details of the generation of noise maps. Examples are the assessment of cut off values and the grid step, the treatment of low levels and of quiet areas, the quality and extent of noise source data (flow and speed), the calculation methods and the methods to assign noise levels to the population.

Levels under 55 dB L_{den} and 50 dB L_{night} (night equivalent sound level) are not reported and often even not estimated. Therefore, cut off values may lead to neglect of the impact of the smaller roads. Health studies need detailed assessment at high and low noise levels, but often the extent of the agglomeration and the calculation grid step do not allow it. Even at relative low levels substantial annoyance can occur due to source specific spectral characteristics.

Valid and reliable noise maps are required not only for their original aim to serve as a basis for action plans, and to verify targets and limits, but also for comparison of EU countries and for the development of a better insight into the impact of noise on health. The large data sets in GIS could be a unique resource for linking noise to health outcomes. From a noise modeller's perspective, noise exposure assessment in health studies requires high quality mapping beyond END requirements and further standardisation across cities and consultants.

Noise maps are appealing for health researchers, since they document noise levels in large study areas which make it possible to link them to health data. But before using this kind of data, the maps must be critically reviewed. For example, it has to be checked to which source the noise levels refer. Since local authorities do not always consider the whole road network but often only the major roads, the levels do not necessarily refer to the most important noise source for a particular building. Therefore, the quality of the noise data has to be evaluated in each specific case. The quality is an important criterion in the selection of study areas and study populations.

Due to missing exposure information additional assessment methods are sometimes required to fill the gaps. The relationship between noise level and noise annoyance usually shows a steady increase in annoyance with increasing noise level in most social surveys so annoyance could serve as indicator of the noise level.

The EC "Good practice guide for strategic noise mapping and the production of associated data on noise exposure" provides a useful tool which can also be used if documented noise exposure data are missing.

It would probably be more realistic to set a cut level at the lower end that refers to the background noise environment. Cut levels of 35 dB during the night and 45 dB during the day seem to be reasonable for road traffic. In urban surroundings it is often difficult to measure such low L_{Aeq}'s. On the other hand, subjects may respond to the occurrence of a single noise event, rather than to the L_{Aeq}. In such cases, it would make sense to keep the low exposure levels in the analysis (e. g. aircraft noise).

Modelling versus measurements

Noise exposure, in general, can be assessed by measurements and by calculation. For exposure assessment in population studies, use of calculated noise data based on established models is preferred. Long-term assessment of noise exposure by measurements only is generally not feasible, particularly not on a large (spatial) scale. Furthermore, the technical possibilities of source-specific acoustical measurement are still limited for large studies. On the other hand, carrying out noise measurements may be useful to obtain additional or missing information about individual exposure conditions and can be used to validate calculated noise levels.

The disadvantage of short-term measurements is that they do not account for seasonal variations or weather conditions. However, in many cases it is reasonable to assume that the long-term exposure does not vary too much from the short-term measurement.

If subjects are falsely grouped into the low noise category or the opposite, this tends to dilute the true association between the exposure and the health outcome. On the other hand, if an association is still found the qualitative reasoning would not be discarded. Carrying out short-term measurements (or traffic counts) can therefore be an option when no other noise information is available.

Noise exposure assessment for health studies in Central and Eastern Europe

Three examples from Central and Eastern Europe were discussed during the ENNAH workshop 3.

Poland

In Poland the END noise mapping data does not deliver the necessary information in order to propose a successful action plan. It is not clear which noise indicator should be reduced first if at a given point in a city there are equal weighted noise levels from different sources. It was proposed that noise annoyance questionnaires should be performed as mandatory with noise maps. According to the results of surveys, noise related to sport activity and neighbours are very large sources of annoyance and therefore should be included in noise maps. It was proposed that each building should have a “noise certificate”. This should work in the same way as “an energy certificate” which already exists.

The former Yugoslav Republic of Macedonia

FYROM is a candidate for joining the European Union. European legislation regarding environmental noise management is partly adopted and implemented. However, FYROM is not at the stage that there are noise maps for large agglomerations or for main roads. Noise exposure assessment is performed with noise measurements in urban centres, according to standardised procedures. L_{day} and L_{night} are the relevant exposure indicators. L_{den} is not assessed yet. There is a need for technical support and for exchange of experience with noise mapping with West European countries to be able to produce noise maps according to END requirements for regulatory purposes, action plans and policy making.

Slovenia

Noise exposure levels were assessed for the city of Ljubljana, the only agglomeration with more than 250 000 inhabitants, major roads and railways. The strategic noise maps were prepared according to END recommended methods on the basis of statistical data from road and railway traffic and on the basis of noise monitoring data for industry. Noise mapping was used to provide information for policy makers and for the public. The evaluation of traffic noise annoyance and sleep disturbance of citizens by surveys would be useful for preparing action plans. Also in Slovenia noise from pubs and neighbours seems to be a problem that is very difficult to solve with the relevant present legislation. Exposure of young people to loud music also needs to be investigated.

4.2.2.2 Issues for noise exposure assessment in health studies

Noise indicators

It is not always easy to choose which noise indicator is the most relevant to use. In practice, often there is not much choice, so the indicator used is that which is available. For comparability between studies and for policy purposes, established noise indicators (e. g. L_{den}, L_{night}) should be included. Since indicators such as L_{den} and L_{dn} are weighted noise indicators (+5 dB for the evening hours, +10 dB for the night time) the addition of non-weighted noise indicators like $L_{Aeq,24h}$ (A-weighted equivalent sound pressure level over 24 hours) in health studies is recommended. In addition to energy-equivalent noise indicators, it may be advisable to consider including event-related indicators like L_{max} (maximum sound pressure level), Number of events, SEL or combinations (NAT = number of exceedances above threshold) as well.

Outdoor-indoor exposure

Standardised and regularly assessed noise indicators in noise maps refer to outdoor exposures. Often only the most exposed façade of a building is considered. The attenuation due to the noise reduction of windows and walls as well as the individual window opening habits determines the indoor exposure. Individual information about sound insulation measures and individual behaviour can be assessed by questionnaire. Measuring indoor noise to assess the long-term exposure is not recommended because of easy interference of the relatively low indoor noise levels by noise from indoor sources.

Individual exposure

The link from environmental exposure to the individual exposure is important in health studies. The relevant time-window plays an important role in this. The night time exposure may be a particularly valid indicator because it refers to sleep and the time of the day when most people stay at home. Distinguishing between the exposure of the bedroom and the living room is essential in this respect. Simple accumulated noise energy throughout the whole day in terms of personal dose is not necessarily a useful indicator, if the levels cannot be related to specific activities and/or noise sources. The time of the day could serve as a proxy to differentiate between activities if no specific information is available. Making use of time activity patterns that are linked to noise exposures could be a feasible way of improving the assessment of individual noise exposure throughout the whole day, since it offers the opportunity to analyse the contribution of different sources in specific time windows.

Historical exposure

Sensitivity analyses could be done, excluding people who were not living for a long period at their present address. In some countries people move a lot, so in such cases the historical exposure from different places of residence has to be assessed. An approach could be the calculation of person-months, where the subjects move from one noise category to another with respect to the retrospective observation period.

Continuous or categorical data analysis

If continuous noise exposure data are available, they should be used for statistical analyses. The continuous data analysis results in figures like "increase in risk per decibel" and assumes a steady increase in risk with increasing noise level over the range of exposure. Categorical analyses are useful when grouped noise data are available from the very beginning (e.g. in noise policies often 5 dB categories are considered). Analysis with categorical exposure categories might give insight in non-linear relationships (e.g. u- or j-shaped associations). The best option would be to provide both, linear trend and categorical data in the presentation of results. Dichotomous data analysis that compares only two groups (e.g. extreme groups or separated according to the median) should be avoided. Such analyses may help to test associations as such, but they do not enable exposure-response consideration, which are needed for practical noise mitigation policies and possible intervention.

Subjective exposure

The response to the sound, in terms of noise annoyance, is considered as an endpoint in social surveys. The question is, whether the objective and the subjective exposure should be treated as separate factors in independent analyses ('either/or') - because noise annoyance itself is partly determined by the noise level - or if both factors should be considered simultaneously in one model. The latter is certainly fine, if prediction is the objective ('best fit'), but problems may arise with respect to the interpretation of statistical associations when hypothesis testing is the objective.

Exposure/effect modifiers

From a statistical point of view all exposure modifying factors and other potential effect modifiers can be treated as interaction terms in the statistical analyses or in stratified analyses (subgroups). Room orientation and window opening habits are some of the relevant factors: smaller effect estimates can be expected in subsamples that do not have rooms/windows facing the street. Also the subgroup that keeps bedroom windows always closed may be a particularly interesting group to be considered in sensitivity analyses. Length of exposure (years of residence) was also found in studies to be an important effect modifier, showing larger effects in subjects that had been living in their homes for at least 10 or 15 years. Type of window (single glazing, double or triple glazing, special sound insulation windows, participation in a sound insulation programme) might be another interesting exposure/effect modifier to examine. The use of other noise reducing remedies such as the use of ear plugs during sleep should also be assessed in the noise questionnaire and be considered in the analyses as an effect modifier (exclusion, interaction, or stratification). The height of buildings and the floor level of an apartment may have an impact (distance) on the perceived exposure. Type of housing and ownership of housing may be other effect modifiers to be assessed and considered, that may to some extent be understood as indicators related to the exposure. Annoyance was found to be an effect modifier of the relationship between the noise level and the health endpoint in some noise studies.

When effect modification is studied at least two important issues should be considered. First, most studies were not designed to study effect modification. Therefore they might not have enough power to assess with sufficient precision the possible effect modification. Second, random error in the variable that modifies the effect (noise sensitivity, annoyance) tends to diminish the observed modification. But error in exposure can create a spurious appearance of modification.

Multiple exposures

Multiple exposures do not only refer to different noise sources that may be present at the same time (e.g. combined exposures from road, rail, aircraft, industrial noise) but also to noise exposures that may be temporarily present at different times of the day (e.g. traffic noise at home, occupational noise at work, leisure noise during leisure, neighbourhood noise during relaxation periods). If not advised otherwise, the separate treatment of different noise sources/factors in the statistical model would probably be the most appropriate way of handling multiple exposures. The same applies to time-activity related noise levels that may be assessed with personal noise dosimeters. It is preferable to distinguish the contribution of different sources.

4.2.2.3 Combined exposure to noise and air pollution

Disentangling the effects of noise and air pollution is a challenging task. Work on the establishment of dose response curves is needed and is ongoing. Accurate assessment of exposure to road traffic noise and to air pollution is a prerequisite for disentangling their effects, and is perhaps the most critical element in epidemiological exposure-effect studies. Clever and innovative use of existing knowledge, as well as emerging new technologies creates new opportunities to enhance epidemiological research into the effects of combined exposure.

For the design of epidemiological studies on the combined effect of traffic related air pollution and noise it is important to have an insight into the correlation of both exposures. Accurate exposure assessment with an adequate spatial resolution is a prerequisite for disentangling the effects of both exposures. Results from several studies were discussed. It was not yet possible to conclude whether the correlation of measurements was better than the correlation between modelled data for air pollution and noise, due to the use of data with different quality, different models and different time-windows. The correlation in rural areas seems to be lower than in cities. The correlation within cities fluctuates. In the WP 3 discussion it was proposed that situations like street canyons and the shielding effects of buildings seem promising places, where a lower correlation may support disentangling of the effects of air pollution and traffic-related noise.

The effect of road traffic noise and traffic related air pollution exposure develop (partly) through different physiological mechanisms. Furthermore, knowledge on the separate mechanisms may enhance studies through choices of focus on the exposure and respondent data to be gathered.

For instance, certain behavioural aspects will affect exposure to noise and air pollution (and their effects) differentially. Exposure in different microenvironments (schools, bedroom) is a topic of interest.

Noise varies much less from day to day compared to air pollution – because the noise level variation mainly depends on the variability in road traffic flow and is to a much lesser extent related to the meteorology than is the case for air pollution. Noise might vary by 2 dB from winter to summer due to temperature but this is a small range compared to air pollution which can vary to a much greater extent. Noise can vary from weekday to weekend but this would be the same for air pollution as it would depend on road traffic levels.

In order to try and separate out effects, study designs will need to include a spatial element. For example set studies in places which are exposed to mostly noise and not air pollution (e.g. rail noise) or study the effect of noise barriers which will reduce noise but not air pollution. Physical characteristics of the built environment may affect transmission of noise and dispersion of air pollution differently (e.g. effect of building and noise barriers, vehicle speed and vehicle distribution patterns).

The results of two Madrid studies suggest that city-averaged daily fluctuations in 'acoustical pollution' may have a short term effect on hospital admissions. In the discussion, alternative explanations for the results were mentioned: noise may actually be a proxy for daily fluctuations in urban activity patterns, or for an element of air pollution which had not been measured (e.g. ultra fine particles (UFP) which has been found to be highly correlated with noise). Short term variation in noise might not produce acute health events such as mortality or hospital admissions but is thought to be related to short term variation in physiological parameters such as blood pressure (BP) and heart rate variability (HRV). This is an important area to investigate because both research communities (noise and air pollution) have started to research the association between parameters including BP and HRV in relation to the two different exposures. Novel simulation techniques can be used to model the temporal variation in more detail. Personal exposure measurement could be used to get an insight into which microenvironments the correlations between noise and air pollution are weak and where they are strong.

4.2.2.4 Novel exposure techniques

Simulation techniques

The temporal variability of the noise level over time is large and varies from location to location. Some health endpoints are clearly related to the intermittent characteristics of the noise source (short term effect such as, instantaneous annoyance, heart rate variability, sleep disturbance, etc.). In the EU noise mapping only involves the long-term average levels so additional information could be relevant when assessing the effects of noise. Attention was paid to: 1) whether there are simulation techniques that could provide this additional information; 2) if the accuracy of these techniques is satisfactory and 3) how these techniques consider complex situations.

Additional information about the noise situation: spectral information

In the urban situation, low frequency noise due to heavy vehicles is underestimated. Different indicators are available to include the spectral content. Dynamic simulation models are available to improve the estimation of the low frequency noise. They make use of information about the deceleration, stops and acceleration of traffic and are an improvement over static models as used in the END. These models are also capable of capturing the temporal variation in the spectra. Dynamic simulation models seem therefore dedicated to the estimation of spectra envelopes and spectra variations, allowing a better estimate of exposure to road traffic noise in urban areas. Unfortunately, the number of studies that have used the spectral information of traffic noise is limited so its relevance for health is not yet clear. The application of this information in studies is very much welcomed.

Additional information about the noise situation: temporal information

A large number of indicators have been introduced to capture the temporal structure of the noise level. From simple to complex: 1) percentile sound levels and derived measures like traffic noise index (TNI) and noise pollution level (L_{NP}), 2) the number of noise events and derived measures like Number Above Threshold or Time Above Threshold, 3) the number of duration of notice events, events potential consciously noticed taking into account habituation and attention focusing, 4) the spectrum of temporal fluctuations and 5) traffic signal scale indicators. Dynamic simulation models are able to estimate these refined indicators, contrary to static models which are not based on a representation of traffic sufficiently precise to do this. The correlation between the different indicators might be high in some locations which will make it difficult to filter out the most promising indicator. With a good selection of study areas it is possible to overcome this potential problem. These indicators could be applied in research to test their usefulness for relating temporal characteristics of the noise exposure to health endpoints.

The application of novel simulation techniques

Suitable simulations are needed to carry out research into detailed noise indicators. Two approaches were presented that, contrary to static models that are only based on average speed, try to assess the location and evolution of vehicles on the road network. Microscopic traffic simulation models consider the exact location and behaviour of individual vehicles over time within a study area that is modelled in great detail.

Behavioural rules form the core of the model. Small-scale changes in infrastructure can have large influences on traffic flows. Linked to a noise emission model for individual vehicles, micro-models can estimate the effect of detailed traffic management on the spectral and temporal structure of noise levels with a high spatial and temporal resolution. All the above mentioned indicators can be calculated. This approach is the most detailed technique for modelling the exposure to traffic noise nowadays available for the size of (part of) a city. The cost of constructing a simulation network in terms of data needs as well as manpower and the need for calibration are the limiting factors. In principle, air pollution can also be considered.

The accuracy of the methods is in general better than the classical static methods used in END, but might differ from situation to situation.

Another approach for micro traffic simulation is based on three physical parameters: the maximum speed reached when traffic is free, the wave speed and the minimum spacing between two vehicles. The model can be refined to take into account the acceleration of vehicles, the influence of buses, lane-changing and conflicts at junctions. It is capable of estimating noise distributions, spectral content and to reveal noise dynamics. Its strength is that the cost of constructing a network is low and that it is easy to calibrate.

For large scale studies, the micro-simulation approach is not feasible. A reasonable simplification is to assume that most of the temporal fluctuation is caused by the traffic originating from the closed line source. It is possible to take into account type and speed of vehicles in the assessment of temporal variation but the influence of acceleration is neglected. Also distance could serve as proxy for dynamics, but this will depend on the type of road. The expected relation with health endpoints is nevertheless non-trivial. Also, it is clear that distance is also a proxy for traffic related air pollution, so the use of distance has to be handled with care and its relevance could differ for the different health endpoints. Also, it is possible to argue the other way around: if for example an indicator in dB(C) appears to be more relevant than an indicator in dB(A), this might refer to an effect of distance instead of an effect of low frequencies.

Besides using the micro-simulation approach in health studies, it is possible to use the models in risk assessment. Locations will be rated differently, depending on the indicator that is used.

It is clear that there is a great need for additional noise indicators in health studies (including loudness, tonality, number of events, low-frequencies, temporal variability, etc.) and that the available micro-simulation techniques can be applied in relative large study areas. If necessary, simplified models can be applied to reduce problems with the size of the area or with the necessary resources. There is a need to apply health studies in those areas where more detailed information on the spectral and temporal aspects of the noise is already available. It is likely that endpoints like annoyance and sleep disturbance that relatively quickly follow the change in noise characteristics are the most promising to follow up. If more insight is obtained in the usefulness of the indicators obtained with these novel techniques, other health endpoints should be studied as well.

Advanced measurement techniques

Improvement of the accuracy of relation between noise exposure and health endpoints is a crucial aim in health studies. A 5 dB error in exposure already "flattens" the slope of the dose-response curve. Advanced measurements techniques can be used to improve the exposure and to reduce misclassification.
The assessment of noise by measurements is still relevant, since: 1) many studies have shown that modelled noise levels can easily differ from reality; 2) it is unlikely that the individual noise exposure can be easily extracted from modelled noise maps; 3) there is increasing awareness that annual average levels do not capture all the relevant information, 4) measurement equipment has developed over time and pre-processing allows more flexibility and makes the calculation of additional indicators possible, and 5) advances in technology have improved the cost effectiveness of measurements.

One of the novel measurement technologies is Micro-Electro-Mechanical-Systems (MEMS). This technology is especially suited to the production of microphones and a number of organisations across the world are working towards the development of measurement grade microphones. MEMS technology has such benefits as low unit cost, simple and low cost calibration, potential for self-calibration or validation within network, wireless operation and multi-parameter sensing – including potential for simultaneous air pollution measures. There is also scope for the assessment of alternative noise indicators (short-term, frequency based, number of events, etc.). The system is in use in different parts of the UK and it is clear that the system can be used to validate crude exposure indicators for health studies. Examples of studies with MEMS showed how well measurements and modelling agree with already reasonable accuracy using standard modelling: 90% of calculated day values within 5 dB on first instance. This could be improved to 90% of calculated day values within 3 dB when a more expensive technique was used. Further improvement is possible with better modelling.

One of the other issues discussed was if novel methods can facilitate the assessment of personal noise dose in health studies. A recent search shows there have been a few examples of studies which have explored the issue of personal exposure as opposed (or in addition) to group or population exposure. Modern instrumentation is available to monitor individual or personal exposure. It is used in occupational rather than environmental studies. However, personal dosimeters are easily affected by uncertainties (e.g. quick movements of the bearer or presence of wind) and this characteristic has limited their use to occupational environments. A cascade study, comparing noise maps with personal dosimetry (or distributed measurements) on the same territory would be very useful to further explore the possibilities of personal exposure for health studies.

Novel measurement techniques generate large data volumes. There is a need to collect related activity information as well, so the knowledge about the activities of people can be used to further refine the collected data. Lastly, it is important to have information about the noise source that contributes to the noise level to be able to relate source characteristics to health endpoints as well. Lack of source recognition is a major drawback for personal dosimetry. Work is needed on ways how to include source recognition in personal dosimetry.

4.2.3 Conclusions and recommendations

Lessons learned from noise mapping for health studies

- Noise maps were required to draw up action plans and compare country results in the EU, so they are not primarily developed for noise assessment in health studies. The maps are a potential vital source for health studies, but their applicability has to be evaluated critically on a case-by-case basis. The major limitation in noise mapping is the road network considered, given the specified cut-off values (55 dB L_{den}; 50 dB L_{night}). In addition, different approaches for the collection and use of input data (traffic flow, speed, composition) leads to differences in quality and accuracy between countries, agglomerations and consultants.
- There is concern about the application of the standard noise maps in health studies. This concern is related to the detail of the assessment (grid size, which façade), the assessment of noise at low levels and the negligence of source spectral characteristics. In spite of this, compelling results from an application in Sweden were shown during the workshop.
- The END has been evaluated and this will lead to major improvements and further standardisation in noise mapping. The next round of noise mapping will include more major roads and agglomerations.

In addition to the recommendations already formulated for noise mapping in the framework of END, specific recommendations can be given for the application in for health studies:

- To increase contrast in exposure for health studies, cut-off points for noise mapping should be lowered (up to 45 dB L_{den})
- Individual levels and not 5 dB contours bands should become available. And the other way around; in health studies cut-off values should be introduced at lower end (for example 45 dB L_{den} for road traffic noise, lower for aircraft and rail noise)
- An extension of the noise assessment, now limited to the most exposed façade, to other facades as well
- The accuracy of maps should be supplied (also for “dummies”); a standardised format for the description of the accuracy is needed.

Noise and health studies in Central & Eastern Europe

- Noise assessment practice in CEE differs between countries, partly related to the stage of integration with the EU. The difference in quality of the noise mapping is in general larger than in other parts of Europe, so an even more critical approach towards the available data is required.
- From the CEE perspective it became clear that noise maps are not the only way to inform the public:
    - Other noise sources, which could have large impacts in many situations, are neglected in noise mapping (neighbours, construction, sports, recreation)
    - The focus in noise mapping is on visual and not on acoustical information which is contradictory

Specific recommendations for noise assessment with a CEE perspective but which are partly valid for other countries as well are:

- Combine noise mapping with surveys on noise annoyance (of other sources as well) to be able to make successful action plans
- Explore the possibilities for “sound maps”
- Further development of noise regulations (e.g. building acoustics) and technical support for implementation of END is needed in some CEE countries

How do health scientists treat noise exposure?

- From a health view point the END indicators L_{den} and L_{night} might not be the most relevant indicators for effects other than annoyance and sleep disturbance. So there is a need for a broader variety of indicators like L_{Aeq} (without penalties for evening or night) for health endpoints or event characteristics (e.g. L_{max}, SEL, Number Above a certain threshold, Time Above a certain threshold).
- Noise exposure indicators should take into account the critical time window and the critical location of exposure. So in the case of sleep, the focus should be on the exposure in the bedroom during the sleeping period. For other endpoints, other locations and time windows apply.
- Exposure assessment is not limited to the modelling or the measuring of noise levels but includes the assessment of exposure modifying factors as well. Exposure modifiers like room orientation, shielding and window opening habits affect the difference between the (modelled) noise level at the most exposed façade and the relevant indoor level. The cumulative noise exposure should be taken into account when health endpoints are studied that are affected by long-term exposure. Attention should be paid to the years of residence and change in residence and/or in exposure.
- Misclassification due to errors in the assessment should be seen in the light of the noise variation already in the population. Also the type of error is vital (random/differential, etc.).

- Noise maps should aim for lower cut-off values to increase exposure contrast which could contribute to the power of health studies.

Novel modelling techniques

- Measurements indicate a great variability of noise over time due to, for example, the effects of acceleration/deceleration of road traffic and the effects of low frequency noise. These phenomena are not often addressed in health studies. This might be one of the reasons for the weak associations between noise and health outcomes.
- New computational methods to calculate noise exposure indicators for spectrum and temporal fluctuations are available for application in relative large study areas. These models make use of micro traffic simulations (driver model, waves). The detailed models are time and cost consuming. Adoption of simplified methods should be considered in health studies. For example, the distance between the road and the receptor might be usable as a proxy for traffic dynamics. Such simplified methods, such as distance, should be used carefully, since they might be associated with other environmental indicators of interest (e.g. air pollution) as well.
- The assessment of specific more refined noise exposure indicators was seen as one of the major opportunities of these novel simulation techniques. Also, the use of these methods in linking exposure to short term health effects was seen as an important new perspective.
- Annoyance and sleep disturbance are seen as the most promising health indicators to be studied. Whether the use of these simulation techniques is promising for other indicators as well can be better judged if results on annoyance and sleep disturbance have become available.
- An important question that still has to be answered is if we should focus in the noise exposure assessment on more detailed methods (e.g. Harmonoise/Imagine), or use the standard calculation methods with more and better input data to generate alternative exposure indicators.

Advanced measurement techniques and personal exposure

- Measurement error affects not only the strength of an association but could also lead to underestimation of relative risk, odds ratio or the slope of a dose-effect relation. Reduction of the measurement error is therefore an important aspect of the assessment.
- From the historical overview of measurement equipment it was identified that now similar but cheaper equipment is available. The quality is much higher and the internal (large) data acquisition facilities make advanced post processing possible.
- Examples showed how well measurements and modelling agree with already reasonable accuracy using standard modelling: 90% of calculated day values within 5 dB on first instance. This could be improved to 90% of calculated day values within 3 dB when a more expensive technique was used. Further improvement is possible with better modelling.

- ❖ The literature on environmental dosimetry is not very developed, but a first study on relating dosimetry to health endpoints was recently published.
- ❖ The conclusions about novel measurement techniques were that they can be used 1) for the assessment of alternative indicators, and 2) to validate crude exposure indicators for health studies.
- ❖ Lack of source recognition is a major drawback for personal dosimetry. Work is needed on how to include source recognition in personal dosimetry.
- ❖ The trade-off between improvement of the accuracy of the modelling and measurement techniques, the size of the study population and the need and availability of other noise exposure indicators should be further discussed.

Noise and air pollution assessment

- ❖ Health effects of road traffic are not only associated with noise but also with air pollution. Efforts are needed to disentangle the effects of both environmental exposures. This will include:
    - Further disclosure of the mechanistic pathways;
    - Refined assessment of exposure to both noise and air pollution (including adequate spatial resolution);
    - Investigating the relative contribution of air pollution and noise;
    - Refinement of exposure-response relationships.
- ❖ Strategies are needed to disentangle the effect of noise and air pollution. These strategies depend on the type of study area and studied health endpoint.
- ❖ The situations of interest are in particular urban areas where physical characteristics of the built environment affect transmission of noise and dispersion of air pollution differently, leading to lower correlations between both exposures (e.g. situations like street canyons, speed and vehicle composition patterns). Also, poor exposure characterisation may affect assessment of exposure, and thereby may distort assessment of exposure response relations. In the case of two correlated exposures, it can affect the assessment of both exposure response relations.
- ❖ Models to calculate noise levels and traffic related air pollution concentrations use the same type of input data. It is not yet possible to state that modelled noise level and air pollution concentrations tend to have higher correlation than measured noise level and air pollution concentrations. The available data differs in quality so it is difficult to draw conclusions. A higher correlation for modelled data may be a result of the use of the same input data.
- ❖ Novel simulation techniques and personal exposure measurement may be needed to disentangle the role of the exposure determinants for traffic related noise and air pollution.

For a full overview on ENNAH WP 3 see deliverable D3.2 in the ENNAH's website.

Figure 5. ENNAH workshop on WP 3, 26-28 April 2010, Gent, Belgium

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WP 4: CONFOUNDING AND EFFECT MODIFYING FACTORS IN NOISE RELATED HEALTH RESEARCH

4.3 Confounding and effect modifying factors in noise related health research (WP 4)


The leader of ENNAH work package 4 was Goran Pershagen from Karolinska Institute, Stockholm, Sweden. He was working on ENNAH with his collaborator Charlotta Eriksson.

The aim of ENNAH WP 4 was to:

1. Identify potentially important confounders/effect modifiers in studies on noise effects on health including air pollution and individual susceptibility factors such as lifestyle/environment and genetic factors.
2. Propose strategies for assessment, analysis and interpretation of the role of such factors in health-related noise research.
3. Facilitate and develop interactions between researchers in different fields relevant for studies of effect modification in relation to noise and health.
4. To perform further policy relevant analyses of the HYENA (Hypertension and Exposure to Noise near Airports) and RANCH (Road traffic and Aircraft Noise exposure and children's Cognition and Health) and other relevant datasets.

4.3.1 Identification of potentially important confounders/effect modifiers

It is clear that several factors need to be considered as confounders and/or effect modifiers in health related noise research. For cardiovascular effects related to road traffic noise an important factor is air pollution from the same source. A large number of epidemiological studies indicate that both short- and long term exposure to air pollution from road traffic is associated with an increased risk of cardiovascular disease (Brook and Rajagopalan, 2010). This seems to be related primarily to exposure to fine particulates, which has also been corroborated in experimental studies. Epidemiological studies indicate a correlation between traffic related noise and air pollution exposure of around 0.3 to 0.6 in different urban environments (Beelen et al., 2009; Selander et al., 2009a; Sörensen et al., 2011). Presentations at the ENNAH workshop 4 confirmed these estimates. This suggests that both factors should be considered in studies of either factor but that it is possible to separate effects of the two exposures. The two most common methods for air pollution exposure assessment in epidemiological studies are dispersion modeling and land use regression, which both seem to perform well (Jerrett et al., 2005). It is important to consider consequences of imprecision in the exposure estimation in the control of confounding.

It is suspected that children are more susceptible to noise exposure effects than adults. For example, noise and other environmental factors such as air pollution may impair children's health and cognitive development. In fact, it has been shown that exposure to noise has an effect on children's cognition. In the RANCH study, chronic aircraft noise exposure was related to impairment of reading comprehension and recognition memory after adjusting for mother's education, socioeconomic status (SES), long-standing illness and extent of classroom insulation against noise. Road traffic noise was associated with increases in episodic memory and with annoyance. However, mental health, self-reported health or sustained attention was not affected by noise exposure (Stansfeld et al., 2005). Road traffic noise has also been reported to impair reading speed and basic mathematics but not affect reading comprehension or mathematical reasoning (Ljung et al., 2009). A higher level of perceived stress has been reported by children with long-term aircraft noise exposure at school (Haines et al., 2001). Several mechanisms were suggested, such as chronic stress and direct effects through impaired attention or speech interference. There is still no theory that can comprehensively explain how noise affects cognitive performance. Noise can also be an indicator of social deprivation. For example, chronic exposure to aircraft noise has been associated with school performance in reading and mathematics after adjusting for school effects, but this association was influenced by socio-economic factors (Haines et al., 2002). Further, it is not known whether the effects of prolonged noise exposure in children are progressive, constant or reversible. For chronic aircraft exposure, it has been seen that the noise exposure affected the development of reading comprehension and was associated with poorer sustained attention and higher self-reported perceived stress (Haines et al., 2001).

Several other factors must be taken into consideration as potential confounders or effect modifiers when studying the effects of noise exposure and health. Depending on the association under study, potential risk factors for the disease should be identified and assessed with regard to their association with the outcome and exposure. According to the results of the ENNAH workshop 4, in addition to air pollution, established confounders in studies on noise and cardiovascular outcomes include age, gender, socio-economic status, ethnicity, smoking, alcohol consumption, relative body weight and physical activity. Additional potential confounders are, for example, heredity, diet, hormone supplementation, noise from other sources and shift work. A recurring confounder in many studies on noise and health outcomes is socioeconomic status. Socioeconomic factors are closely related to numerous factors influencing the risk of disease and can thus be considered as a proxy for these. Furthermore, there may be social inequalities in the residential exposure to traffic noise in urban areas (Havard et al., 2011). During the workshop, it was also recognized that few studies consider more than one noise source at a time and noise from other sources is an often overlooked confounder. A future challenge is to develop methods to assess the total noise exposure and to disentangle the effects from different sources.

A number of the presentations at the workshop reported on effect modification by certain factors in studies with varying outcomes. In addition to air pollution, factors such as gender, individual noise sensitivity, annoyance, attitude towards the noise source, employment status, exposure to multiple noise sources, adaptability to stress and genetic predisposition were discussed as effect modifiers in studies on noise and cardiovascular outcomes. A summary of the evidence of a gender difference in noise effects showed inconclusive results. More studies report effects in men (Babisch et al., 2005; Barregård et al., 2009; Eriksson et al., 2010) than in women (Bluhm et al., 2007; Rhee et al. 2008); however, some studies also report no differences (de Kluizenaar et al., 2007; Selander et al., 2009a). The observed differences may be caused by chance or bias but can also arise from biological differences in the progression of cardiovascular disease between the sexes. It was concluded that future studies need to address the potential differences further. Noise annoyance and individual noise sensitivity are two recurring effect modifiers, independent of outcome, and should be carefully assessed. It is noted however, that the timing of the measurement of these factors may be of importance for their properties as modifiers.

Identification and assessment of potentially important confounders in studies of noise effects on health are essential for the validity of the results. To assess individual susceptibility and detect vulnerable subgroups, the moderating effects of a large number of factors also need to be considered.

4.3.2 Strategies for assessment, analysis and interpretation of the role of moderating factors in health-related noise research

In studies of effect modification or interaction it is important to define the model used in the analysis. The two most used models are the additive and multiplicative model. Interactions are often analyzed in noise research, for example to identify sensitive subgroups of the population or to serve as a basis for setting priorities in prevention (Selander et al., 2009a; Selander et al., 2009b). Studies of interactions may also shed light on aetiological mechanisms.

In the ENNAH workshop 4 the participants were asked to draw a "causal diagram" for a selected exposure (e.g. aircraft or road traffic noise) and an outcome (e.g. sleep disturbances, cognition, cardiovascular diseases).

The causal diagram is one type of four major causal models used in health-science research (Greenland and Brumback, 2002). The main advantage of the causal diagram is that it can illustrate qualitative population assumptions and sources of bias not easily seen with other approaches. Specifically, the causal diagrams illustrate the relationship between variables, and can point out both intermediate terms (on the causal pathway between a factor and the outcome) and supply a simple visual method to check for confounders. This will facilitate correct adjustment of factors in the analyses.

A causal diagram is used as a method to structure the relationship between a set of predictors and an outcome, which can serve as a tool for analysis (Figure 6 and Figure 7). The aim of the exercise was to identify important confounders and effect modifiers for examples of associations and discuss the potential influence on the results.

The discussion of causal webs provided interesting ideas for studies of interactions in health related noise research, both for cardiovascular and cognitive effects. Effect modification by age and sex has often been detected for noise related health effects (e.g. Selander et al., 2009b; Sörensen et al., 2011) but, as indicated at the workshop, no firm conclusions can be drawn because of conflicting evidence. Studies of interactions should be given a high priority in noise research.

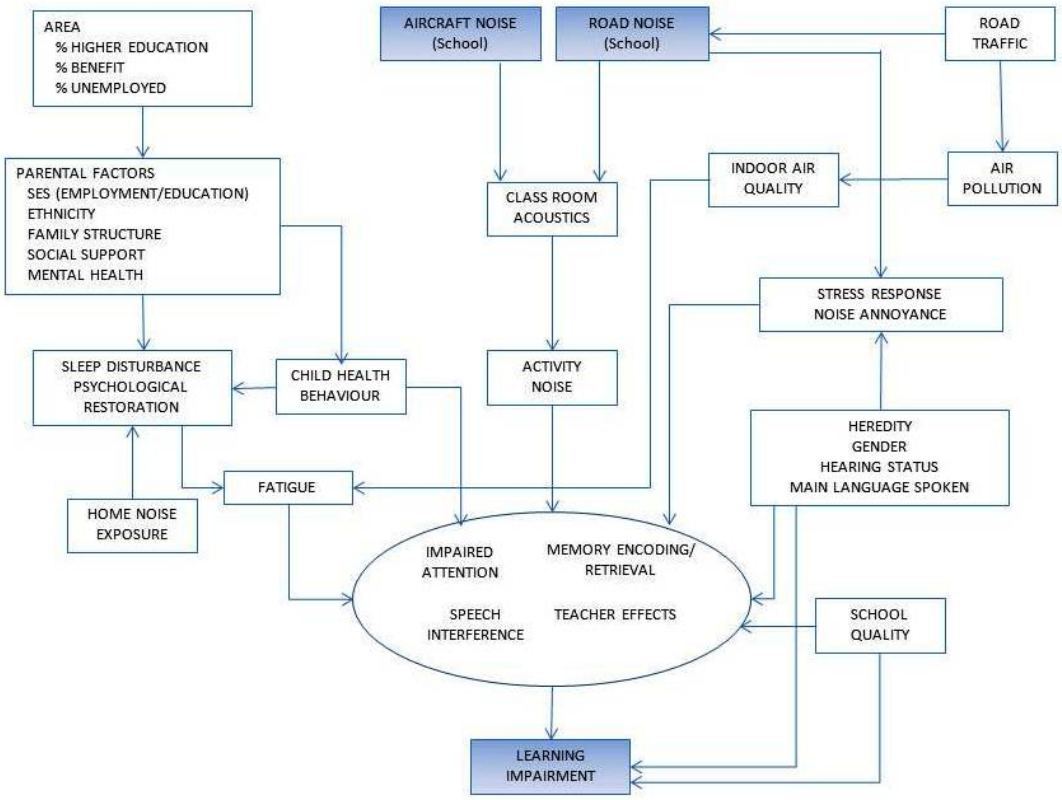


Figure 6. Association between road traffic and aircraft noise and learning impairment

Figure 6 presents a causal diagram for the relationship between aircraft and road noise and learning impairment in children. At the presentation of this causal diagram, several exposure modifying factors in the school were mentioned such as window glazing and classroom design (e.g. type of flooring, furniture). Air pollution was included as an intermediate factor between road traffic and indoor air quality. Home noise exposure, rather than aircraft or road traffic noise was believed to affect sleep and psychological restoration. Another factor on the causal pathway from road traffic noise exposure to learning impairment is the stress response and noise annoyance, which was thought to be both an intermediate variable between noise exposure and the outcome, but also affected by personal characteristics which could act as confounding variables.

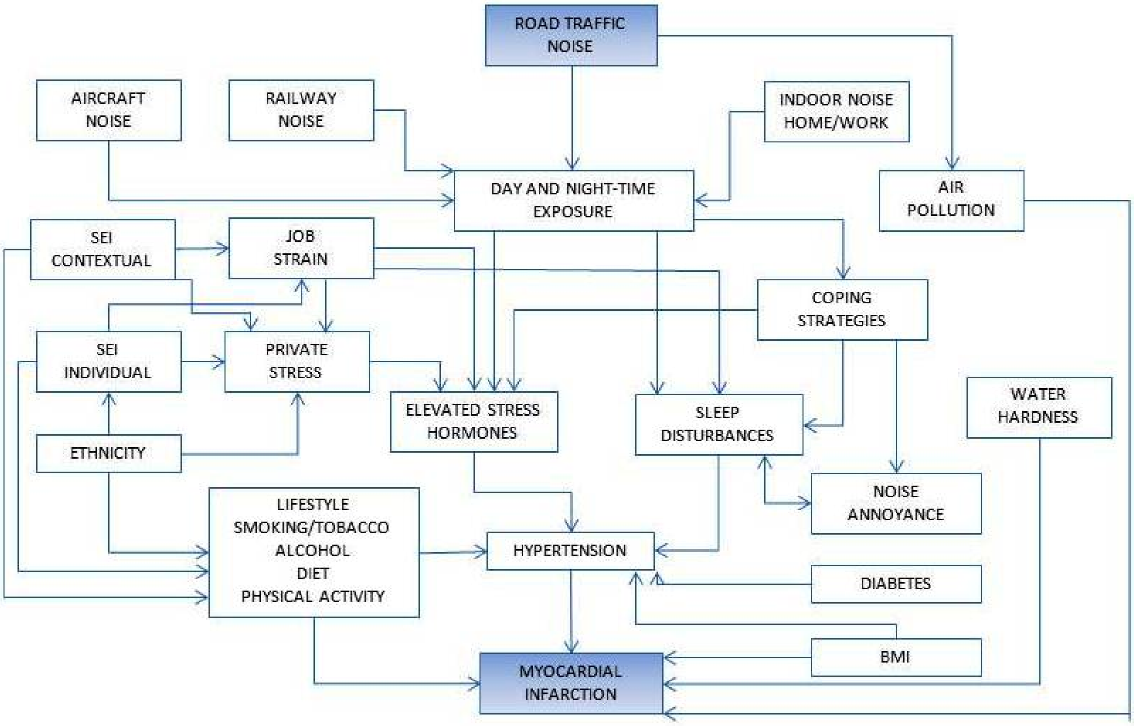


Figure 7. Association between road traffic noise and myocardial infarction

In Figure 7 additional noise sources such as railway and aircraft are also included. Here road traffic noise is thought to present its effect in three major ways: by causing elevated stress hormone levels, sleep disturbance and by its correlation with air pollution. Elevated stress hormones are a key component of this causal web. Levels of stress hormones may be affected by the noise exposure as well as occupational and private stress, but can be modified by different coping strategies. Elevated stress hormones and sleep disturbance will in this causal web cause hypertension, a condition also affected by lifestyle factors such as smoking, body mass index (BMI), diet, alcohol and physical activity but also diabetes. Lifestyle factors in turn are believed to be related to various factors, e.g. ethnicity, and individual and area-level Socioeconomic Index (SEI). According to this causal diagram, air pollution is on the causal pathway between road traffic and myocardial infarction, hence acting as an intermediate variable between the exposure and the outcome. In this causal diagram, the health effect of the exposure is believed to be modifiable through different coping strategies which will affect the magnitude of the sleep disturbance, stress hormone levels and noise annoyance. Noise annoyance is in this causal diagram not believed to be on the pathway to the outcome of interest, or any other health measures.

4.3.3 Confounding and effect modifiers in RANCH, HYENA and German noise studies

The cross-national (Netherlands, Spain, United Kingdom) cross-sectional *RANCH study* aimed to investigate the relationship between aircraft as well as road traffic noise exposure at school and children's health and cognition. Aircraft noise at school was associated with impairment of reading comprehension, recognition memory, and increased annoyance after adjusting for socioeconomic factors and classroom insulation (glazing) against noise.

Further analyses of RANCH undertaken as part of WP 4 found no interaction between early biological risk and aircraft or road traffic noise. However, children with early biological risk were more likely to have poor mental health than children without biological risk. In addition, other factors may act as effect modifiers. Coping strategies such as covering the ears, stop working, tuning out/switching off, and waiting for noise to finish employed by children whilst learning may influence the effect of noise on cognition. Analyses also indicated that air pollution did not relate to children's health and cognition in RANCH, and that the previously observed noise effects remained after taking air pollution into account (Clark et al., 2012).

The aim of the HYENA study was to investigate the relationship between noise exposure near airports and cardiovascular disease outcomes in six study areas in Europe, and for three study sites to examine whether this association was affected by air pollution levels. The aircraft noise L_{Aeq16h} distribution by country showed higher exposures for the UK and the Netherlands than for Sweden, whereas the road traffic noise L_{Aeq24h} distribution was similar for the three countries. For NO_2, there are quite considerable differences between the countries with no overlap between the UK and Swedish data despite the similarities in road traffic noise distribution.

In German studies on noise and cardiovascular outcomes, besides 'typical' established confounders (age, gender, socio-economic status, lifestyle factors etc.), additional potential confounders include family history of disease, food intake, hormone intake, shift work, noise from other sources (e.g. work noise) and noise sensitivity were identified. In these studies, effect modification was indicated for gender (increased risk primarily for males) employment status (increased risk for the unemployed), attitude towards the noise source (positive attitude possibly protective), exposure to other noise sources (increased risks in presence of more than one source) and annoyance (annoyed subjects seem to have a higher risk).

It is important to recognize that the confounding and effect modifying properties of the factors mentioned above may be related to type of study design, method for assessing outcome (self-reporting or objective measurements) and in which order the assessment of exposure and outcome are performed. To reduce the risk, intermediate factors in the causal pathway between exposure and outcome should be identified.

4.3.4 Additional analyses of Swedish data

To assess the confounding and interacting effects of air pollution on the association between road traffic noise and cardiovascular disease, we analyzed data from two existing Swedish studies.

4.3.4.1 Study populations and methods

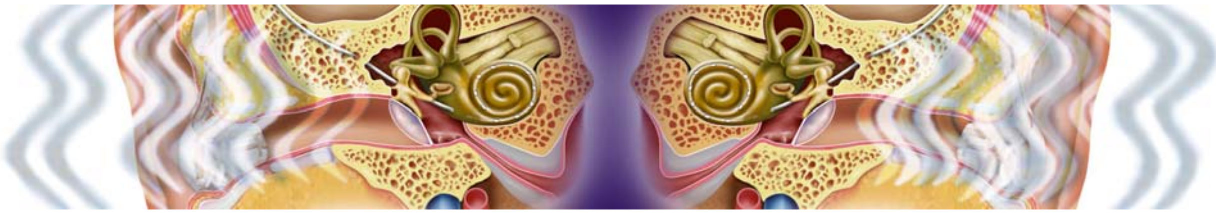
The "Roadside" study is a nation-wide cross-sectional study aiming at assessing cardiovascular health effects of living near busy roads and railways with regard to noise and air pollution exposure. Road traffic noise was expressed as the L_{den} level at the most exposed façade of a dwelling for 2598 subjects residing in the three major cities in Sweden (Stockholm, Gothenburg and Malmö). In these cities, strategic noise mapping had been conducted according to the EU directive (2002/49/EC). The exposure assessment was made by Geographical Information Systems, linking residential coordinates to digital noise maps. Questionnaire data regarding building and dwelling orientation in relation to nearby roads and railways were used to refine the level of exposure. Exposure to NO_2 and PM_{10} was assessed by dispersion modeling (SIMAIR) by the Swedish Meteorological and Hydrological Institute (Gidhagen et al., 2009).
The case-control study "ROOM" (Road traffic noise and myocardial infarction) was conducted to assess the risk of myocardial infarction (MI) in relation to long-term residential exposure to road traffic noise (Selander et al., 2009a). The study was based on the Stockholm Heart Epidemiology Program which was conducted in Stockholm County between 1992 and 1994. In total 1571 cases and 2095 controls were included. Road traffic noise levels were assessed for all addresses of each study subject from 1970 until the entry into the study. The 24-hour average A-weighted sound pressure level ($L_{Aeq\,24h}$) was assessed manually, using paper maps and area photos in addition to traffic information. Input parameters were distance and angles to nearby roads, number of vehicles and speed. The contribution of distant large roads (>20 000 vehicles per 24-hour period) were also accounted for. Time-weighted average NO_2 was used as an indicator of long-term exposure to traffic related air pollution. The exposure assessment was performed using the AIRVIRO dispersion modeling system in conjunction with retrospectively constructed emission databases (SMHI, 1993; Bellander et al., 2001).

The correlation between noise and air pollution was assessed by the Pearson correlation coefficient. In both studies, the associations between outcomes, exposures and additional covariates were assessed by logistic regression models. Effect modification was assessed by inclusion of interaction terms in the regression model or through stratified analyses.

4.3.4.2 Results

In the Roadside study, the correlation between L_{den} levels and NO_2 and PM_{10} was 0.43 and 0.38 respectively. In ROOM, the correlation between $L_{Aeq\,24h}$ and NO_2 was 0.60. Age and education were the only variables significantly related to self-reported hypertension and CVD. Diabetes, physical activity and smoking were found to confound the association between road traffic noise and MI. Adjustments for air pollution indicators did not affect the association substantially in any of the studies. However, a minor (7%) confounding effect was seen for fatal MI outside of hospital. No significant interaction between noise and air pollution was found, although the statistical power in the two studies were limited.

In conclusion, the correlation between air pollution and noise exposure is study specific and related to differences in exposure assessment methods and study area characteristics. Also the confounder and effect modifiers are study specific and must be evaluated according to the hypothesis under study and biologically plausible mechanisms.



4.3.5 Conclusions and recommendations

- Confounding and effect modification are important to consider in health related noise research.
- For cognitive outcomes socioeconomic factors are crucial to take into account. Effect modification by coping and psychological restoration may also be important.
- For cardiovascular outcomes socioeconomic factors are generally important as well. When road traffic noise is focused on, air pollution exposure needs to be taken into consideration.
- Socioeconomic classification should consider both individual and contextual confounding.
- Well validated methods are available for estimating individual air pollution exposure, primarily based on dispersion modeling or land use regression.
- There is a great need for further studies on interactions in relation to noise induced health effects, this may be important both for identification of susceptible subgroups and for setting priorities in prevention. As a minimum effect modification by age and sex should be investigated.

For a full overview on ENNAH WP 4 see deliverable D4.2 in the ENNAH's website.

Figure 8. ENNAH workshop on WP 4, 6-7 September 2010, Stockholm

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WP 5a: MEASUREMENTS OF HEALTH OUTCOMES IN EPIDEMIOLOGICAL STUDIES ON NOISE
&
WP 5b: EUROPEAN HEALTH IMPACT ASSESSMENT

4.4 Measurements of health outcomes in epidemiological studies on noise (WP 5a)

ENNAH's Work Package 5a was led by Francesco Forastiere of the Department of Epidemiology, Lazio Regional Health Service (Italy) in liaison with his collaborator Carla Ancona.

WP 5a focused on measurement of health outcomes in epidemiological studies on noise concerning the following issues: cardiovascular diseases, children's health, biological indicators, respiratory diseases, general health status, sleep and mental health.

The main aim of WP 5a was:

1. To discuss the improvement of the measurement of health outcomes relevant to noise research
2. To get consensus on standardized methodologies to be used in future studies on health effects of noise
3. To make recommendations for further research.

Specific Task Forces (TF) for this work package were organized according to the different outcomes. The TFs considered a conceptual noise-health effect framework and prepared a review of existing methods for health outcome assessment. The outcomes were selected based on comprehensive discussions during the Work Package 2 (WP 2) on the "Review of evidence of noise related health effects".

In the context of WP 5 two technical ENNAH workshops were organised on 22-23 November 2010 in Athens: WP 5a on measurements of health outcomes in epidemiological studies on noise and WP 5b on health impact assessment.

The agendas of these two workshops can be found in Appendix A of the present report.

During the first workshop (WP 5a) ENNAH partners discussed the measurement of health outcomes relevant to noise research including cardiovascular diseases, children's health, biological indicators, respiratory disease, general health status, sleep and mental health. For each specific health effect various aspects were considered, including the outcome definition and the available assessment tools, the existing diagnostic guidelines available, the usual ranges of prevalence and incidence rates, validity and reliability issues, and the main approaches already used in epidemiological research to assess the health effects of noise.

WP 5a was useful to identify gaps in knowledge and provide recommendations for noise effects assessment methods in health studies. The discussion highlighted the importance of scientific reports with standardized outcome definitions, making clear conceptual distinctions between short term and long term effects (air pollution studies were mentioned as a clear example of this distinction), conceptual overviews of the exposure-disease pathways, and proposals of plausible biological mechanisms of the effect.

It was concluded that the instruments used to measure the outcomes should be tailored for the specific age groups under study: infants, children, adolescents, adults, and the elderly.

Biological indicators should be used according to their intrinsic reliability and considering the possibility of well defined clinical interpretation of the results.

Emerging areas of research were identified for specific age ranges and groups:

- For children: perinatal disorders, growth hormones, puberty, sleep disorders
- For adults: fertility, reproductive disorders, diabetes, secondary hypertension
- For the elderly: diabetes, Transient Ischemic Attack, stroke.

4.4.1 Cardiovascular diseases

The main cardiovascular outcomes considered were: Blood Pressure (BP)/ Hypertension; Nocturnal BP, BP dipping; Heart Rate, Heart Rate Variability; Coronary Artery Disease (CAD); Angina Pectoris; Acute Myocardial Infarction (AMI) ; Intima-Media Thickness (preclinical CVD). For each outcome, definition, assessment tools and exclusion criteria were presented and discussed.

In particular the issues related to BP were examined: when and in which conditions to measure it (i.e., home versus work), the variability of the measurement, how often nocturnal BP has to be measured, which is the right definition of hypertension, WHO definition versus self-reported doctor-diagnosed hypertension or self-reported use of antihypertensive treatment, threshold issues, and BP dipping.

For Angina pectoris and AMI, issues related to the standardization of diagnoses and their validity were tackled. For AMI we have to deal with a change of definition over the years: in the past it was a combination of two of the following: typical symptoms (chest discomfort), enzyme rise (total CK, CK-MB, AST, LDH), and typical electrocardiogram (ECG) pattern, while the current definition provides a typical rise and gradual fall (troponin) or more rapid rise and fall (CK-MB) of biochemical markers of myocardial necrosis with at least one of the following: a) ischemic symptoms; b) development of pathologic Q waves on the ECG; c) ECG changes indicative of ischemia (ST segment elevation or depression); or d) coronary artery intervention (e.g., coronary angioplasty).

The main points of the general discussion were:

- Consider whether short-term or long-term effects.
- Ranking by quality of the study is not easy.
- Investigate whether spot measurements add information over questionnaire data.
- In surveys, explore non-participation rates and potential selection bias; also by socioeconomic status (SES).
- Quality of registry data often not known.
- Registry data; differences in coding hospital discharges.
- In registry studies, consider out of hospital cardiac arrest.

- Specific protocols needed for BP measurements.
- Continuous recording instruments for blood pressure are not well suited for epidemiological studies (affected by movements). New instruments are becoming available.
- Self reporting of BP could be biased.
- Too many measurements (8/12 in guidelines per visit; impossible in field studies). How many and which measurements have to be used?
- Need for BP Guidelines in children.
- White coat effect has to be taken into account, also for children.
- TIA and Stroke should be investigated.
- New methods/technologies for continuous BP monitoring should be evaluated.
- IMT is related to hypertension and worth studying.
- The role of revascularization to define frequency of cardiovascular disease (CHD) should be evaluated.

4.4.2 Biological indicators

The noise/stress hypothesis was presented: noise activates the pituitary-adrenal-cortical axis and the sympathetic-adrenal-medullary axis. Changes in stress hormones including epinephrine, norepinephrine and cortisol are frequently found in acute and chronic noise experiments. The catecholamines and steroid hormones affect the organism's metabolism. Cardiovascular disorders are especially in focus for epidemiological studies on adverse noise effects. The main physiological indicators and the relative diagnostic methods were presented: brain activity (EEG), ocular activity (EOG), cardiac activity (ECG), respiratory activity, muscular activity (EMG), electric skin response (EDR), endocrine activity (catecholamines, cortisol, thyroid), and immunoactivity (immunoglobulins, cytokines, lymphocytes, etc.). During the talk special emphasis was given to cortisol and catecholamines. Some caveats were mentioned during the presentation: the uncertainties in qualifying and quantifying noise exposure, the difficulties in separating effects of noise from other factors (confounders and/or modifiers), the lack of homogeneous criteria for quantifying outcomes, secretory patterns of hormone excretion vary between individuals and are subject to pulsatile bursts and circadian rhythms, high inter- and intra-individual variability in noise sensitivity, coping strategies, and vulnerability to stress and difficulties in connecting short-term responses to long-term effects.

During the discussion, the following key points emerged:

- Response to stress is immediate with or without annoyance. There is a direct effect on the alarm phase. The problem is the repetition of the stimulus. The perception is important in relation to the adaptation of the response.
- Population differences for cortisol.
- Cortisol in urine, saliva, and hair.

- Cortisol awaking response (CAR) - but the specific meaning should be clarified (anticipated response, adaptation to night work).
- Blood lipids and inflammatory markers should be studied.
- Prolactin is a secondary stress hormone. Consider also dopamine and serotonin.
- Additional outcomes: Growth and growth hormones, puberty, menstrual cycle, fertility.

4.4.3 Children's health

A comprehensive overview of the health effects of noise in children was provided. The main outcomes used in epidemiological studies on noise exposure and children's health were presented and discussed such as hearing loss, annoyance, sleep disturbance, hormonal changes, CVD, cognitive effects and mental health. For each outcome, definition, ICD codes, prevalence data, existing guidelines/references, main conclusions, and recommendations were presented.

Effects of aircraft noise on children cognitive outcomes have been most extensively studied: Munich Airport study (memory deficits and reading comprehension); RANCH study (impaired reading comprehension and recognition memory); Tyrol Study (effect on intentional and incidental memory smaller than found around airports). While studies have established noise effects on annoyance, complex cognitive tasks and sleep disturbance, relatively few studies have examined the effects of noise on child mental health: Haines et al., 1997; Stansfeld et al., 2009; Lercher, 2006; Ristovska et al., 2007; Evans et al., 1998.

OHRKAN – An epidemiologic study on hearing in adolescents

Several studies in Germany have investigated the effect of noise on hearing loss. The OHRKAN study, its methods and some preliminary results were presented. This study had three objectives: the description of the hearing ability in adolescents; estimation of the prevalence of risky behaviour; and identification of risk factors for hearing loss. It is a cohort study which considers pupils of 14 and 15 years old from 2009 to 2011 with a consecutive follow-up planned for up to 10 years. There was a high response rate among schools, and data collection continued until July 2011.
Main points emerged from the discussion:

- Cognitive function – reading and memory are the most important. No standardized memory test exists but country specific ones could be used.
- Conceptual work to be done on all the health outcomes (especially on mental health).
- Distinguish between acute and chronic noise exposure.
- Night time exposure is important.
- Age ranges are important, most of the evidence relates to the age range 8-14 years. Perform more studies on adolescents and below 8 years.

- The health effects of personal audio devices should be investigated, also in relation to other potentially harmful activities (e.g. drug abuse).

4.4.4 Respiratory diseases

Main results from the WHO Large Analysis and Review of European housing and health Status (LARES) study were presented. Advantages and disadvantages of the main outcome assessment tools in respiratory epidemiology including questionnaires, registration of diagnoses made by clinicians, and functional measurements or tests (spirometry and peak expiratory flow) were discussed.

Special emphasis was given to asthma. It was in general supported that asthma should be included as an outcome in future studies on noise effects. It was stated that current evidence on the association between noise and asthma is weak. The following reasons have been discussed: 1) in studies on traffic noise confounding by air pollution is a serious problem. Air pollution is known to be a trigger of asthma attacks. In addition it might increase the risk of developing asthma but evidence on this issue is unclear; 2) cross-sectional studies on the association between traffic noise annoyance and asthma (such as LARES) are prone to reporting bias: physically ill subjects are more likely to report noise annoyance. High noise exposure may lead to awakening during the night. Awakened subjects are more likely to perceive asthmatic symptoms at night; 3) the mechanism of a noise effect on asthma is unclear. In general noise is believed to cause a stress response in humans which causes stress hormones to increase. However, these hormones (noradrenaline, cortisol) are substances which are used in medications to relieve symptoms of asthma. Therefore it seems unlikely that the stress reaction is related to asthma; 4) an increased noise annoyance in subjects with asthma may be due to increased noise sensitivity. No studies on noise sensitivity in subjects with asthma are known.

For new studies on asthma the following recommendations were made:

1) To separate the effects of traffic noise and traffic related air pollution. The mechanisms of noise and air pollution effects should be considered. Noise effects are usually mediated by the stress reaction while air pollution effects are usually mediated by inflammation;

2) To conduct cohort studies among individuals with asthma to evaluate prospectively the effects of noise. There is a group of researchers in Portugal working in “vibroacoustic disease”. This is a pathology observed among subjects exposed to very high levels of noise, particularly to occupational exposure to low frequency noise. Respiratory symptoms might be included in this pathology. However, “vibroacoustic disease” is not an accepted disease and the credibility of this concept is unclear.

The conclusions drawn were:

1) Questionnaires are a convenient tool to assess respiratory symptoms provided that there is clear and widely accepted definition of the outcome;

2) When studying the relation of exposure to asthma or asthma-like symptoms, an operational definition should include both clinical physiological findings and a clinical history;

3) When studying the relation of exposure to asthma or asthma-like symptoms questions with very high specificity (>99%) should be used, and

4) Peak expiratory flow monitoring could be a valuable and helpful tool to examine whether noise exposure trigger symptoms in asthmatic patients.

Key points emerged from the discussion:

- Difficult to separate noise and air pollution effects. Potential interaction of noise stress and air pollution.
- Diagnosis difficult but standard methods are available.
- Respiratory symptoms questionnaires have been developed (ECRHS, ISAAC).
- Asthma is not a single disease; low sensitivity of current instruments but high specificity. Better to use instruments with high specificity.
- PEF and lung function tests are standardized.
- Mechanisms should be studied further in relation to catecholamines, cortisol and immune function. Neuronal reflex could be involved.
- Follow specific asthmatic cohorts to evaluate noise as a trigger for short term effects.

4.4.5 General health status

The issue about the “Comprehensive lower level health related endpoints - health status and environmental Quality of Life” was presented. It was highlighted that neither the stress response theory nor the general health outcomes deal with the effects of lower levels of noise exposure (this relates to noise levels below the current END noise mapping limits: L_{den}<55 dBA). However, the perception of lower levels of environmental noise exposure is an important contributor to the overall judgement of quality of life. Furthermore, it is unclear how lower levels of noise would have an impact on health over a long time scale. It was also noted that lower noise level does not necessarily have a negative effect on the human body (e.g. *restoration in quiet zones).*

The measurement of quality of life (health related and environmental) and wellbeing would result in a better understanding of how noise and annoyance is related to health status and whether an intervention would change health. Several measurement methods were presented. A clear distinction was made between health-related quality of life and health-related environmental quality. It was concluded that:

- Comprehensive lower level health indicators should be more often utilized in noise surveys
- Environmental quality of life needs to be included in a perspective that addresses sustainability and positive health

- A multi-sensoric assessment would be more appropriate than a mono-sensoric one, and
- A single factor approach is not sufficient in environmental health assessment; quality of life concepts are more suitable to establish differences between communities.

During the discussion the WG 5a members agreed that investigating the health endpoints related particularly to lower levels of noise exposure is necessary, especially regarding to annoyance. Currently there are some questionnaires about quality of life, but a standardised measurement method is needed. It was also discussed whether vitality or fatigue could be an indicator of noise effects - therefore it might be useful to include this in the health outcome investigations. The question about the length of the latency period of low level noise induced health problems was addressed.

Key points emerged from the discussion:

- The real meaning of annoyance should be further evaluated: it might be only the perception of the exposure per se or it could be a health effect.
- There is gap in the interpretation of the distinction between annoyance and real diseases. These items go into "Perception related research" and "Protection of life quality".
- Perceived health status has been largely used in surveys. It is a good predictor of future mortality. It is also an indicator of health related quality of life and health care needs.
- More multidimensional and holistic measures should be developed.
- The "Environmental Quality of Life" index represents a useful measure for comparison across countries.

4.4.6 Sleep

Sleep disturbance is one of the most common complaints raised by noise-exposed populations, and it can have a major impact on health and quality of life. The physiological reactions due to continuing noise processing during the night time lead to primary sleep disturbances, which in turn can impair daytime functioning. The noise-induced sleep disturbances hypothesis was discussed. Noise affects sleep in terms of immediate effects (e.g., arousal responses, sleep stage changes, awakenings, total wake time, autonomic responses) and after effects (e.g., self-reported sleep disturbance, daytime performance, cognitive function deterioration). Sleep disturbances can be measured electrophysiologically, using the so-called polysomnography (PSG), or epidemiologically, using survey questionnaires. Polysomnography, i.e. the simultaneous recording of the electroencephalogram (EEG), the electro-oculogram (EOG), the electromyogram (EMG), and other physiological variables remains the gold standard for measuring and evaluating sleep. Even shorter activations (≥3 seconds) in the EEG and EMG, so-called arousals that would not qualify to be scored as an awakening, can be detected with the polysomnogram. These arousals are usually accompanied by cardiac activations that may be responsible for long-term adverse health effects of noise on the cardiovascular system. However, polysomnography also has some disadvantages. EEG, EOG, and EMG electrodes and wires are somewhat invasive and may influence sleep. The instrumentation of subjects is cumbersome and cannot be done by the subjects themselves. Finally, sleep stage classification requires trained personnel and is known to have high inter- and intra-observer variability.

Vulnerable groups:

1) Children have higher awakening thresholds than adults and therefore are often seen to be less sensitive to night noise. However, children are developmentally in a very sensitive phase and relatively minor sleep disturbances may have detrimental effects for the development of the child. Additionally, children also spend more time in bed and usually go to bed and get up during busy 'shoulder hours'. For these reasons children are considered a risk group.

2) Shift workers are at particular risk. They must sleep during the day at an adverse phase of their circadian rhythm, which already causes a partial sleep deprivation by two to four hours. In addition, daytime equivalent noise levels are 8 to 15 dBA higher compared to the night. However, little is known about the contribution of noise to the sleep disturbances of shift workers.

Key points emerged from the discussion:

- Primary effects: alteration of sleep structure (latency to the first sleep, number of arousals, time in slow-wave sleep). Number of noise-related awake periods increases (decrease of normal awake periods).
- After-effects: low performance (fatigue and sleepiness), memory consolidation and increase in reaction time.
- Long-term effects: CVD of multifactorial origin. Non-specific alterations and no habituation.
- Chronobiology: reduction light and noise amplitude and reduction of the physiological amplitude of melatonin and cortisol.
- Autonomic reactions depend on the type and time of noise.
- Sleep recording method of choice.
- Questions of sleep quality and disturbances and objective measurements. Methodology not well-standardized.

4.4.7 Mental health

Assessment of mental health/psychiatric disorders is based on clinical assessment and elucidation of symptoms. Mental health outcomes studied included psychiatric hospital admission rates, psychological symptoms, screening questionnaires for psychological distress, standardised psychiatric interviews, use of prescribed and non-prescribed medicines, and use of health services. A comprehensive literature overview on environmental noise and mental health and their measures was provided. Some examples of how to measure chronic and acute psychological symptoms both in adults and children were presented. Psychological symptoms are usually measured using questionnaires: different scales and questionnaires for psychological distress were presented. The issue of the validation of screening questionnaires against interviews was discussed.

It was concluded that:

- The gold standard assessment of psychiatric disorder is the standardized interview, despite the fact that it can be expensive and time consuming for large samples.
- Specific, validated self-report questionnaires for depression and anxiety can be very useful in large studies.
- Measures of mental health should be backed up by other measures like prescribed medication, salivary cortisol, and health service attendance.

Key points emerged from the discussion:

- Hospital admissions: it is a valid indicator especially for patients with more severe conditions but also likely to be influenced by other factors e.g. socioeconomic status
- List of Symptoms: acute (tinnitus) and chronic. Response bias and negative affectivity (complain about environment and disease). Attribution effect.
- Screening Questionnaires: very general, provide no diagnoses (e.g. GHQ).
- Specific symptoms Questionnaires (acute and chronic depression and anxiety): can be a good way to measure depression or anxiety but more difficult to assess whether disorder reaches thresholds for clinical caseness.
- Well being scales: positive mental health.
- Validation of questionnaires against interview usually show a high false positive rate, especially when the prevalence of the health condition is low.
- Standardized psychiatric interview: number and severity of symptoms, response rate may be low.
- Can be administrated by face-to-face interview, (also in CAPI), if there are few symptoms this can be done in a short time, with symptoms it will be longer.
- Use of medication: prescriptions and self prescribed.
- Standard instruments for children (9+ years): more than one measure is better in children (get information from parents or teachers as well).
- Age differences: specific studies in elderly are missing (long care facilities). Noise is not less disturbing for the elderly.
- Gender differences and marital status.
- Post-partum depression.

4.4.8 Conclusions and recommendations

- It is important to provide standardised outcome definitions and use appropriate terms in scientific reports and peer reviewed papers.
- Need for a clearer conceptual distinction between short-term and long-term effects (as in air pollution studies). Research on incidence of diseases should be separated from research on aggravation of pre-existing conditions.
- Need for a conceptual overview of the exposure-disease pathways for some disorders/diseases.
- Plausible biological mechanisms should be postulated before including a noise related health outcome.
- The instruments should be tailored for the specific age groups under study (infants, children, adolescents and the elderly).
- Consider risk of recall bias for self-reported disorders versus complexity of measurements with a potential low response rate.
- For acute effects laboratory studies are worthwhile but application in the field is essential to establish an association under realistic conditions. Need more research for long term effects.
- Although some outcomes have been already relatively well-studied in experimental settings, application in field studies (in every day life) would be desirable, especially for acute health effects, in particular for people with chronic diseases.
- Evaluate the effects of interventions and remedial actions. It can be useful also for etiological studies.
- New biological indicators are proposed: prolactin, blood lipids, inflammatory markers, and serotonin.
- Biological indicators should be used according to intrinsic reliability and consider the possibility of a well defined clinical interpretation of the results.
- Stress and coping model is a well established framework for noise.
- Use already on-going cohort studies (add noise component/assessment).

Emerging areas of research were identified for specific age ranges:

- *Children*: perinatal disorders, growth hormones, puberty, sleep disorders
- *Adults*: fertility, reproductive disorders, diabetes, secondary hypertension
- *Elderly*: diabetes, transient ischemic attack (TIA), stroke.

For a full overview on ENNAH WP 5a see deliverable D5.3 in the ENNAH's website.

Figure 9. ENNAH Workshop 5, 22-23 November 2011, Athens

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4.5 European Health Impact Assessment (HIA) (WP 5b)


ENNAH Work Package 5b was led by Nino Kuenzli of the Swiss Tropical and Public Health Institute in liaison with his collaborator Laura Perez.

WP 5b focused on noise Health Impact Assessment (HIA) and discussed approaches and methods for health impact evaluation on noise with the aim of reaching consensus on some criteria for conducting health impact assessment for noise in Europe and identity data gaps.

HIA is a methodology to evaluate the health impacts of policy scenarios or actions and has been proved very useful to bridge science and policy to reduce environmental exposures. The ENNAH WP 5b, gave an opportunity to bring together experts active in the noise HIA field in Europe, and compare approaches and methods currently used in HIA with the ultimate scope to recommend common criteria for conducting a European-wide HIA evaluation.

During the workshop, several examples of noise HIA currently conducted in Europe at local and multinational level were presented as support for the discussion of criteria and identification of needs.

All the examples indicated that there is already an existing standardized framework for performing calculations of attributable cases and Disability-adjusted life years (DALYs) for some specific noise outcomes for which sufficient evidence exists to suggest causal adverse effects, such as annoyance, sleep disturbance, cardiovascular disease (hypertension, angina or myocardial infarction). Because annoyance has been shown to constitute the largest burden for noise, there is a need for developing more meaningful aggregated indicators of health and well-being into the noise HIA process (e.g quality of life and cardiovascular measures).

The role of vulnerabilities (what sub-groups of the population are most susceptible or otherwise) will need special consideration in quantification. It has only been minimally integrated in current evaluations, although this is of primary relevance for European wide policy. While there is lack of sufficient epidemiological evidence to fully evaluate vulnerabilities, workshop discussions helped to identify some areas of priority such as evaluating impacts for different socio-economic groups or integrating reading disability in children as new HIA indicator.

The multinational examples presented during the workshop also provided an overview of some difficulties one will be faced with in large scale assessments in relation to comparability of exposure and other input data needed. For example, the analysis of data, gathered during the first round of strategic noise mapping in the context of the European Environmental Noise Directive (END), present problems of comparability and inconsistency between different countries for a number of reasons, yet the actual data cover only a relatively small percentage of the European population.

However, future data will be of better quality and will be a great asset for European wide HIA, when a harmonised methodological framework for noise assessment (CNOSSOS-EU) will become available in Europe (Kephalopoulos et al, 2012).

A Europe-wide evaluation will thus require developing proxy measures of noise exposure, especially for non-urban areas. Similarly, standardized methodologies will be needed to distribute modelled noise levels from END maps to population in buildings taking into account regional urban differences. The latter has been recently undertaken formally by the European Commission (DG ENV, DG JRC) and the EU Member States as one of the tasks of the CNOSSOS-EU process.

4.5.1 Overview of ongoing HIA European activities

Several projects or programs related to the evaluation of the impact of environmental noise exposure are ongoing in Europe. These include among others:

The Environmental Burden of Disease (EBD) project which is led by the World Health Organization (WHO) and deals with evaluation of the burden of disease related to the environmental noise exposure in Europe.

The project on "Common NOise ASSessment MethOdS in EU" (CNOSSOS-EU) which is co-ordinated by DG JRC on behalf of DG ENV with the objective to provide technical advice on the preparation of the common European assessment methods to be used by the EU Member States for strategic noise mapping after adoption as specified in the Directive 2002/49/EC.

Two major interrelated European projects, HEIMTSA ("Health and Environment Integrated Methodology and Toolbox for Scenario Assessment") and INTARESE ("Integrated Assessment of Health Risks of Environmental Stressors in Europe") that brought together internationally leading scientists in the areas of epidemiology, environmental science and biosciences to collaborate on developing and applying new, integrated approaches to the assessment of environmental health risks and consequences, including noise, in support of European policy making on environmental health.

The many different working groups of experts created during the aforementioned projects have helped develop the current framework for the noise HIA methodology. Several of these experts also participated in ENNAH workshop WP 5b.

A European-wide HIA should thus build on these existing experiences. The discussions undertaken and the conclusions drawn during the ENNAH Workshop 5b were formulated and principally based on documents prepared in relation to ongoing projects and programs related to HIA and listed in the reference section of the present report. This especially includes the recent WHO-JRC report on 'Burden of disease from environmental noise' (WHO–JRC, 2011) and 'Good practice guide on noise exposure and potential health effects' (EEA, 2010) issued by the European Environment Agency (EEA). Because all the methodological details can be found in these reports, in the following focus will be only on key methodological aspects and uncertainties discussed during the workshop with the objective to further help the identification of specific needs to move the noise HIA methodology forward and help minimising the noise related health impact in Europe.

4.5.2 HIA methodological approach

General methodological approach

For most health outcomes, the HIA methodology proposed is based on deriving a population attributable fraction (PAF). This approach uses the exposure-response function (i.e. the quantitative association between noise exposure and some health outcome) obtained from epidemiological studies and the distribution of noise exposure within the study population to estimate the fraction of disease in the population that is attributable to noise. The PAF is then applied to the disease estimates in the population. For some noise-related outcomes, such as sleep disturbance, tinnitus or annoyance, it is possible to estimate the burden directly through local, national or international surveys. With this approach, an estimate of the prevalence of the outcome attributable to different environmental noise levels would only be necessary.

Selection of outcomes and exposure-response functions (ERFs)

Based on the review of the evidence, on-going projects have recommended sleep disturbance, annoyance, hypertension, myocardial infarction, and tinnitus as health end points to be included in the HIA. There is also sufficient evidence to consider cognitive impairment in children, although the interpretation and communication of results in relation to the burden of the long-term effects may be difficult. No meta-analytic ERF for sleeping medication use has been proposed so far but its potential use as an indicator of psycho-social effects is attractive. Evidence for hearing impairment due to leisure noise, especially among adolescents listening to music with MP3 devices, has been considered not adequate enough to be incorporated in HIA already, but its consequence both in terms of audition for adolescence and potential social isolation may be relevant for public health and deserves further research for burden quantification.

A major limitation of the existing evidence on the health effects of noise exposure is a general lack of coverage of different noise sources. Thus, the current HIA methodology proposes transposition of ERFs from one source to another, with the related uncertainties that this implies. Further research is needed to develop ERFs for most relevant outcomes and type of sources, such as traffic.

The influence on health effects from the pattern of noise events (i.e. sleep fractionation due to repeated noise events) has not yet been explored in ERFs and its potential consequence in terms of latency of effects or leading to a differentiation between short-term and long-term effects is unknown. Similarly, differences in exposure due to living in a high or low background and interaction of co-exposures, such as air pollution, may also be relevant in the association with health effects, but have not been adequately evaluated so far. A better understanding of these issues is important for the development of protective policies.

Population exposure

To evaluate population exposure, the current approach uses the strategic noise mapping in the first reporting phase of European Environmental Noise Directive (2002/49/EC, "END", processed in 2007). END maps should have the advantage of being comparable between different countries to a large extent especially for 'hot spots' of noise. Common indicators of END maps include L_{den} (day-evening-night equivalent level) considered as an appropriate metric to assess annoyance and L_{night} (night equivalent level) considered as a metric to assess sleep disturbance.

The analysis of data gathered during the first round of END has shown problems of comparability and inconsistency between different countries. The actual data covers also only a relatively small percentage of the European population because the maps are mostly developed for large urban areas. Spatial averaging of modelled noise levels over more than a few metres is not acceptable either. Hence the large experience built up in the scientific community regarding EU-wide air pollution modelling is of limited use for noise assessment. A European-wide evaluation will thus require developing proxy measures of noise exposure, especially for non-urban areas. Similarly, standardized methodologies will be needed to distribute modeled noise levels from END maps to populations in buildings taking into account regional urban differences.

The latter has been recently undertaken formally by the European Commission and the Member States as one of the tasks of the CNOSSOS-EU process. Thus, future END data will be of better quality and will be a great asset for European-wide HIA. One should however be aware of additional potential heterogeneous modeling and the reporting level of the different countries. For example, many countries partly lack L_{night} data in reporting. Recalculation from L_{den} is possible but problems with validity of recalculations may exist (e.g. L_{night} in rural areas is much lower and there may be sleep pattern differences between regions). The indicators proposed in END may also differ from the indicators used in the ERFs which may limit the validity or conduction of the risk assessment altogether. The future review of END is expected to propose a larger range of indicators, but matching with newer evidence from ERFs that may use yet different noise indicators because of biological plausibility, for example, may not always be possible.

Target noise levels and scenarios on exposure changes

There is relative agreement on target levels to achieve based on current epidemiological evidence. A L_{night} of 40 dB has been proposed by WHO and a L_{den} of 50 dB by the EEA. There is however a need to optimize and prioritize policy scenarios in the risk assessment evaluation, for example, to better understand the benefits of noise dilution around 'hot spots' against the risks of having more people affected, to take into account differences in sleeping habits between regions, and to consider new sleeping patterns (changes in time of sleep and duration of sleep) that are occurring in the population.

Risk quantification

The current burden calculations are mostly expressed in Disability-adjusted Life Years (DALYs) using published disability weight (DW) such as those compiled by the WHO. DALYs are very sensitive to choices of DW. This may affect especially non-direct health outcomes such as annoyance and sleep disturbance, which constitute the largest part of the burden in all noise HIA conducted so far. There is no good understanding of the health impact that these outcomes may represent or which vulnerable groups are more affected and why. When evaluating the total burden for different health end-points, issues of double counting may thus also arise. Due to these limitations, it would be convenient to consider developing more integrative objective and subjective quality of life outcomes. Similarly, exploring the integration of population level cardiovascular risk scores in the risk assessment methodology could also benefit the development of better prevention strategies for modifiable risk factors such as noise. There is large heterogeneity in the availability of health data across EU countries, and data to develop these indicators may not be available at this point. Small-scale noise surveys on annoyance and sleep disturbance have shown large regional differences. Taking into account contextual differences seems to be an essential task for the design and implementation of appropriate noise preventive or protective measures. Conducting local surveys may be necessary to capture these setting-specific differences.

The translation into costs may be a necessary step within a European-wide evaluation of environmental noise burden. HEIMTSA has now provided a noise valuation review and recommendations for use which is available online. Several endpoints are covered including acute myocardial infarction, hypertension, sleep disturbance and annoyance. While a stated preference approach is recommended, the uncertainty in the monetary valuation is still substantial because of lack of data for central and eastern European countries and for some specific relevant outcome (i.e. cognitive development), and a need for better evaluation of cost of sleep disturbances in relation to loss of productivity.

Current risk quantification ignores the broader context of noise exposure such as related non-noise effects, and other societal impacts and qualitative aspects that should be part of a HIA.

Finally, exploration of alternative communication of results (e.g. noise protection zones) based on the results of risk assessment could also be useful tool for population and decision-makers.

Vulnerabilities

Current evaluations are generally based on adult populations and, due mostly to a lack of existing ERFs, have ignored sub-groups of the population that may be more susceptible or otherwise will need special consideration in quantification. While middle aged populations may be altogether more susceptible to sleep disturbances and related health consequences, it is not the case for some specific outcomes like cognitive development in children that will need a separate evaluation. In adults, gender, co-morbidities, co-exposure and other lifestyle factors may interact in the association with noise. A larger comparative risk assessment framework would identify which vulnerable risk group would benefit or be most impacted by hypothetically changing a set of modifiable factors, including noise, in accordance with future policies or preventive programs. But this requires the development of more complex population vulnerability profiles, based on relevant characteristics and factors predicting disease that need to first be identified at the individual level. As a beginning for a European wide HIA on noise, it has been recommended to evaluate exposure for different socio-economic groups to support some first-hand policy decisions.

4.5.3 Conclusions and recommendations

- The criteria for an European wide HIA should be built on the existing experiences from other major European projects, and integrate a systematic identification and description of key uncertainties and limitations in the identification of specific needs to move the noise HIA methodology forward and help minimise noise impact in Europe.
- For comparison and consistency purposes a European-wide HIA could be applied as such, although further research and methodological development, overlapping with those identified in other ENNAH workshops, are needed. For example, methods for expanding the coverage of the noise data available for the European population are needed.
- The strategic noise mapping in the context of the END provides an opportunity to perform a European-wide burden calculation of the long-term health effects of noise.
- Based on several expert working groups, a methodology to evaluate DALYs has already been developed for several health end-points.
- Because annoyance and sleep disturbance, two "soft" health outcomes, have been shown to constitute the largest noise burden in past evaluations, the development of aggregated indicators of health and well-being (e.g quality of life and cardiovascular scores) would prove meaningful to evaluate setting and implementing specific policy options.
- The role of vulnerabilities or what sub-groups of the population are most susceptible will also need a special consideration, an issue only marginally integrated in current evaluations. Of special priority is the evaluation of impacts for different socio-economic groups to take into account setting-specific co-exposures and environmental justice.

For a full overview on ENNAH WP 5b see deliverable D5.3 in the ENNAH's website.

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WP 6: NEW STRATEGIES FOR NOISE AND HEALTH RESEARCH IN EUROPE

4.6 New strategies for noise and health research in Europe (WP 6)


ENNAH Work Package 6 was led by the ENNAH project co-ordinator Stephen Stansfeld of Queen Mary, University of London and deputy co-ordinator Charlotte Clark.

The objectives for ENNAH WP 6 were as follows:

Objectives

1. To synthesise the data on needs for new research, new noise exposure techniques and measurement of moderating factors and health outcomes.
2. To exchange information from ENNAH WPs 2 to 5 to develop new research strategies for noise and health.
3. To model specific mechanisms linking environmental noise and health outcomes.
4. To formulate new hypotheses linking noise exposure and health outcomes to be investigated in future research.
5. To discuss and refine research designs to answer key research questions.
6. To brainstorm new ways of developing research designs and collaborations for future studies.

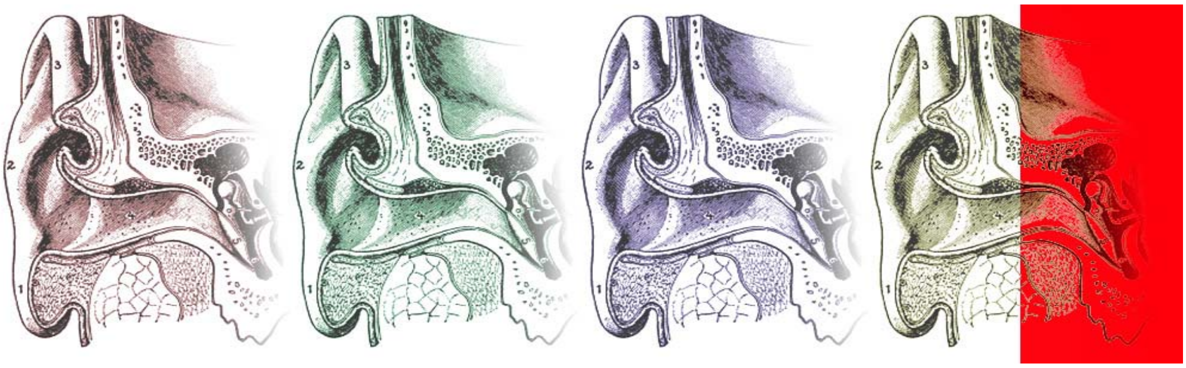
ENNAH WP 6 organized a workshop, which helped to bring together outputs from the earlier workshops organised in the context of the ENNAH project with the purpose of developing new strategies for noise and health as the primary outcome of the ENNAH network. This took into account the existing state of knowledge and gaps in understanding on noise and health. Areas were identified where future research will probably yield useful results for policy and scientific knowledge. The development of new techniques for assessment of noise exposure, including large scale noise mapping across Europe gives greater scope for the development of novel research designs involving large populations linking noise exposure maps and health register data. However, as it was already recognised in earlier workshops, this does require high quality noise map data which is standardised across different European countries. Another focus of the workshop was to try and develop better specification of physiological models that underly the associations of noise and health outcomes. This can help to formulate critical hypotheses for use in further research in testing health effects.

Therefore, this workshop helped to develop a number of research recommendations, which will be discussed more in detail later in the text and also summarised shortly in the concluding part of the present report.

It was an important imperative to strengthen the evidence base for the effects of environmental noise on chronic disease outcomes and also reduce the widespread impact of environmental noise on annoyance and quality of life. The priority was given to those research recommendations which were related with more severe health effects such as on cardiovascular morbidity, but also to include those very widespread effects on annoyance, children's cognition, mental health and sleep disturbance which affect a very large number of EU citizens.

Some cross cutting themes were identified that were relevant across the range of health outcomes. There is clearly a need for more robust assessment of exposure effect relationships for different samples including vulnerable groups and using different noise metrics. Many of the current studies examining noise and health are cross-sectional. There is a problem with these studies because you cannot easily attribute causality and it is difficult to assess issues of selection of people in and out of the area related to noise exposure. Thus, there is a need for longitudinal cohort studies that examine noise exposure at baseline and follow subjects up and observe health effects over time. Moreover, there is a need for very practical studies that assesses the health benefits of interventions to reduce noise exposure. Only in this way can we test whether interventions that reduce noise may also help to reduce annoyance and health effects.

Very many studies focus on energy averaged measures of noise level. In recent studies there has been less of a focus on the number of noise events or on peak sound events that may be relevant for particular health outcomes. Also in longitudinal studies there needs to be more focus on the duration of noise exposure, because duration of exposure to a stressor is likely to be relevant in the causation of chronic disease. Future research should also examine the effects of combined noise sources on health outcomes as well as the effects of noise in combination with other environmental stressors including air pollution. For too long research in air pollution and noise has been carried out separately. Sources such as road traffic are responsible for both noise and air pollution simultaneously. There have now been studies that have included both of these pollutants and their effects but there is scope for more studies in this area to try and disentangle the relative contributions of noise and various types of air pollution. In the future it is also going to be important to look further at potential factors that moderate the effect of environmental noise on health. In the past there has been research on noise sensitivity and the identification of vulnerable groups to noise effects, but there is more that could be done in this area. Finally, a more detailed specification of the underlying biological mechanisms for noise and health effects can help to formulate the future hypotheses that can be used to test health effects.



4.6.1 New directions for noise and coronary heart disease research

The evidence brought together in ENNAH WP 2 suggests sufficient evidence of an association between long term noise exposure and cardiovascular disease. Most studies have primarily investigated road traffic noise and aircraft traffic noise. The question to answer is - at what magnitude are effects seen and at what empirically detectible cut off level?

<u>Specific EU policy implications</u>

- The Environmental Noise Directive (END) indicates that environmental noise action plans should be developed to reduce the harmful effects of noise exposure and its Annex 3 states that dose effect curves should be used to assess the effect of noise on populations. Thus while the END relates primarily to exposure assessment, efforts should be put into establishing consistent and robust exposure-response relationships between environmental noise and cardiovascular outcomes.
- In terms of noise exposure assessment indicators, the conclusions from ENNAH WP 3 suggested that END proposed indicators, L_{den} and L_{night}, (L_{eq} based indicators) should be used to study chronic effects of noise on health. Possibly, in addition to these standard metrics, this could include non-weighted L_{eq} for health endpoints as well as considering event-related measures such as L_{max} and SEL. Noise maps are continually developing and noise propagation models are well developed.
- The results of some discussed Swedish studies (Rosenlund et al., 2006; Selander et al., 2009) suggest that future research should develop and test the European END maps in epidemiological studies. END maps can be used for assessment of individual residential traffic noise exposure, but to enhance precision information on exposure, exposure-moderating factors must also be taken into account. Automated methods may be used, but should be supplemented by questionnaire data.

Future research challenges

- Preliminary exposure-response curves are available for road traffic noise in relation to myocardial infarction (Babisch, 2008), for aircraft noise in relation to hypertension (Babisch and van Kamp, 2009) and for road traffic noise in relation to hypertension (van Kempen and Babisch, 2012). There is a need to improve the precision of existing exposure-response curves by carrying out further studies and periodically summarising existing work including further studies using meta-analysis.
- Considering health endpoints in ENNAH WP 5, refinement is needed for the estimated exposure-response functions for previously studied cardiovascular endpoints (blood pressure, MI). In the conclusion of this work package it was considered that only disease specific morbidity and mortality should be examined, including disease specific confounders in analyses. Standardised reliable and valid questionnaire assessment of cardiovascular outcomes should be used, but ideally clinical measurements should be prioritised. The main emphasis probably should be on classical cardiovascular end points to strengthen and update existing exposure-response curves which are most important for health impact assessment. Ischaemic heart disease (coronary heart disease) should include myocardial infarction and hypertension with stroke as a new end point. Stress indicators and intermediate variables may be valuable to identify mechanisms and pathways and high risk groups.
- Another important aspect to consider is the effect of differences in day and night time exposure to noise and the impact of noise on sleep disturbance and subsequently on health. Hence, noise exposure of the bedroom may be important to measure.
- Exposure assessment is complex and also needs further research on such issues as the effects of combined exposure from different noise sources, combined noise and air pollution exposure and disentangling impacts in relation to various urban features. There is a particular need for studies on combined effects of exposure to traffic related air pollution and noise on the cardiovascular system and interaction effects between noise and other environmental stressors.
- Air pollution and noise exposure does not just affect cardiovascular disease via effects on blood pressure – it would be important to pay more attention to alternative mechanisms and quantify the relationship between noise and cardiovascular outcomes e.g. by setting up a new cohort study and through further exploiting existing data.
- Studying effects in situations where correlations between noise and air pollution are lower, is one approach to disentangling relative contributions. NO_2 might not be the best indicator for traffic related air pollution, because it could originate from far distances. Future research will need to clarify which component of air pollution is implicated in various health effects.
- Access to a quiet side within a dwelling has to be studied further in relation to health effects.

- ENNAH WP 4 identified the main modifiers of exposure. Some of them were already included in epidemiological studies such as window orientation and length of residence more than 15 years (Babisch et al., 1999), some should be considered more, and in future studies: effects of shielding, room location, window opening, insulation, age, gender and other exposures (e.g. air pollution) and possible vulnerable groups.
- There is still controversy over whether subjective noise sensitivity represents biological vulnerability for cardiovascular disease or whether people who are already ill become more vulnerable to noise. Better measurement of exposure modification will reduce exposure misclassification and increase precision in noise and health research.
- New, less studied cardiovascular disease endpoints might include the measurement of stroke, long term cortisol measurement from hair, intima media thickness measures in the carotid artery, non-dipping of blood pressure and heart rate variability.
- There is a question as to whether other noise sources (railway, industrial and wind farm noise) should also be studied to develop exposure-response relationships. Neighbourhood noise might also be worth considering although it is very difficult to measure.
- Cardiopulmonary outcomes do not seem being a relevant outcome in noise research, because of their lack of specificity and the lack of evidence of respiratory pathology associated with noise exposure. It is suggested that heart failure and atherosclerosis might be worth studying though and patients selected for revascularization might be a good sample to study.

4.6.2 New directions for noise and annoyance research

The development of a society with health promoting soundscapes is an important issue for the future. Soundscape annoyance is very specific to a particular microenvironment and may be influenced by window closure. The soundscape characterisation can be complex and a distinction can be made between acoustic characterisation and perceptual characterisation. Soundscapes can be defined along dimensions of eventfulness and pleasantness.

Dose-response relationships have been established for aircraft, road and rail noise with annoyance, traffic noise and sleep disturbance and industrial noise and annoyance (Miedema and Vos, 2004). Wind turbine noise has also been related to annoyance (Janssen et al., 2009).

Specific EU policy implications

Considering health promoting soundscapes, there needs to be a focus on sound quality as well as sound level. The EU policy actions and goals work at different levels. At the smallest scale - proximal spaces, it means creating better homes, hospitals, gardens, workplaces and institutions. At the medium to large scale it means making safer more pleasant, less stressful, neighbourhoods, parks and cities, and at the global scale managing global environmental changes and reducing environmental risks. Potentially annoyance is involved in all the other adverse effects of noise. Similarly, there are very many environmental noises which are annoying apart from road traffic noise and these should be considered.

Regarding annoyance curves – the EU has supported soundscape research- for example the car manufacturer Mercedes has tweaked engine sounds to make them more pleasant- we have conducted studies of positive soundscapes and autonomic responses in the COSMA project (COSMA, 2009-2013). This approach links the physical environment to the individual listener's perception of the noise. Personality factors may be important for individuals, but are less relevant for policy.

Future research challenges

- ❖ There should also be a focus more broadly on soundscape characterisation and the identification of quiet areas and restorative environments. We need to also look at where people spend their time and how that relates to health outcomes. It is also important to distinguish short term from long term annoyance.
- ❖ The future needs in annoyance research include updating dose-response relationships, particularly noting the trends in levels of increasing aircraft noise annoyance over recent years.
- ❖ The impact of step changes in noise exposure on annoyance is still not entirely worked out. There may be interactions between noise annoyance and other environmental noise exposures that need to be understood. Also, there could be further work on the link between annoyance and health effects.
- ❖ Annoyance responses to combinations of noise sources need to be assessed, perhaps in terms of responses to overall soundscapes.
- ❖ Dose-response relationships are needed for new sources of noise such as wind turbines, high speed railways, and air conditioning. It is important to quantify the impact of additional factors such the presence of noise insulation, quiet façades, the influence of nearby green areas, the number and distribution of high level noise events and spectral aspects, e.g. (low frequency noise). Other considerations such

as the way the dwelling is laid out, the provision of noise reducing architecture should also be included.

- The interaction between noise annoyance and other environmental annoyances remains a gap. There is a need to design a combined model of all the interrelations between noise exposure and annoyance and non-acoustic factors (Miedema, 2007).

Still outstanding questions are:

- How to use the ISO questions for annoyance for combined noise exposures remains a challenge?
- How to measure soundscape quality and how to add the positive aspect of soundscape to the assessment?
- Is a single event indicator a better descriptor of annoyance?
- Is the equal energy principle L_{eq}, L_{den}, relevant for annoyance?
- Is annoyance merely a consequence of exposure – or a mediator as well?
- Should we include annoyance in all causal health models? However, it would be surprising if annoyance turned out to have an influence for all health outcomes.
- How should we treat annoyance in statistical models?
- Should we be focussing on the determinants of noise annoyance other than noise exposure?

Perhaps the greatest present challenge is not to decrease the adverse health effects, but to create good and health promoting soundscapes.

4.6.3 New directions for noise effects on hearing research

A major focus for future research directions would be on the risk of hearing loss from personal music players (PMPs), as 17% of teenagers have lost some of their hearing after leisure noise exposure and are not aware of it (Holmes et al., 1997).

Specific EU policy implications

- The SCENIHR Group (Scientific Committee on Emerging and Newly Identified Health Risks) of the European Commission reported in 2007 on emerging and newly identified health risks of noise exposure (EC- SCENIHR, 2008). This group assessed whether exposure to noise from personal music players (PMP)s and other devices might cause quantifiable health risk, in particular hearing loss and to identify the level of noise emission beneath which the health of citizens could be safeguarded and to identify priority risk issues for further research. The sale of portable audio devices has accelerated enormously in the first decade of the 21st century and listening levels across a series of studies ranged from 60-110 dBA, in some cases even to about 120 dBA (earbuds). Assuming that an average PMP user listens for 7 hours per week this would exceed the noise at work regulations if the sound level for the PMP exceeded 89 dBA.

- 5-10% of young listeners are at high risk of hearing loss after five or more years of exposure. Those include individuals listening to music over 1 hour a day at a high volume control setting. Therefore, longitudinal long term cohort studies are needed to conclude whether exposure to PMP music in teenagers may influence hearing at older ages.

Future research challenges

- There is evidence for combined effects of noise and organic solvents, but still there is need for further research to characterise the dose-response/effect relationships and establish safety limits of solvents in occupational settings. The mechanisms of noise and solvent effects should be further explored in terms of central auditory processes and the influence of age, gene polymorphisms and vulnerability factors.
- While considering research on PMP, it may be fruitful to look at temporary threshold shifts as well as hearing damage, both of which could be implicated in learning and cognitive effects. Also, in examining hearing outcomes, a life course approach may be useful.
- There is a need to identify populations at risk for developing hearing loss due to environmental exposure to noise and solvents and volatile organic compounds.

4.6.4 New directions for noise and sleep research

There are a variety of noises that may disturb sleep, including road traffic, railway and aircraft noise, wind turbine noise, industrial noise, noise from neighbours and leisure time noise. Determination of effects may be complicated by additional exposure to light pollution, chemical pollution and psychosocial stressors and time pressure that may also influence sleep.

Future research challenges

- Distinguishing spontaneous and induced awakenings is important. Sleep disturbance may also have effects on memory consolidation. Performance at work the following day after sleep disturbance may be impaired. It is also important that nocturnal noise exposure may contribute to the genesis of multifactorial diseases and increased and accelerated ageing. Vulnerable groups to sleep disturbance may be defined by lower thresholds for disturbance and/or stronger reactions to noise. Groups that are thought to be vulnerable include children, those with existing ill-health, insomniacs and older persons.
- Future research may include the effect of combined noises, combined environmental stressors, appreciation of vulnerable groups and studies of those with chronic diseases. This may be carried out in extended field studies with new methods of recording disturbance including cardiac arousals, as well as established measurement tools such as actimetry and subjective assessment. Gaps in knowledge on future research focus also on: after-effects; the role of the distribution of events or the length of quiet periods; and the long term mechanisms for effects. A (psycho) physiological effect model for noise exposure is needed which integrates the newest insights of brain and stress research.
- It is important to clarify the association and mechanisms between sleep disturbance and disease; to quantify and compare the noise dose that would contribute to disturbed sleep with other factors e.g. light; vulnerability needs to be examined in terms of noise sensitivity, light sleepers, old age; and we need to establish valid dose-response curves for cardiovascular response during sleep and noise. Further research is also required on noise exposure during the day that might affect sleep. Future studies should also control for 'normal' arousals and heart rate variability during REM sleep stages.

4.6.5 New directions for noise and mental health research

Psychiatric hospital admission studies show no consistent associations with aircraft noise exposure, but community studies show some association between aircraft noise, road traffic noise and symptoms with some consistency for the effects of noise on anxiety symptoms and anxiety-related medication. But in general there is not a consistent body of positive results. There is moderate evidence that aircraft and road traffic noise impairs quality of life in children, but little evidence that it is related to formal psychological disorders.

<u>Future research challenges</u>

- ❖ There are needs to the further research on:
  - individual dosimetry
  - further studies of medication use
  - coping with noise as potential moderating factor
  - further exploration of socioeconomic status effects
  - noise sensitivity building on the evidence of associations with neuroticism and a significant genetic component to noise sensitivity
  - positive effects of psychological restoration and indicators of well-being and quality of life.
- ❖ There is a strong correlation between noise sensitivity and environmental sensitivity. Recent research has found that people with mental health problems have a greater need to have access to quiet areas and are more likely to visit quiet areas. Therefore, improved characterisation of environmental sensitivity and the development of an objective measurement tool would aid understanding of the role of noise sensitivity.
- ❖ In terms of noise exposure measurements, it may be helpful to consider using L_{max} as well as L_{eq} and to assess accumulating noise exposure measures across home and work.
- ❖ There needs to be work on low frequency noise and there is a possibility of using END noise maps for mental health studies.
- ❖ Research priorities in mental health include longitudinal studies using standardized clinical interviews to measure psychiatric disorder. These studies should involve multiple, environmental and social stressors particularly focussing on high levels of noise exposure and accompanying mental health outcomes with hormonal and physiological measures.

4.6.6 New directions for noise exposure and children's health research

Children in urban areas are exposed to both noise and air pollution, and future studies need to distinguish the health effects of these pollutants and also investigate the effect of combined exposure.

Recommendations for future research include:

- the harmonisation of child health outcome measures.
- the assessment of exposure-response curves specifically for child populations.
- defining vulnerable settings and vulnerable groups.
- investigating the long-term health effects of noise exposure especially for children young than 8 years old and
- further exploring the role of behavioural changes, coping behaviour, and psychological restoration in noise effects on children's health.

Other areas of research interest could be:

- Child pedestrian traffic accidents in relation to use of MP3 players
- The effect of noise on causing headaches in children
- Studies of the combined effect of passive smoking and noise may be productive
- The interaction between ethnicity and noise exposure in which there may be differences in blood pressure.

4.6.7 New directions for noise effects on cognition research

Evidence for the effects of noise, and in particular aircraft noise, on children's cognition has strengthened in recent years. Many studies demonstrate that children exposed to chronic aircraft noise exposure at school have poorer reading comprehension and memory than children who are not exposed. However, the evidence is predominantly cross-sectional. Recent advances include the use of larger-scale epidemiological community samples and better characterisation of noise measurement but there remain several gaps in knowledge that should be the focus of future research.

<u>Future research challenges</u>

There are a few well controlled field studies of noise and cognition in children including the Munich Study (Hygge et al., 2002), the RANCH study (Stansfeld et al., 2005; Clark et al., 2006) and The Tyrol Study (Lercher et al., 2002). In fact, children and adults have comparable slopes in dose-effect curves, but there are no comparable and reliable field studies of chronic noise and cognition in adults.

The following research directions could be identified:

- Understanding the burden of disease and disability-adjusted life years in relation to noise exposure and cognitive impairment. So far the assumption has been made that there is no lasting effect of noise exposure on cognition after the cessation of noise exposure. This has not, as yet, been empirically tested.
- GIS-based noise exposure maps and GIS-based effect measures could be studied. Longitudinal studies would probably be a preferred option.
- Longitudinal studies are needed for understanding the causal pathways between noise exposure and cognition. Studies of the long-term consequences of aircraft noise exposure during school for later cognitive development and educational outcomes have not yet been conducted and remain of prime policy importance.
- To date there has been little research testing sound insulation of classrooms and future research needs to examine whether learning impairments related to aircraft noise can be reduced by sound insulation of the classroom in large scale studies.
- Future studies should incorporate a range of additional noise metrics and examine their associations with children's learning and cognitive performance to explore noise characterisation in more detail. As for other health outcomes, studies have

yet examined in detail how aircraft noise exposure may interact with other environmental stressors that co-occur with airport operations such as air pollution or road traffic noise. It is possible that the combined exposure to these transport related stressors could interact and increase their single effects.

- Greater understanding is needed of the mechanisms of working memory and episodic long-term memory.
- There needs to be further study of speech intelligibility and memory in less than perfect acoustical classroom conditions. Further studies examining classroom acoustical factors such as reverberation and speech-to-noise ratios in relation to performance are required in larger scale studies.
- An emphasis should be put on cognition and wellbeing.
- The assessment of acute and chronic exposure to levels of noise less than 70 dBA should be investigated.
- An important issue to look at is the scaling of noise effects against other forms of environmental insult and mapping of basic cognition, e.g. memory to cognitive processes such as reading and thinking. This requires a mixture of laboratory and field studies in a range of locations, for instance, home and school but also the workplace.
- Whilst recent evidence of exposure-effect relationships between noise exposure and children's cognition has provided knowledge about thresholds for effects, further examination of exposure-effect relationships in different contexts, for different samples and vulnerable groups, and for different noise metrics remains a research and policy priority.

For a full overview on ENNAH WP 6 see deliverable D6.2 in the ENNAH's website.

Figure 10. ENNAH workshop on WP 6, 16-18 February 2011, London

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WP 7: INFORMATION STRATEGY PLAN & DISSEMINATION

5 ENNAH INFORMATION STRATEGY PLAN & DISSEMINATION (WP 7)


ENNAH's work package 7 was led by European Commission's Joint Research Centre - Institute for Health and Consumer Protection (JRC-IHCP) and co-ordinated by Stylianos Kephalopoulos in liaison with his collaborator Jurgita Lekaviciute.

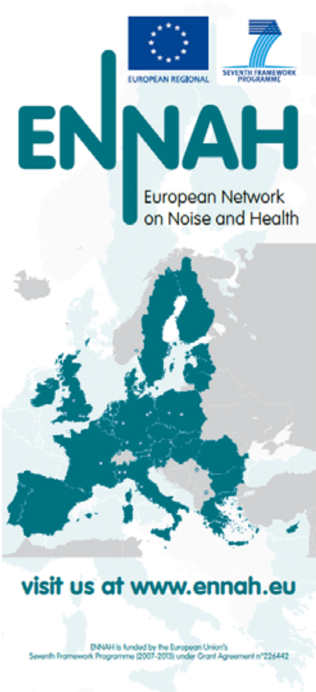
The main objective of ENNAH WP 7 was to develop an information strategy plan and dissemination of the scientific findings of ENNAH through dedicated actions focused on the various target groups of end-users (scientific community, policy makers in EC and member states, NGOs, industries and general public).

JRC-IHCP set up the platform for ENNAH end users, which included almost two-hundred experts and stakeholders from different organizations.

Dissemination of the ENNAH findings were specifically achieved through: (a) the ENNAH Website; (b) the production of ENNAH Newsletters (4 in total), ENNAH Leaflets (3 in total) and the ENNAH film sent to a wide target audience (scientific community, policymakers and other stakeholders); (c) Publications in scientific journals and conferences and (d) the ENNAH final Conference and final report.

Further communication with the scientific community and the end-users in the EU Member States was established and publications were jointly published. All participating institutes had an excellent track record in presenting the results of the ENNAH outcome in a large variety of scientific fora, often as invited speakers, including major scientific conferences, special workshops and policy-oriented meetings.

5.1 Results of dissemination



5.1.1 ENNAH Website

In the autumn of 2009, the ENNAH project website (www.ennah.eu) was setup and launched by the ENNAH co-ordinator (QMUL, UK). It contains details of the network, the organizations and people involved in the ENNAH project and includes all ENNAH's outcomes: workshops presentations, reports, scientific papers, newsletters and leaflets.

5.1.2 ENNAH Newsletters

Four electronic newsletters, outlining the work performed in the context of the ENNAH network, were released. They were made available in both, electronic format (http://www.ennah.eu/newsletters?lang=en) and hard copies.

The first ENNAH newsletter (Figure 11) was released in early 2010 and it presented the ENNAH project's objectives, planned activities and partnership. The second newsletter produced in August 2010 and presented the news from project activities: from two workshops related to WP 2 (held in London, on June 2010) and to WP3 (held in Gent, on April 2010), as well as news from INTERNOISE 2010, where some ENNAH partners were participating.

Figure 11. ENNAH Newsletters

The third ENNAH newsletter also presented the news from the following two workshops related to WP4 (held in Stockholm, on September 2010) and to WP 5 (held in Athens, on November 2010). There were also presented participation of several ENNAH partners in The WHO meeting on "Burden of disease from environmental noise" as well as experience from Slovakia on capacity building in Central Europe and experience from ENNAH young researcher exchange programme. The final – fourth ENNAH Newsletter presented the last workshop related to WP 6 (held in London, 2011) and the final ENNAH conference (held in Brussels, on July 2011). This newsletter also presented the common work of ENNAH partners from Central and Eastern Europe, South-East Europe and Newly Independent States on review on environmental noise and health research, as well as ENNAH dissemination through video broadcasting, in several international conferences and one more experience from Young Researcher Exchange Programme (Figure 11). All the cover pages of the newsletters are shown in the Figure 11.

5.1.3 ENNAH leaflets

Three ENNAH leaflets were prepared in collaboration with the Network Co-ordinator and the WP leaders to inform about the objectives and major outcomes of the WP2 on evidence (Leaflet 1) and WP6 on new strategies (Leaflet 2). The final leaflet, presenting ENNAH outcomes from the policy maker's perspective (Leaflet 3), was prepared at the end of the project and distributed to the end-users by well established channels. The cover pages of all three leaflets are shown in figure 12.

Figure 12. ENNAH Leaflets

5.1.4 ENNAH platform of end-users

A platform of end-users was set up for ENNAH which included experts and stakeholders from the following organizations:

- **European Commission**: Directorate-General (DG) Research, DG Environment, DG Enterprise, DG MOVE, DG SANCO and Agencies: European Environmental Agency (EEA) and European Railway Agency (ERA) – 9 representatives;
- **Commission Working Groups on Noise Policy**: Assessment of Exposure to Noise (*WG AEN*), Airport noise (*WG AN*), Health and Socio-economics (*WG HSEA*), Outdoor Equipment, Railway Noise and Road Traffic Noise – 6 representing experts;

- **WHO-Regional Office for Europe –** one representative;
- **WHO Temporary Advisors** (*Risk assessment of environmental noise*) – 43 experts from national authorities, scientists working in research institutes and universities in noise field;
- **DG ENV Noise Regulatory Committee** - 41 experts from national EU authorities;
- **Observers States –** 4 representatives from Norway, Switzerland and Turkey.
- **EEA Expert Panel on Noise –** 11 experts
- **Non-governmental organizations –** 4 organizations
- **Local authorities**: EUROCITIES, Council of European Municipalities and Regions (CEMR/CRRE) and National Roads Authority – 5 representatives at all
- **Industry –** 11 industry related unions and associations
- **Non-EU organizations** (US Federal Aviation Agency (FAA) and US National Institute for Occupational Safety and Health (NIOSH) – 2 institutions
- **Related European projects**: **CALM II Network, COST TD0804** (*Soundscapes of European Cities and Landscapes*), **ECTRI** (*European Conference of Transport Research Institutes*), **EFFNOISE (***Effectiveness of Noise Mitigation Measures***), ESCAPE** (*European Study of Cohorts for Air Pollution Effects*), **HEAVEN** (*Healthier Environment through Abatement of Vehicle Emission and Noise*), **HEIMTSA** (*Health and Environment Integrated Methodology and Toolbox for Scenario Assessment*), **HOSANNA** (*Holistic and sustainable abatement of noise by optimized combinations of natural and artificial means*), **HYENA** (*Hypertension and Exposure to Noise near Airports*), **IDEA** (*Intelligent Distributed Environmental Assessment*), **IMAGINE** (*Improved Methods for the Assessment of the Generic Impact of Noise in the Environment*), **INTARESE** (*Integrated Assessment of Health Risks of Environmental Stressors in Europe*), **QCITY** (Quiet City Transport), **RANCH (**Road traffic and Aircraft Noise exposure and children's Cognition and Health)**, ROTRANOMO** (*Development of a Microscopic Road Traffic Noise Model for the Assessment of Noise Reduction Measures*), **SILENCE** (*Quieter Surface Transport in Urban Areas*), **SOUNDSCAPE** (*Soundscape Support to Health*), **STAIRRS** (*Strategies and Tools to Assess and Implement Noise Reducing Measures for Railway Systems*), **X2-NOISE** (*Aircraft External Noise Network Phase II*) – 19 projects in total.

This platform and associated list of contacts were used for the invitations to the ENNAH workshops and final conference and for disseminating the ENNAH newsletters and leaflets.

<u>For a full overview of deliverable D7.3 see in the ENNAH's website.</u>

5.1.5 Publications in scientific journals and conferences

The main achievements of the network through the work within WP1-WP7 were disseminated also through the publications in scientific journals and through the participation of ENNAH partners in international conferences and also in expert meetings. Of particular importance was participation of several ENNAH partners at the fifth ministerial conference on the environment and health in Parma, Italy (10-12 March 2010) and at the WHO meeting on "Burden of Disease from Environmental Noise" (Bonn, Germany, 14-15 October). Work done through collaboration of different ENNAH partners was presented in key international conferences related to noise and health: EURONOISE 2009, INTERNOISE 2010, 2011, ISEE 2011 and ICBEN 2011.
Numerous oral or poster presentations and scientific publications (manuscripts or posters) have been made during and after the project period.

Scientific peer-reviewed publications

1. Argalášová-Sobotová, L., Lekaviciute, J., Jeram, S., Sevcíková, L., Jurkovicová, J., 2013. Environmental noise and cardiovascular disease in adults: Research in Central, Eastern and South-Eastern Europe and Newly Independent States. *Noise and Health,* 15(62), pp.22-31.

2. Babisch, W., 2011. Cardiovascular effects of noise. *Noise and Health*, 13(52), pp.201-204.

3. Belojevic, G., 2013. Editorial: Wind of change. *Noise and Health,* 15(62), p. 1.

4. Belojevic, G., 2013. Noise and performance: Research in Central, Eastern and South-Eastern Europe and Newly Independent States. *Noise and Health,* 15(62), pp.2-5.

5. Belojevic, G., Paunovic, K., Jakovljevic, B. Stojanov, V., Ilic, J., Slepcevic, V., Saric-Tanaskovic M., 2011. Cardiovascular effects of environmental noise: research in Serbia. *Noise and Health,* 13(52), pp.217-220.

6. Bluhm, G., Eriksson, C., 2011. Cardiovascular effects of environmental noise: research in Sweden. *Noise and Health,* 13(52), pp.212-216.

7. Clark, C., Sörqvist, P., 2012. A 3 year update on the influence of noise on performance and behavior. *Noise and Health,* 14(61), pp.292-296.

8. Clark, C., Crombie, R., Head, J., van Kamp, I., van Kempen, E., Stansfeld, S.A., 2012. Does traffic-related air pollution explain associations of aircraft and road traffic noise exposure on children's health and cognition? A secondary analysis of the United Kingdom sample from the RANCH project. *American Journal of Epidemiology,* 176(4), pp.327-337.

9. Crombie, R., Clark, C., Stansfeld, S.A., 2011. Environmental noise exposure, early biological risk and mental health in nine to ten year old children: a cross sectional field study. *Environmental Health*, 10:39.

10. Davies, H., Kamp, I.V., 2012. Noise and cardiovascular disease: a review of the literature 2008-2011. *Noise and Health*, 14(61), pp.287-291.

11. Floud, S., Vigna-Taglianti, F., Hansell, A., Blangiardo, M., Houthuijs, D., Breugelmans, O., Cadum, E., Babisch, W., Selander, J., Pershagen, G., Antoniotti, M.C., Pisani, S., Dimakopoulou, K., Haralabidis, A.S., Velonakis, V., Jarup, L.; HYENA Study Team. 2011. Medication use in relation to noise from aircraft and road traffic in six European countries: results of the HYENA study. *Occupational and Environmental Medicine*, 68(7), pp.18-24.

12. Hume, K.I., Brink, M., Basner, M., 2012. Effects of environmental noise on sleep. *Noise and Health*, 14(61), pp.297-302.

13. Jeram, S., Lekaviciute, J., Krukle, Z., Argalasova-Sobotova, L., Ristovska, G., Paunovic, K., Pawlaczyk-Luszczynska, M., 2013. Community response to noise: Research in Central, Eastern and South-Eastern Europe and Newly Independent States. *Noise and Health,* 15(62), pp.12-21.

14. Laszlo, H.E., McRobie, E.S., Stansfeld, S.A., Hansell, A.L., 2012. Annoyance and other reaction measures to changes in noise exposure - A review. *The Science of the total environment*, 435-436C, pp.551–562.

15. Lekaviciute, J., Argalasova-Sobotova, L., 2013. Environmental noise and annoyance in adults: Research in Central, Eastern and South-Eastern Europe and Newly Independent States. *Noise and Health*, 15(62), pp.42-54.

16. Lercher, P., Botteldooren, D., Widmann, U., Uhrner, U., Kammeringer, E., 2011. Cardiovascular effects of environmental noise: Research in Austria. Review of studies in Alpine valleys over 25 years –exposure response and effect modification. *Noise and Health*, 13(52), pp.234-250.

17. Ndrepepa, A., Twardella, D., 2011. Relationship between noise annoyance from road traffic noise and cardiovascular diseases: a meta-analysis. *Noise and Health,* 13(52), pp.251-259.

18. Paunovic, K., 2013. Noise and children's health: Research in Central, Eastern and South-Eastern Europe and Newly Independent States. *Noise and Health*, 15(62), pp.32-41.

19. Paunovic, K., Stansfeld, S., Clark, C., Belojevic, G., 2011. Epidemiological studies on noise and blood pressure measurements in children: observations and suggestions. *Environment International,* 37(5), pp.1030-1041.

20. Pawlaczyk-Luszczynska, M., Dudarewicz, A., Zaborowski, K., Zamojska, M., Sliwinska-Kowalska, M., 2013. Noise induced hearing loss: Research in Central, Eastern and South-Eastern Europe and Newly Independent States. *Noise and Health*, 15(62), pp.55-66.

21. Ristovska, G., Lekaviciute, J., 2013. Environmental noise and sleep disturbance: Research in Central, Eastern and South-Eastern Europe and Newly Independent States. *Noise and Health,* 15(62), pp. 6-11.

22. Sliwinska-Kowalska, M., Davis, A., 2012. Noise-induced hearing loss. *Noise and Health,* 14(61), pp.274-280.

23. Stansfeld, S., Crombie, R., 2011. Cardiovascular effects of environmental noise: research in the United Kingdom. *Noise and Health*, 13(52), pp.229-233.

24. van Kempen, E., 2011. Cardiovascular effects of environmental noise: research in the Netherlands. *Noise and Healt*h, 13(52), pp.221-228.

25. van Kempen, E., Babisch, W., 2012. The quantitative relationship between road traffic noise and hypertension: a meta-analysis. *Journal of Hypertension,* 30(6), pp.1075-1086.

Participation in conferences

1. Argalasova-Sobotova, L., Paunovic, K., Belojevic, G., Jeram, S., Ristovska, G., Lekaviciute, J., Preis, A., Jurkovicova, J., Sevcikova, L., Sliwinska-Kowalska, M., Stansfeld, S., 2011. Highlights on environmental noise and health research in Central and Eastern Europe, South-East Europe and Newly Independent States. *Proceedings of INTER-NOISE 2011* The 40th International Congress and Exposition on Noise Control Engineering, "Sound Environment as a Global Issue". Tokyo: The Institute of Noise Control Engineering of Japan and the Acoustical Society of Japan.
2. Bockstael, A., Coensel, B., Lercher, P,, Botteldooren, D., 2011. Influence of temporal structure of the sonic environment on annoyance. *ICBEN 2011.*
3. Bockstael, A., Botteldooren, D., Vinck, B., 2009. Speech recognition in noise with active and passive hearing protectors: a comparative study. *EURONOISE 2009.*
4. Clark, C., 2011. The European Network on Noise & Health (ENNAH): new directions in noise and health research. *Aviation Noise Impacts Roadmap Annual Meeting 2011* (QMUL) (Oral Presentation)
5. Clark, C., 2011. Future research priorities from the European Network on noise and health (ENNAH), Conference EPH (Environment and Public Health in Society) *Consultative Conference Berlin-Potsdam*, 7-9th November 2011, Germany
6. Clark, C., Sorqvist, P., 2011. 3 year update on research on effects of noise on health and behaviour. *ICBEN 2011.*
7. Clark, C., Stansfeld, S., Head, J., 2009. The long-term effects of aircraft noise exposure on children's cognition: findings from the UK RANCH follow-up study. *EURONOISE 2009.*
8. Floud, S., 2012. Heart disease and stroke in relation to aircraft and road traffic noise in six European countries – the HYENA study. *Conference ISEE* 2012, 26-30th August 2012, Columbia, South Carolina, USA.
9. Foraster, M., Basagaña, X., Aguilera, I., et al. 2011. Cross-sectional association between road traffic noise and hypertension in a population-based sample in Girona, Spain (REGICOR-AIR project). *ICBEN 2011.*
10. Hansell A, Laszlo HE. 2011. Reviewing evidence on noise exposure and non-auditory health effects in the European Network for Noise and Health (ENNAH). *ICBEN 2011*.
11. Hansell, A., Floud, S., Laszlo, H., Jarup, L., 2010. Review of the Evidence on Noise Exposure and Non-Auditory Health Effects in the European Network for Noise and

Health (ENNAH). In *Proceedings of 39th International Congress on Noise Control Engineering – INTERNOISE 2010*, 13-16 June, Lisbon, Portugal.

12. Hume K. 2011. Overview of research into sleep disturbance due to noise in the last three years. *ICBEN 2011.*
13. Laszlo HE, Hansell A. 2011. The types of human response to changes in noise exposure – a review. *ICBEN 2011.*
14. Laszlo HE, Berry BF, Abbott P, Hansell AL. 2012. Environmental noise and cardiovascular disease - Observations on a well know dose-response relationship. *Internoise 2012*, 19-22 August 2012, New York, USA
15. Laszlo, H.E., Janssen, S.A., Babisch, W., Hansell, A.L., 2012. Noise sensitivity and sleep disturbance. *Internoise 2012*, 19-22nd August 2012, New York, USA
16. Lekaviciute, J., de Kluizenaar, Y., Laszlo, H.E. et al., 2012. Cardiovascular effects of the combined exposure to noise and outdoor air pollution: A review. *Internoise 2012*, 19-22nd August 2012, New York, USA
17. Ohlau, K., Lambert, J., 2011. Health costs of noise: what have we learnt from the literature and their use in noise policy? *ICBEN 2011.*
18. Paunovic, K., Belojevic, G., Jakovljevic, B., et al., 2009. The effects of road-traffic noise on blood pressure of children aged 7-11 years in Belgrade. *EURONOISE 2009.*
19. Ristovska, G., Laszlo, H.E., Hansell, A., 2012. Summary of evidence for reproductive outcomes associated with occupational and environmental noise exposure. *19th International Congress on Sound and Vibration* 8 -12th July 2012 Vilnius, Lithuania
20. Sliwinska-Kowalska, M., 2011. Contribution of genetic factors to noise-induced hearing loss. *ICBEN 2011.*
21. Stansfeld, S., Clark, C., 2012. Does traffic-related air pollution explain the associations of aircraft and road traffic noise exposure with children's health and cognition? *19th International Congress on Sound and Vibration* 8 -12th July 2012 Vilnius, Lithuania
22. Stansfeld, S.A., 2011. Outcomes of the European Network on Noise and Health (ENNAH) (Plenary Session). In: Imaizumi H. (Ed.) *Proceedings of INTER-NOISE 2011 on DVD-ROM.* The 40th International Congress and Exposition on Noise Control Engineering, "Sound Environment as a Global Issue". Tokyo: The Institute of Noise Control Engineering of Japan and the Acoustical Society of Japan
23. Stansfeld, S.A., 2009. New Directions in Noise and Health Research. *EURONOISE 2009* (Plenary Session)
24. van Kempen, E, W., Babisch, W., 2011. The quantitative relationship between road traffic noise and hypertension: a meta-analysis. *ICBEN 2011*.
25. van Kamp, I., Davies, H. ,2011. Noise & Health in vulnerable groups: a review. ICBEN 2011.

Posters

1. Nolli, M., Licitra, G., 2011. Example of correction of soundscape: an intelligent and interactive audio system for masking the noise and increase the pleasantness inside a sonic garden in Florence. *ICBEN 2011.*
2. Paunovic, K., Belojevic, G., Stojanov, V., Jakovljevic, B., 2011. The effects of recorded traffic noise on hemodynamic parameters in healthy women - a pilot study. *ICBEN 2011.*

WHO expert meeting on Burden of Disease from Environmental Noise, Bonn, Germany, 14-15 October, 2010

1. Ristovska, G., Sobotova, L. Need for knowledge transfer and capacity building in the New EU members, SEE and CIS countries.
2. Houthujis, D. Uncertainties in the EBD estimation.
3. Babisch, W. Updating exposure-response relationship for cardiovascular diseases.
4. Janssen, S. Updating exposure-response relationship for sleep disturbances.
5. Lekaviciute, J., Kephalopoulos, S. How useful are the strategic noise maps as exposure data for estimating burden of diseases?
6. Belojevic, G., Ristovska, G. How can EBoDE methods be applied to the countries not having the strategic noise maps?
7. Stansfeld, S., Jeram, S., Belojevic, G., Ristovska, G. Role of experts networks (e.g., ENNAH, ICBEN) in the capacity building and risk communication in the member states.
8. Kephalopoulos, S. Communication and dissemination informing the policy-makers and the public: CNOSSOS-EU in relation to WHO BoD from environmental noise project.

Fifth Ministerial Conference on Environment and Health “Protecting children’s health in a changing environment” Parma, Italy, 10–12 March 2010

Symposium "ENVIRONMENTAL NOISE AND HEALTH: THE ENNAH NETWORK" organized by Stephen Stansfeld (QMUL, UK) and Rohko Kim (WHO-Europe).

1. Stansfeld, S. The ENNAH network: designing new noise and health research in adults and children.
2. Babisch W. Noise, annoyance, blood pressure and hearing in German 8-14 year old children.
3. Nilsson M. Using noise maps and geographic information systems to assess individual traffic noise exposure.
4. Pierik F. Health effects of road traffic-related noise and air pollution.

5.1.6 ENNAH Final event

The Final ENNAH event was held on 6 July 2011 at the Committee of the Regions in Brussels. This conference was the concluding event of the ENNAH project. It was co-organized by the ENNAH's project coordinator Queen Mary, University of London jointly with the European Commission's Joint Research Centre – Institute of Health and Consumer Protection.

An objective of this meeting was to inform EU policy makers and other interested stakeholders (80 representatives from European Commission services and from Environment and Health Ministries in the EU MS, noise scientists, delegates from industry, WHO, NGOs) about the major findings of the network concerning strategies for research that will enable mechanisms for noise effects on health to be further examined and implemented in EC policies on noise, air pollution and related health effects.

The conference was opened on behalf of the European Commission by Andrea Tilche (DG Research & Innovation). Afterwards four key note lectures were given by ENNAH co-ordinators (Stephen Stansfeld and Charlotte Clark) and WP leaders (Anna Hansell and Goran Pershagen). ENNAH project`s coordinator Stephen Stansfeld presented the successful ENNAH outcomes: bringing together European researchers on noise, having developed proposals for new research on environmental noise and health, having contributed to training a new generation of researchers and having established a platform for new collaborative research in Europe on environmental noise and health.

Anna Hansell, leader on Work package 2 on Review of evidence, presented the findings of the literature review which took into account an evaluation of evidence for noise-health relationships, evidence of health outcomes and gaps in current knowledge. She also presented a questionnaire —a formal on-line survey— to be filled in by all ENNAH members to rank further the gaps in current knowledge.

Goran Pershagen, leader of Work package 4 on Moderating factors, gave the presentation on a Research strategy for environmental noise and cardiovascular disease. He proposed future research on cardiovascular effects of environmental noise: 1) develop and test European Environmental Noise Directive maps for use in epidemiological studies and risk assessment; 2) investigate the role of noise in ongoing European studies on cardiovascular effects of air pollution; 3) use biomarkers to assess exposure to noise and other environmental stressors.

Charlotte Clark talked about the gaps in knowledge and ENNAH research recommendations related to environmental noise and cognitive performance and learning in children. Among the research priorities in this field was to further examine the exposure-effect relationships in different contexts, for different samples and vulnerable groups, and for different noise metrics. Among other research recommendations she pointed out the need for primary research studies, research with adolescents, very young children and adults as well as studying national exam performance and noise map data. She also presented the results from the RANCH *(Road traffic and Aircraft Noise and children's Cognition and Health)* project and highlighted the main gaps in knowledge related to exposure reduction, long-term health consequences of noise exposure and classroom acoustics.

Two more representatives from European Commission: from DG ENV (Joachim D'Eugenio) and DG ENTR (Bernd Merz) gave the speeches, concerning the status of the implementation of the EU Environmental Noise Directive and the latest developments on Industrial Policy and Product Legislation respectively. They also stressed the increasing efforts undertaken by the European Commission to integrate noise related health aspects in these two noise policy instruments.

The conference was closed by the discussions about future research strategies and policy orientations in noise and health. The discussions were stimulated by a Panel of experts composed of representatives from: DG R&I (Tuomo Karjalainen), DG ENTR (Bernd Merz), DG ENV (Joachim D'Eugenio), DG JRC (Stylianos Kephalopoulos), WHO (Rokho Kim) and leading scientists in noise and health (Wolfgang Babisch, Birgitta Berglund, Staffan Hygge, Sonja Jeram and Stephen Stansfeld).

The main points raised and recommendations made during the plenary discussion are summarised below:

- The outcomes of ENNAH were appreciated, in particular because of the wide array of recommendations made, which are relevant to both EU policy makers and research community working on environmental noise as well as on air quality. These recommendations range from the more severe (cardiovascular morbidity) but less prevalent health effects to the omnipresent effects (annoyance, problems on children's cognition, mental health, and sleep disturbance), which affect a large number of EU citizens.
- The need to strengthen the evidence base for the effects of environmental noise on chronic disease outcomes and reduce the widespread impact on annoyance and quality of life was emphasised.
- It was recommended that ENNAH findings on assessment of noise exposure and measurement of health outcomes in noise studies form the basis for developing new research strategies and prioritising key gaps for future research on noise (also in relation to air pollution) and associated health effects. It will also contribute to more informed environmental policy making which can combine economic growth with higher standards of living and better health.
- The importance of the involvement of ENNAH partners from Central and Eastern Europe was acknowledged, which has raised the profile of noise research in these countries and also led to greater cooperation across Europe, whilst supporting the on-going WHO capacity building activities on health risk assessment of environmental noise. Capacity building and adequate training for EU member states, accession countries and Newly Independent States (NIS) is an important prerequisite for reliably applying the guidance for estimating the burden of disease from environmental noise which was recently published jointly by WHO and JRC.
- As the task of reliably performing Environmental Burden of Disease (EBD) estimations is tightly linked to the availability and quality of noise exposure data (mainly becoming available via the rounds of strategic noise mapping foreseen by

the END), it was recommended that on-going and future noise and health activities which are carried out by European Commission (DGs, ENV, ENTR, MOVE and JRC) and EEA in support of various EU noise-related directives and by the WHO should be aligned, anchored and run in a co-odinated way as already streamlined by the CNOSSOS-EU framework.

Figure 13. Final ENNAH Conference, 6 July 2011, Brussels

5.1.7 ENNAH Final report

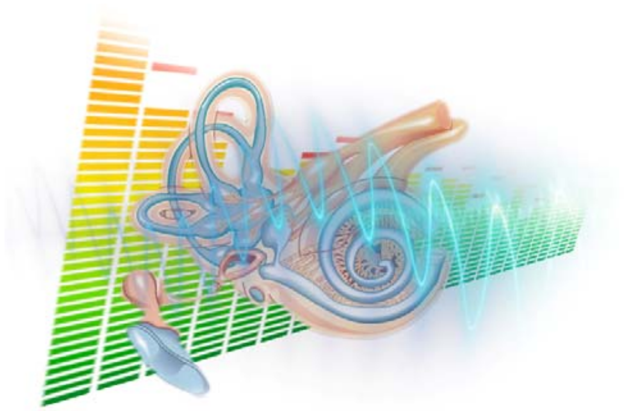
The current final report was prepared by JRC-IHCP, as WP 7 leader in liaison with the ENNAH co-ordinator on the basis of the individual workshop reports provided by the ENNAH WP leaders.

This report summarises the outcomes of the individual work packages 2 to 6 and also include a specific section describing the ENNAH strategic impact, and recommendations for setting priority needs and developing new research strategies for noise and health (taking into account the existing state of knowledge in the area of noise and related health effects and identified gaps in knowledge).

The ENNAH final report will be distributed to all the ENNAH partners and the relevant stakeholders included in the ENNAH dissemination platform of end-users (see 5.1.4).

5.1.8 ENNAH film

ENNAH was also disseminated using an innovative approach – by creation on the film on the network. It was done by ENNAH partners from Cardiff University, Andrew Smith and Paul Allen – who has recently trained as a film director.
The aim of the film about the ENNAH project was to describe the activities of the different work packages and to offer some suggestions for future directions. It was intended to give an indication of the breadth of the work packages and to stimulate interest in the subject matter. The film can currently be viewed from www.ennahfilm.com.



ENNAH YOUNG RESEARCHER EXCHANGE PROGRAMME

6 ENNAH YOUNG RESEARCHER EXCHANGE PROGRAMME

The ENNAH young researcher exchange programme funded exchanges between countries and academic disciplines with the aim of establishing research partnerships among a new generation of noise and health researchers (Table 4).

Table 4. The ENNAH young researcher exchange programme funded exchanges

Successful applicant	Institution of origin	Exchange research institution	Research subject and results obtained
Anneliese Bockstael	Ghent University, Belgium	Medical University of Innsbruck, Austria	Investigating exposure-effect relationships for traffic noise: analyzing existing datasets in search of the most important noise and health quantities.
Sarah Floud	Imperial College London, UK	University of Athens, Greece, RIVM, the Netherlands and the Karolinska Institute, Sweden	The influence of exposure to air pollution on the association between transport noise and health outcomes
María Foraster Pulido	Centre for Research in Environmental Epidemiology, Spain	Swiss Tropical institute, Switzerland	Traffic-related noise and air pollution effects on blood pressure
Helena Jahncke	University of Gävle, Sweden	Raunhofer-Institut für Bauphysik, Germany	The relationships between speech intelligibility, cognitive performance and health in open-plan offices
Mara Nolli	Environmental Protection Agency of Tuscany Region, Italy	University of Stockholm, Sweden	Long-term exposure to road traffic noise and health effects focusing on the use of noise maps and annoyance on cardiovascular disease
Katrin Ohlau	University of Stuttgart, Germany	French Institute of Science and Technology devoted to Transport planning and networks, France	How a monetary estimate of health damages and annoyance caused by traffic noise can be carried out in Europe
Katerina Paunovic	University of Belgrade, Serbia	Queen Mary, University of London, UK	Novel methods of blood pressure measurement in children in relation to noise exposure
Patrik Sörqvist	University of Gävle, Sweden	Cardiff University, UK	The role of working memory capacity and noise exposure

Elise van Kempen	RIVM, the Netherlands	Federal Environment Agency, Germany	Updating a meta-analysis on the effects of environmental noise on the blood pressure of children and adults
Gordana Ristovska	Institute of public health of Former Yugoslav Republic of Macedonia, FYROM	Imperial College London, UK	Reproductive outcomes in relation to road and aircraft noise exposure

Ten exchanges among young researchers have been funded by ENNAH from applicants working in epidemiology and public health, psychology, acoustics, engineering, audiology and medicine (Table 4)

We were able to establish ten exchanges rather than the original five planned within the same financial envelope, because most participants exchanged for shorter periods than originally envisaged.

ENNAH was subsequently able to organise a bursary to cover registration and accommodation costs which enabled all ten ENNAH Young Researchers to attend the ICBEN conference in London July 2011 to present their work either as an oral or poster presentation. This was a valuable networking experience for the young researchers. Several journal papers are in progress or have been accepted based upon the research conducted as part of this young researcher exchange programme.

For a full overview on ENNAH young researchers exchange activities see deliverable D1.3.

OVERALL CONCLUSIONS, RESEARCH RECOMMENDATIONS AND FUTURE STEPS

7 OVERALL CONCLUSIONS, RESEARCH RECOMMENDATIONS AND FUTURE STEPS

One of the main ENNAH project tasks was to identify ENNAH research recommendations for setting priority needs and developing new research strategies for noise and health. The research recommendations listed below start with the more severe (cardiovascular morbidity) but less prevalent health effects, and lead on to the omnipresent effects (annoyance, children's cognition, mental health, and sleep disturbance) which affect a large number of EU citizens.

The research needs are relevant across Eastern and Western Europe. An important imperative is to strengthen the evidence base for the effects of environmental noise on chronic disease outcomes and reduce the widespread impact on annoyance and quality of life. These noise and health associations should be further strengthened by future research as there will be definite public health implications.

Some cross-cutting themes that were identified across health outcomes were:

- The need for the further assessment of exposure-effect relationships in different contexts, for different samples and vulnerable groups, and for different noise metrics remains a research and policy priority.
- There is a need for longitudinal cohort studies.
- Future studies need to have more detailed noise characterization - little is known about the health effects of the number of noise events or peak sound events.
- Studies also need to validate whether the exposure data from the EU END noise maps is useful for assessing the health impacts of noise.
- Future research should examine the effects of combined noise sources on health outcomes, as well as the effects of noise in combination with other environmental stressors, including air pollution.
- Moderators and mediators of the associations between noise and health, e.g., noise sensitivity, noise annoyance, as well as exposure modifiers should be addressed in future studies.
- A better specification of physiological models underlying the associations of noise and health outcomes can help to formulate critical hypotheses that can be used to test health effects.

Research on environmental noise and cardiovascular disease

- To establish thresholds for serious health risk, research should focus on providing further evidence for exposure-response relationships between road traffic noise exposure and cardiovascular health effects including cardiovascular risk markers, hypertension and myocardial infarction.

- Research should measure classic cardiovascular end-points as well as indicators on the pathway such as hypertension. New outcomes that should also be considered include stroke.
- New large prospective longitudinal cohort studies with detailed noise exposure assessment and objective assessment of cardiovascular outcomes would be the best solution to address these issues but consideration should also be given to the use of existing cohort studies.
- Cohort studies should take account of co-exposures and effect modifiers such as air pollution that may affect associations between noise from road traffic and hypertension or myocardial infarction, as well as noise exposure at the back and front of the building façade.

Research on environmental noise and children's cognitive performance

- Future studies need to examine whether learning impairments related to noise exposure can be reduced by sound insulation of the classroom using large scale studies.
- Longitudinal cohort studies of children's cognition and school performance should be carried out to examine whether cross sectional findings such as impairment of reading comprehension and memory with aircraft and road traffic noise persist over time.
- The burden of disease and long term disability should be calculated for cognitive impairment in childhood.
- Studies should include pre-school children, as well as primary and secondary school children.
- Future studies should also examine the role of internal classroom acoustics in the associations between external environmental noise exposure and cognitive performance and academic achievement. There also needs to be further study of speech intelligibility and memory in less than perfect acoustical classroom conditions.
- Further laboratory studies of the mechanisms of working memory and episodic long-term memory are required.

Research on environmental noise and mental health

- Longitudinal studies using standardised clinical interviews to assess mental health diagnoses (common mental disorders such as affective and anxiety disorders), taking into account exposure to other environmental and social stressors would advance this area of research.

- Additional measurement of stress hormones (cortisol and catecholamines) would further strengthen these studies
- Studies should also include the measurement of moderating factors such as noise sensitivity and should involve genetic analyses of vulnerability to environmental stressors.
- Developments in neuroscience also suggest the scope for future functional magnetic resonance imaging (f-MRI) studies of responses to noise in the laboratory.

Research on environmental noise and annoyance

- There is a need to update the evidence on annoyance to aircraft noise in view of recent trends of increasing annoyance responses. Studies are also needed to quantify the impact of emerging noise sources such as high speed rail and wind turbine noise, as well as the effectiveness of intervention measures to reduce noise.
- Further studies of annoyance by transportation noise should quantify the effects of situational aspects, such as noise insulation, the presence of a quiet side to noise exposed buildings, quiet areas, as well as source characteristics such as the rate of occurrence and level of individual noise events.
- The effects of combined noise exposures on annoyance and the effects of other environmental annoyances on noise annoyance should also be explored in future research.

Research on environmental noise and sleep

- Future research should assess the effects of combined noises and combined environmental stressors on sleep, as well as developing knowledge about groups vulnerable to sleep disturbance.
- These studies may be carried out in extended field studies with new cost-effective methods of recording disturbance including cardiac arousals, as well as established measurement tools such as actimetry and subjective assessment.

Research on environmental noise and hearing loss

- Although most studies, so far, have found little impact on permanent threshold shift in young people there is a need for longitudinal cohort studies of personal listening device usage in young people to answer this question substantively.
- Further studies of organic solvents and noise exposure are also necessary to gain further evidence for dose-response relationships.

Emerging topics for environmental noise research

- The following health outcomes have been little studied in relation to environmental noise and should be the focus of new studies in the field:
    - Reproductive outcomes
    - Neonatal health and early child development
    - The after-effects and health impact of noise-disturbed sleep
    - The effects of combined noise sources on health outcomes
    - The effects of noise in combination with other environmental stressors, especially air pollution
- Moderators and mediators of the associations between noise and health could also benefit from further study e.g. noise sensitivity and noise annoyance.

Future needs for exposure-assessment in noise and health research

- Whilst noise mapping and the use of Geographical Information System techniques has advanced environmental noise assessment across large areas, future studies will need to address the current limitations of these methods, particularly in terms of the coverage of the road network; the cut-off values at the lower end; the quality and comparability of the input data across countries; and the grid size.
- The emphasis on energy averaged noise measures has led to a neglect of the measurement of numbers of events in studies, and in transport noise studies this has become increasingly relevant as the magnitude of noise related to individual transport sources has reduced but the number of events has increased. Studies using C-weighting of sound, and low frequency sound, vibration and noise might also be relevant in relation to health and wellbeing.

ENNAH STRATEGIC IMPACT

8 ENNAH STRATEGIC IMPACT

The ENNAH Network has successfully brought together scientists from a range of disciplines working on the common problem of environmental noise and health. The ENNAH workshops have generated new contacts between scientists and allowed productive scientific discussion. ENNAH has also brought together scientists working on air pollution and noise to work together. It has been the foundation for several new research proposals submitted to the EU, including ENACT, NEFELI, NECHTAR (Initial Training Network) as well as an Erasmus Mundus doctoral proposal. Shared expertise has been helpful in suggesting common recommendation for new noise maps. The involvement of our Central and Eastern European Partners has raised the profile of noise research in these countries and led to greater cooperation across Europe, recognised in joint papers and the WHO meeting on the Burden of Disease.

Lead users of the research

Researchers within the ENNAH Network have benefited from the Network's activities. Dissemination to international conferences such as ICBEN and Internoise has also led to this expertise being disseminated further afield including to the FAA in USA contributing to their deliberations on new noise and health research. Secondly, the Network results have been fed back to policy makers at two meetings in Brussels and at a workshop co-organised with DEFRA in the UK. Policy makers have also attended our workshops and our newsletters and leaflets have been disseminated to policy makers through our directory of end users. We anticipate our findings will be relevant to policy makers involved with the European Noise Directive. These include both our recommendations about noise maps, our findings on assessment of noise exposure and measurement of health outcomes in noise studies and our final recommendations for research. These recommendations are directly relevant to EU policy makers who are responsible for developing new calls for research proposals.

Our findings have been disseminated through the workshops, newsletters, scientific leaflets, peer-reviewed papers, conference papers, conference presentations and a website.

A further important outcome of ENNAH has been building up research capacities through the training of junior researchers and doctoral students as part of the next generation of environmental researchers working on noise and health.

Exploitation of the results

The ENNAH Network is establishing a framework for future noise research. This is the start of a process. The future research will help to clarify the associations of environmental noise and health to improve the guidance for policy makers. More precision in defining health effects, for which this Network is a first step, will contribute to more informed environmental policy making which can combine economic growth with higher standards of living and better health. As noise exposure effects large numbers of the EU population better management of noise could lead to higher levels of wellbeing for very large numbers of people. Exploitation of the ENNAH Network findings has been almost exclusively in the scientific and policy implications arena. Interaction has been established with policy makers and EC services to communicate the recommendations of the project concerning needs for new research strategies on noise, air pollution and related health effects in the EU. Policy makers have acknowledged the helpfulness of ENNAH in providing ideas where future thinking on noise and health issues should focus. A greater understanding of the adverse effects of noise can be used for better informed policy making and for prioritising key gaps for future research.

9 LIST OF CONTRIBUTORS

The list of contributors is composed from the ENNAH partners and the participants in the various Workshops organised in the context of the ENNAH project.

Ancona Carla
Dipartimento di Epidemiologia, Azienda Sanitaria Locale Roma E (ASL), Rome, Italy

Babisch Wolfgang
Federal Environment Agency (UBA), Berlin, Germany

Basner Mathias
University of Pennsylvania, Division of Sleep and Chronobiology University of Pennsylvania Perelman School of Medicine, USA

Belojevic Goran
Institute of Hygiene and Medical Ecology, Faculty of Medicine, University of Belgrade (BU), Belgrade, Serbia

Berglund Birgitta
Gösta Ekman Laboratory, Stockholm University (SU), Stockholm, Sweden

Berry Bernard
Berry Environmental Ltd (BEL), Shepperton, UK

Bockstael Annelies
University of Gent, Gent, Belgium

Botteldooren Dick
Acoustics Group, Department of Information Technology, Ghent University (UGENT), Ghent, Belgium

Cadum Ennio
Regional Environmental Protection Agency for Piedmont, (ARPAP), Turin, Italy

Clark Charlotte
Centre for Psychiatry, Barts & the London School of Medicine & Dentistry, Queen Mary, University of London (QMUL), London, United Kingdom

Costa Giovanni
University of Milan, Milan, Italy

De Kluizenaar Yvonne
The Netherlands Organisation for Applied Scientific Research (TNO), Delft, the Netherlands

De Sio Simone
University of Rome "La Sapienza" (URome), Rome, Italy

Dimakopoulou Konstantina
Department of Hygiene, Epidemiology and Medical Statistics, Medical School, National and Kapodistrian University of Athens (NKUA), Athens, Greece

Eriksson Charlotta
Institute of Environmental medicine, Karolinska Institute, Stockholm, Sweden

Flindell Ian
University of Southampton (USouthampton), United Kingdom

Floud Sarah
Imperial College London (IC), London, United Kingdom

Forastiere Francesco
Dipartimento di Epidemiologia, Azienda Sanitaria Locale Roma E (ASL), Rome, Italy

Foraster Maria
Center for Research in Environmental Epidemiology (CREAL), Spain

Griefahn Barbara
Leibniz Research Centre for Working Environment and Human Factors (IFADO), Dortmund, Germany

Hansell Anna
Imperial College London (IC), London, United Kingdom

Haralabidis Alexandros
Department of Hygiene, Epidemiology and Medical Statistics, Medical School, National and Kapodistrian University of Athens (NKUA), Athens, Greece

Houthuijs Danny
National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands

Hume Ken
The Centre for Aviation Transport and the Environment, Manchester Metropolitan University (MMU), Manchester, United Kingdom

Hygge Staffan
University of Gävle, Laboratory of Applied Psychology (GAVLE), Gävle, Sweden

Jeram Sonja
Institute of Public Health of the Republic of Slovenia (IVZRS), Ljubljana, Slovenia

Karakatsani Anna
National and Kapodistrian University of Athens (NKUA), Athens, Greece

Katsouyanni Klea
Department of Hygiene, Epidemiology and Medical Statistics, Medical School, National and Kapodistrian University of Athens (NKUA), Athens, Greece

Kephalopoulos Stylianos
European Commission, Joint Research Centre, Institute for Health and Consumer Protection, Ispra, Italy

Klaeboe Ronny
Institute of Transport Economics (TOI), Oslo, Norway

Kuenzli Nino
Institute for Social and Preventive Medicine at the Swiss Tropical Institute (STI), Basel, Switzerland

Lambert Jacques
French Institute of Science and Technology devoted to Transport planning and networks (IFFSTAR), France

Laszlo Helga Elvira
Imperial College London (IC), London, United Kingdom

Lekaviciute Jurgita
European Commission, Joint Research Centre, Institute for Health and Consumer Protection, Ispra, Italy

Lelong Joël
French Institute of Science and Technology devoted to Transport planning and networks (IFFSTAR), France

Lercher Peter
Medical University Innsbruck, Division of Social Medicine, Dept of Hygiene, Microbiology and Social Medicine (MUI), Innsbruck, Austria

Leventhall Geoff
Acoustical Consultant, Active Noise, United Kingdom

Licitra Gaetano
Environmental Protection Agency of Tuscany Region (ARPAT), Florence, Italy

Memoli Gianluca
Memolix Environmental Consultants (MEM), Pisa, Italy

Miedema M. E. Henk
The Netherlands Organisation for Applied Scientific Research (TNO), Delft, the Netherlands

Nilsson Mats E.
Gösta Ekman Laboratory, Stockholm University (SU), Stockholm, Sweden

Nolli Mara
Environmental Protection Agency of Tuscany Region (ARPAT), Florence, Italy

Ohlau Katrin
Universitaet Stuttgart (USTUTT), Institute of Energy Economics and the Rational Use of Energy IER), Stuttgart, Germany

Palazzuoli Diego
Environmental Protection Agency of Tuscany Region (ARPAT), Florence, Italy

Penell Johanna
Karolinska Institute, Stockholm, Sweden

Perez Laura
Institute for Social and Preventive Medicine at the Swiss Tropical Institute (STI), Basel, Switzerland

Pershagen Göran
Institute of Environmental medicine, Karolinska Institute, Stockholm, Sweden

Persson Waye Kerstin
Göteburg University, Sweden

Philipps-Bertin Chrystèle
French Institute of Science and Technology devoted to Transport planning and networks (IFFSTAR), France

Preis Anna
Adam Mickiewicz University, Institute of Acoustics (AMU), Poznan, Poland

Ristovska Gordana
Republic Institute for Health Protection (RIHP), Skopje, Macedonia

Sliwinska-Kowalska Mariola
Nofer Institute of Occupational Medicine (NIOM), Lodz, Poland

Smith Andrew
Centre for Occupational and Health Psychology, School of Psychology, Cardiff University (CU), Cardiff, United Kingdom

Sobotova-Argalasova Lubica
Comenius University, Institute of Hygiene, Faculty of Medicine (CUB), Bratislava, Slovakia

Stansfeld Stephen
Centre for Psychiatry, Barts & the London School of Medicine & Dentistry, Queen Mary, University of London (QMUL), London, United Kingdom

Swart Wim
National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands

Theorell Tores
Karolinska Institute, Stockholm, Sweden

Twardella Dorothee
Bavarian Health and Food Safety Authority, München, Germany

Van Kamp Irene
National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands

Van Kempen Elise
National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands

ENNAH partners

Queen Mary, University of London, United Kingdom

Karolinska Institute, Sweden

Medical University of Innsbruck, Austria

ARPA Piemonte, Italy

Manchester Metropolitan University, United Kingdom

Swiss Tropical Institute, Switzerland

Leibniz Research Centre, Germany

Stuttgart University, Germany

University of Gent, Belgium

Nofer Institute of Occupational Medicine, Poland

Technical University Berlin, Germany

Cardiff University, United Kingdom

Imperial College London, United Kingdom

ASL Rome, Italy

Institute of Transport Economics, Norway

Berry Environmental Ltd., United Kingdom

Stockholm University, Sweden

Federal Environmental Agency, Germany

University of Gävle, Sweden

Organization for Applied Scientific Research, Netherlands

Helmholtz Zentrum, Munich, Germany

Institute of Public Health, Slovenia

Comenius University of Bratislava, Slovakia

National Institute for Public Health and the Environment, Netherlands

European Commission, Joint Research Centre

Adam Mickiewicz University, Poland

University of Belgrade, Serbia

Environmental Protection Agency, Tuscany Region, Italy

Perelman School of Medicine, University of Pennsylvania, USA

French Institute of Science and Technology devoted to Transport, Planning and Networks, France

National and Kapodistrian University of Athens, Greece

Memolix Environmental Consultants, Italy

Institute of Public Health, Former Yugoslav Republic of Macedonia

ANNEXES

ANNEX A. AGENDAS OF ENNAH WORKSHOPS

Agenda of ENNAH WP2a workshop
"Evidence of Noise-Related Health Effects"

29th September 2009

School of Medicine, St Mary's Campus, Imperial College London

Time	Detail	Speaker
14.15-14.25	**Introduction and welcome to Workshop 2a**	Anna Hansell (IC) WP2 Package leader
14.25-14.45	**Lecture: Draft WHO Review on Noise and Health**	Stephen Stansfeld (QMUL)
14.45-15.15	**Lecture: DEFRA (UK Government) review of health effects on Noise**	Bernard Berry
15.15-16.30	**Breakout Discussion Groups -** **'What is important, What is in progress, what is missing?'** • Consideration of DEFRA and WHO reviews • What other reviews should be considered, if any?'	Anna Hansell (IC) Sarah Floud (IC) Charlotte Clark (QMUL)
15.30-16.00	**Coffee/Tea served**	
16.30-17.00	**Feedback from discussion groups** **Close of meeting**	
17.00-18.00	**ENNAH - Committee meeting – for WP leaders**	
18.30-21.30	**Social event**	

Agenda of ENNAH WP2a workshop
"Evidence of Noise-Related Health Effects"

30th September 2009

School of Medicine, St Mary's Campus, Imperial College London

Time	Detail	Speaker
09.30-11.00	**Talks from invited experts** • Introduction to soundscape research and the COST network • Joint effects of noise and air pollution • Effects of noise from different sources • Transportation noise and traffic-related air pollution and children's cognitive functioning	Prof Jian Kang (Sheffield University) Sarah Floud (IC) Gaetano Licitra (ARPAT) Elise van Kempen (RIVM)
11.00-11.30	**Coffee/Tea Break**	
11.30-12.30	**Breakout Discussion Groups -** **'What is missing in existing reviews?'** • What research areas, susceptible groups, countries etc. do published reviews not cover or cover well? • Are there other specialist areas we should engage with? • What grey literature sources should be searched to inform this and future reviews?	Anna Hansell (IC) Sarah Floud (IC) Charlotte Clark (QMUL)
12.30-13.30	**Lunch**	
13.30-15.00	**Feedback from discussion groups and identification of areas for follow-up**	
15.00	**Close of meeting**	

Agenda of ENNAH WP2b workshop
"Evidence of Noise-Related Health Effects"

Thursday 24th June

Wolfson Institute room 129+130, Charterhouse Square, London EC1M 6BQ

Time	Detail	Session Leader	Speaker
11.30-13.00 **GO6** Rothblat (no.4 on the map)	**Registration + Lunch**		
13.00-13.30 **room 129** Wolfson (no2 on the map)	**Introduction**	Anna Hansell	
13.30-15.00 **room 129** Wolfson (no2 on the map)	**Session I.** Noise sources	Gaetano Licitra (ARPAT)	Ian Flindell (ISVR, University of Southampton)
13.30-15.00 **room 130** Wolfson (no2 on the map)	**Session II.** Characteristics of noise (frequency...) and its effect on health	Kerstin Persson-Waye (Göteborg University)	Geoff Leventhall (Acoustical Consultant)
15.00-15.30 **GO6** Rothblat (no.4 on the map)	**Tea and coffee break**		
15.30-17.00 **room 129** Wolfson (no2 on the map)	**Session III** Noise and co-exposures	Yvonne de Kluizenaar (TNO)	Jurgita Lekaviciute (JRC)
15.30-17.00 **room 130** Wolfson (no2 on the map)	**Session IV** Vulnerable Groups	Charlotte Clark (QMUL)	Irene van Kamp (RIVM)
19.00 **Hat & Feathers pub** corner of Clerkenwell and Goswell road (red map)	**Dinner**		

Agenda of ENNAH WP2b workshop
"Evidence of Noise-Related Health Effects"

Friday 25th June

Wolfson Institute room 129+130, Charterhouse Square, London EC1M 6BQ

Time	Detail	Session Leader	Speaker
09.30-11.00 **room 129** Wolfson (no2 on the map)	**Session V** Occupational noise	Sarah Floud (IC)	Helga E. Laszlo (IC)
09.30-11.00 **room 130** Wolfson (no2 on the map)	**Session VI.** Acute vs. long term effects of noise	Francesco Forastiere (ASL)	Simone de Sio (La Sapienza Rome)
11.00-11.30 **G08** Rothblat (no.4 on the map)	**Tea and coffee break**		
11.30-13.00 **room 129** Wolfson (no2 on the map)	**Session VII** Stress and social impact	Stephen Stansfeld (QMUL)	Barbara Griefahn (IFADO)
11.30-13.00 **room 130** Wolfson (no2 on the map)	**Session VIII** Positive effects of noise & noise reduction interventions	Anna Hansell (IC)	Katrin Ohlau (USTUTT)
13.00-13.30 **G08** Rothblat (no.4 on the map)	**Sandwich Lunch**		
13.30-14.30 **room 129-130** Wolfson (no2 on the map)	**Plenary discussion**		
14.30-15.00 **room 129-130** Wolfson (no2 on the map)	**Closure**		

Agenda of ENNAH WP3 workshop
"Exposure Assessment for health studies"

Monday 26th April 2010

Ghent University, "Het Pand", Onderbergen 1, 9000 Gent, Belgium

Time	Detail	Speaker
13.00-14.00 Kloostergang	**LUNCH**	
14.00-14.30 Priorzaal	**Registration**	
14.30-18.00 Priorzaal	**Welcome + Address** **Opening of the workshop**	Stephen Stansfeld (UK)
	- CURRENT PRACTICES -	
	How do health scientists treat (noise) exposure? What are the most common used epidemiological study designs and what kind of exposure indicators can be distinguished? How can misclassification of exposure be reduced taking into account exposure modifying factors, like noise insulation, room orientation, time activity, use of mitigation measures?	Wolfgang Babisch (DE) Danny Houthuijs (NL)
	Noise exposure assessment and health studies in Central and Eastern Europe Perspectives on noise exposure assessment and health studies in Central and Eastern Europe. Is noise mapping the only way to provide information for policy makers and the public? What kind of other data-sources can be used? Are there specific needs for noise and health research in Central and Eastern Europe?	Anna Preis (PL) Gordana Ristovska (MK) Sonja Jeram (SI)
	Lessons from EU noise mapping for health studies? The current practice of noise mapping in Europe and its potential use for health studies will be discussed using the experiences from national noise and health studies and strategic noise mapping activities in Europe. The advantages and limitations of current practices such as the accuracy of noise maps, their validity, the pro and cons of cut off values, the experiences with the Good Practice Guide for Strategic Noise Mapping and what to do if input data is missing will be addressed to assist future scientific research.	Gaetano Licitra (IT) Mats Nilsson (SE)
19:30	**Social Event restaurant meal at Monasterium PoortAckere (**Tel. 0032 9 269 22 62, www.monasterium.be)	

Agenda of ENNAH WP3 workshop
"Exposure Assessment for health studies"

Tuesday 27th April 2010

Ghent University, "Het Pand", Onderbergen 1, 9000 Gent, Belgium

Time	Detail	Speaker
09.00-13.00 Priorzaal	**- FUTURE TECHNIQUES -**	
	Novel exposure simulation techniques It is important to have information about the spectrum and temporal distribution of noise exposure in relation to different sources and to different health outcomes. Can novel exposure simulation techniques provide this information? Is it necessary to incorporate other noise indicators than L_{den} and L_{night} like frequency of events, low frequency noise, and is this feasible? How can the relevant information for health studies be extracted from the results of novel simulation techniques?	Dick Botteldooren (BE) Joël Lelong (FR)
11.00 Coffee break Kloostergang	**Advanced measurement techniques and personal exposure** Noise measurements can play a vital role in understanding which activities and sources contribute to the daily noise exposure. Novel measurements techniques will become available to assess the reliability of noise model predictions with a high spatial resolution and the daily and seasonal variations in noise levels. Can novel measurement techniques be used for the assessment of alternative indicators (peak levels, number of events)? Can they facilitate the assessment of personal noise dose in health studies? Can they be used to validate crude exposure indictors in health studies?	Bernard Berry (UK) Gianluca Memoli (UK)
	Combined exposure to noise and air pollution Health effects of road traffic are not only associated with noise exposure but also with traffic related air pollution. Is the noise and air pollution community assessing the same effect, but is it attributed to different exposures? Are we able to separate the effects of combined exposure? Recent results of studies into combined exposure will be discussed?	Yvonne de Kluizenaar (NL) Wim Swart (NL) Sarah Floud (UK)
13.00-14.00 Kloostergang	**LUNCH**	

Agenda of the joint COST-ENNAH Workshop

Tuesday 27th April 2010

Ghent University, "Het Pand", Onderbergen 1, 9000 Gent, Belgium

Time	Detail	Speaker
14.00-18.00 Vermeylen	**Address and Opening of the workshop** **Introduction to the COST initiative, the working group and the workshop**	Jian Kang (UK) Dick Botteldooren (BE)
16.00 Coffee break Kloostergang	**COST Soundscape of European Cities and Landscapes meets other disciplines** Visual system and in particular the role of attention could be a great source of inspiration for understanding the perception of our sonic environment. Moreover, our senses are strongly coupled and therefore we cannot ignore the visual system while studying soundscapes. This talk will introduce soundscape researchers to the knowledge available in other fields and will give some food for thought in trying to understand soundscapes. Multisensory (audiovisual) perception and is well known for her work on emotion. Her talk will introduce the newest findings in these areas and allow soundscape researchers to contemplate bringing more "emotion" into their work. Music perception, soundscapes could be regarded as the music of the city and as such it is quite fascinating to explore how soundscape research could learn from music. His talk will focus on an embodied approach to sound and music perception.	Boris Velichkovsky, (DE) Beatrice De Gelder (NL) Marc Leman (BE)
	Plenary discussion	

Agenda of the joint COST-ENNAH Workshop

Wednesday 28th April 2010

Ghent University, "Het Pand", Onderbergen 1, 9000 Gent, Belgium

Time	Details	Speaker
09.00-13.00 Vermeylem	**<u>Measuring how the soundscape affects persons</u>** The person enjoying the urban environment, living in it, or just visiting will be influenced by the soundscape. Aesthetic emotions may arise, stress levels may change, etc. How can we measure the effect the sonic environment has on this person while experiencing or on the long run?	Catherine Lavandier (FR) Sarah Payne (UK) Danièle Dubois (FR)
11.00 Coffee - break Kloostergang	**<u>Measuring soundscapes with persons</u>** The person can also be used as a measurement instrument. Bringing persons into a sonic environment with the purpose of assessing its quality has been suggested in the way of "sound walks", but one can also bring the sonic environment to the lab in order to assess it provided this can be done in an ecologically valid way. But how can one be sure that the narrative the person uses to describe the soundscape fulfills the requirements of a good measurement? How can personal factors and other context be eliminated?	Mats Nilsson (SE) Anna Preis (PL)
	<u>Measuring the sonic environment in a human mimicking way</u> From the very start of physical noise measurement, attempts were made to include knowledge on the human auditory system. A-weighting can be seen as the early 20th century approach. The availability of computational power today allows going far beyond. Both a more holistic approach and an analytic approach are possible. The holistic approach tries to model the human as a system reacting to the sonic environment as a whole and come up with measures like pleasantness and other more abstract concepts. The analytic approach attempts to approximate all steps in the human perception process like spatial unmasking, stream segregation, sound recognition in computational methods. An important question is of course what is feasible.	
13.00-14.00 Kloostergang	**Sandwich lunch**	

Agenda of ENNAH WP3 workshop
"Exposure Assessment for health studies"

Wednesday 28th April 2010
Ghent University, "Het Pand",Onderbergen 1, 9000 Gent, Belgium

Time	Details	Speaker
14.00-16.00 Sacristy	**Lessons learned and future directions** A plenary discussion on what we have learned from the ENNAH and COST introductions and how we can use these insights for future noise & health and soundscape research.	
	Discussion of plans on the secondary analysis of exposure and exposure-modifiers (RANCH/HYENA/BBT/ALPNAP)	Sarah Floud (UK) Charlotte Clark(UK) Helga E. Laszlo (UK)Wolfgang Babisch (DE) Annelies Bockstael (BE) To be announced, Stockholm University, Sweden
	Future research directions on exposure assessment for health studies Future arrangements	
16.00	**Closure**	

Agenda of ENNAH WP4 Workshop
"Confounding and Effect Modifying Factors in Noise Related Health Research"

Monday 6th September 2010

Hotell-Norrtull St Eriksgatan 119, Stockholm, Sweden

Time	Detail	Speaker
12.00-13.00 room "Galleriet"	**Registration and lunch**	
	Moderator: Ronny Klaeboe	
13.00-13.30	Welcome, introduction, aims and deliverables (including round of presentations)	Göran Pershagen
13.30-14.00	Results of WP2: Identification of confounding and effect modifying factors in health related noise research	Stephen Stansfeld Jurgita Lekaviciute
14.00-14.30	Confounding and effect modification in RANCH and HYENA	Charlotte Clark
14.30-15.00	Independent and joint health effects of air pollution and noise	Klea Katsouyanni
room "Galleriet"		
15.00-15.20	**Coffee/Tea Break**	
	Moderator: Göran Pershagen	
15.20-15.40	Population studies on health effects of combined exposure to noise and air pollution	Yvonne de Kluizenaar
15.40-16.00	Cardiovascular effects of air pollution and noise in Swedish studies	Göran Pershagen
16.00-16.20	Correlation between traffic-generated noise and air pollution	Maria Foraster
16.20-16.40	Oslo traffic study, part I and II	Ronny Klaeboe
16.40-17.00 room "Galleriet"	Discussion	
18.00	**Dinner**	

Agenda of ENNAH WP4 Workshop

(Confounding and Effect Modifying Factors
in Noise Related Health Research)

Tuesday 7th September 2010

Hotell-Norrtull , St Eriksgatan 119, Stockholm, Sweden

Time	Detail	Speaker
	Moderator: Ronny Klaeboe	
08.30-08.50	Individual noise sensitivity, stress and genetics	Töres Theorell
08.50-09.10	Gender differences in noise effects	Charlotta Eriksson
09.10-09.30	Confounding and effect modification in German noise studies and the Hyena study	Wolfgang Babisch
09.30-09.50	Moderators in noise annoyance studies: an overview	Jacques Lambert
09.50-10.00 room "Galleriet"	Discussion	
10.00-10.20	**Tea +Coffee break**	
	Moderator: Göran Pershagen	
10.20-10.40	Introduction to group assignment – Web of causation	Johanna Penell
10.40-12.00 room "Galleriet"	Group assignment	
12.00-13.00	**Lunch**	
	Moderator: Göran Pershagen	
13.00-13.45	Presentation of group assignment (approx. 10 min/group)	
13.45-14.30	Discussion of group assignment – implications for analyses	
14.30-15.00 room "Galleriet"	Summation of workshop	Göran Pershagen

Agenda of ENNAH workshop 5a

(Measurements of health outcomes in epidemiological studies on noise)

Monday 22th November 2010

Kostis Palamas Building, Akadimias 48 & Sina, 105 62 Athens

Time	Detail	Session Leader	Speaker
08.30-09.00	**Registration**		
09.00-9.10	**Introduction WP5a**	Francesco Forastiere (ASL)	
09.10-9.30	Key points from the WHO Meeting Burden Of Disease From Environmental Noise Bonn, 14-15 October 2010		Stephen Stansfeld (QMUL)
09.30-11.00	**Session I.** Cardiovascular diseases	Ennio Cadum (ARPAP)	Alexandros Haralabidis (NKUA)
11.00-11.30	**Tea and coffee break**		
11.30-13.00	**Session II.- III.** Biological indicators Children's health Including: OHRKAN - an epidemiologic study on hearing in adolescents (Dorothee Twardella)	Jurgita Lekaviciute (JRC)	Giovanni Costa (University of Milan) Irene van Kamp (RIVM)
13.00-14.00	**Lunch**		
14.00-15.30	**Session III. – IV.** Respiratory diseases General Health Status	Klea Katsouyanni (NKUA)	Anna Karakatsani (NKUA) Peter Lercher (MUI)
15.30-16.00	**Tea and coffee break**		
16.00-17.30	**Session V.-VI.** Sleep Mental health	Carla Ancona (ASL)	Barbara Griefahn (IFADO) Stephen Stansfeld (QMUL)
19.00	**Pre arranged Dinner**		

Agenda of ENNAH workshop 5b
"European Health Impact Assessment"

Tuesday 23rd November 2010,

Kostis Palamas Building, Akadimias 48 & Sina, 105 62 Athens

Time	Detail	Session Leader	Speaker
09.00-10.00	**WP5a Conclusions**	Francesco Forastiere (ASL) Klea Katsouyanni (NKUA)	
10.00-10.15	**Introduction WP5b**	Laura Perez (Swiss TPH)	
10.15-11.00	**Session I. -** Health impact assessment overview of approaches and met Laura Perez (Swiss TPI)		
10.15-10.35	**Presentation 1:** Review of methods		Laura Perez (Swiss TPH)
10.35-10.55	**Presentation 2:** Examples in the environmental health field linked to policy: national project on HIA for environmental risks carried out in Piedmont, Veneto, Emilia Romagna, Marche, Tuscany, Sicily		Ennio Cadum (ARPAP)
11.00-11.30	**Tea and coffee break**		
11.30-13.00	**Session II. -** Noise health impact assessment in Europe-where do we stand? chaired by Peter Lercher (MUI)		
11.30-11.50	**Presentation 1:** Bremer Basetunnel: a transnational EHIA on rail and road traffic. Approach and results for noise		Peter Lercher (MUI)
11.50-12.10	**Presentation 2:** Airport noise and health impact – the UK perspective		Bernard Berry (BEL)
12.10-12.30	**Presentation 3:** The example of health risk assessment in		Lubica Argalasova (CUB)

	Bratislava – environmental noise and cardiovascular risk		
12.30-12.50	**Presentation 4:** Future HIA noise in Italy; approach for estimating the impact of noise on health in the municipalities surrounding the Malpensa Airport for compensatory remediation measures to the Airport authorities		Ennio Cadum (ARPAP)
12.50-13.00	Open floor discussion		
13.00-13.30	**Lunch**		
13.30-15.00	**Session III. -** Specific approaches, methods, challenges and needs for noise HIA in Europe. chaired by Francesco Forastiere (ASL)		
13.30-14.00	**Presentation 1:** Noise HIA in a broader environmental context		Katrin Ohlau (USTUTT)
14.00-14.20	**Presentation 2:** European HIA: health and exposure comparability issues		Stelios Kephalopoulos (JRC)
14.20-14.40	**Presentation 3:** Traffic noise effects on sleep: Impact assessment and mitigation		Mathias Basner (PEN)
14:40-15.00	**Presentation 4:** Translating noise impacts into costs – example UK		Bernard Berry (BEL)
15.00-15.30	**Tea and coffee break**		
15.30-16.30	**Session IV. –** Discussion and conclusions chaired by Laura Perez (Swiss TPH)		
15:30-15:45	**Presentation 1:** Specific approaches and needs – Selections of CRFs, evaluation of population exposure and approach for quantifications		Laura Perez (Swiss TPH)
16.30	**Adjourn meeting**		

Agenda of ENNAH workshop 6
"New strategies for noise and health research in Europe"

Wednesday 16th February 2011

Wolfson Institute room 130, Charterhouse Square, London EC1M 6BQ

Time	Detail	Speaker
12.30-13.30	**LUNCH**	
13.30-13.45	**Welcome + opening of the workshop** **Film on Noise and Health**	Stephen Stansfeld
13.45-15.30	**New directions for noise & coronary heart disease research**	**Champion:** Wolfgang Babisch **Discussants/Respondents:** Goran Pershagen Danny Houthuijs discussion
15.30-16.00	**TEA AND COFFEE BREAK**	
16.00-17.30	**New directions for noise & annoyance research**	**Champion:** Birgitta Berglund **Discussants/Respondents:** Sabine Janssen Jacques Lambert discussion
19:00	**Evening meal at Hat and Feathers pub**	

Agenda of ENNAH workshop 6
"New strategies for noise and health research in Europe"

Thursday 17th February 2011

Wolfson Institute room 130, Charterhouse Square, London EC1M 6BQ

Time	Detail	Speaker
09.00-10.30	**Think Tank: the role of genetics in noise effects on health** 'Genetic factors in relation to the effects of environmental stressors on health' 'Genetic component of noise sensitivity'	Chair: Stephen Stansfeld Paolo Vineis Marja Heinonen-Guzejev Discussion
10.30-11.00	**TEA AND COFFEE BREAK**	
11.00-12.00	**Think Tank: Stress and health** Methods of investigating biological pathways linking stress and health	**Chair:** Charlotte Clark Andrew Steptoe Discussion
12.00-13.00	**New directions for noise effects on hearing research**	**Champion:** Mariola Sliwinska-Kowalska **Discussant/Responsent**: Adrian Davis Discussion
13.00-14.00	**LUNCH**	
14.00-15.30	**New directions for noise & sleep research**	**Champion:** Barbara Griefahn **Discussants/Respondents:** Sabine Janssen Ken Hume Discussion
15.30-16.00	**TEA AND COFFEE BREAK**	
16.00-17.15	**New directions for noise & mental health research** Moderating factors of the relationship between environmental noise exposure and children`s health and cognition (The RANCH Project)	**Champion:** Stephen Stansfeld **Discussant/Respondent:** Irene van Kamp Rosanna Crombie Discussion
17.15-18.15	**ENNAH co-ordinating committee meeting** **[committee members only]**	Stephen Stansfeld/Charlotte Clark
19:00	**Evening meal at Smith's**	

Agenda of ENNAH workshop 6
"New strategies for noise and health research in Europe"

Friday 18th February 2011

Wolfson Institute room 130, Charterhouse Square, London EC1M 6BQ

Time	Detail	Speaker
09.00-10.00	**Think tank: Cross-cutting themes and research gaps**	Anna Hansell/Helga E. Laszlo
10.00-11.00	**New directions for noise effects on child health research**	**Champion:** Irene van Kamp **Discussant/Respondent:** Goran Belojevic discussion
11.00-11.30	**TEA AND COFFEE BREAK**	
11.30-13.00	**New directions for noise effects on cognition research**	**Champion:** Staffan Hygge **Discussants/Respondents:** Dylan Jones Charlotte Clark discussion
13.00-14.00	**LUNCH**	
13.30-14.30	**Plenary discussion**	**Chair:** Stephen Stansfeld
14.30-15.00	**Close of meeting**	

ANNEX B. LIST OF LITERATURE REVIEW PAPERS

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ANNEX C. QUALITY ASSESSMENT OF LITERATURE REVIEW PAPERS ON NON-AUDITORY EFFECTS OF NOISE (WP2)

Following a web based search (The Cochrane Collaboration, Web of Science for related papers) and hand search (epidemiology related books) for quality assessment of general review papers it was concluded that quality assessment is mainly focusing on systematic reviews and meta-analyses. Therefore the WP2 work package decided to set up criteria that are thought to be more suitable for different types of reviews identified within the ENNAH literature review work.

The criteria for assessing scientific quality of research reviews based on the combination of AMSTAR measurement tool that is used to assess the methodological quality of systematic reviews

(http://www.springerlink.com/content/qj5073804n1227x6/), the Critical Appraisal Skills Programme (CASP) crib sheet for a systematic review (http://www.casp-birmingham.org/) and a quality assessment tool for review papers presented in Appendix C in Chou R, Norris S, Carson S, Chan BKS. Drug Class Review on Drugs for Neuropathic Pain. 2007

(http://www.ncbi.nlm.nih.gov/books/NBK10597/). Furthermore two extra questions were included concerning the type of the review and numbers cited that is based on the record shown in Web of Science by 05 September 2012.

No tool is available for assessing the quality of grey literature; therefore only two distinctions have been made:

- Institutional and governmental reports including WHO and other national/international organisation reports are highlighted in dark grey
- Thesis, conference proceedings and other grey literature are highlighted light grey.

The following criteria were judged or each review paper:

1. Was the research protocol reported?
   YES if review states the research question, inclusion criteria, database used and something about research terms. (1 point)
2. Was the research comprehensive?
   YES if at least two electronic sources were searched. (1 point)
3. Was there any inclusion/exclusion criteria provided?
   For example including grey literature, language... (1 point)

4. Was selection bias avoided?

    YES if review gives information about the number of identified studies and number of excluded ones (with reason explanation) (1 point)

5. Was the scientific quality of included studies assessed and reported?

    YES if methodological rigor and scientific quality of identified papers are considered (1 point)

6. What was the type of the review?

    Systematic review, meta-analysis (3 points)
    Critical review (2 points)
    Narrative review (1 point)

7. Number of citations?

    For papers published between 1980-1990:
        1-20 (0 point)
        21-35 (1 points)
        35< (2 points)
    For papers published between 1991-2000:
        1-15 (0 point)
        16-25 (1 points)
        25< (2 points)
    For papers published between 2001-2009:
        1-10 (0 point)
        11-20 (1 points)
        21< (2 points)
    For papers published after 2010:
        1-5 (0 point)
        6-10 (1 points)
        11< (2 points)

1-4 points: yellow   5-7 points: orange   8-10 points: red

→ Better quality

Yellow, orange, red highlights refer to the quality of the review paper published in peer-reviewed journal

Table A. Quality of identified review papers published in peer-reviewd journals (yellow – low quality score, orange – medium quality score, red – high quality score)

Abel 1990	Marquis-Favre et al. 2005b	Babisch 2000	Babisch 2008
Alves-Pereira 1990	Maschke 2011	Babisch 2006a	Babisch & van Kamp 2009
Babisch 2002	Maschke & Hecht 2004	Banerjee 2012	Clark et al. 2007
Babisch 2003	Maschke et al. 2000	Brown & van Kamp 2009a	Egan 2003
Babisch 2004	Maschke et al. 2003	Duncan 1993	Kaltenbach et al. 2008
Babisch 2011	Mathenson et al. 2003	Job 1988	Morrell et al. 1997
Belojevic et al. 2003	Michaud et al. 2007	Knopper & Ollson 2011	Ndrepepa & Twardella 2011
Belojevic et al. 2011	Moehler 1988	Miedema & Vos 2003	Perron et al. 2012
Berglund et al. 1996	Muzet 2007	Paunović et al. 2010	van Kempen & Babisch 2012
Bluhm & Eriksson 2011	Muzet 2011		van Kempen et al. 2002
Borg 1981	Nemecek et al. 1981		
Brown & Lam 1987	Olaosun et al. 2009		
Brown & van Kamp 2009b	Osada 1988		
Bruni et al. 2011	Ouis 2002		
Clark & Stansfeld 2007	Ouis 2001		
Cohen & Weinstein 1981	Ouis 1999		
Cosa & Cosa 1989	Passchier & Passchier 2000		
de Jong 1990	Passchier & Passchier 2005		
Dalton & Behm 2007	Pirrera et al. 2010		
Fidell et al. 2010	Prasher (2009)		
Finegold 2010	Raschke (2004)		
Griefahn 1991	Rylander 2006		
Hancock & Pierce 1985	Schust (2004)		
Hoffmann et al. 2009	Seidman & Standring 2010		
Hume 2010	Shield et al. 2010		
Hygge 2011	Smith 1990		
Ising & Braun 2000	Smith 1991		
Ising & Kruppa 2004	Smith 2003		
Ising et al. 1999	Spreng (2004)		
Job 1996	Stansfeld 1992		
Kawada 1995	Stansfeld & Clark 2011		
Kawada 2004	Stansfeld& Crombie 2011		

Kawada 2011	Stansfeld & Matheson 2003		
Kjellberg 1990	Stansfeld et al. 2000		
Klæboe 2011	Tomei et al. 2009		
Kohlhuber & Bolte 2011	Tominsek & Bilban 2011		
Kujala & Brattico 2009	van Kempen 2011		
Lercher 1996	Waye 2011		
Lercher 2011	Weinstein 1982		
Leventhall (2004)	Wilkins & Action 1982		
Ljungberg 2009	Zaharna & Guilleminault 2010		
Marquis-Favre et al. 2005a			

Table B. Identified grey literature reviewing the literature on environmental noise and health (dark grey - institutional and governmental reports, light grey - thesis, conference proceedings and other grey literature)

Anonymus 1990	Diaz et al. 2001	Lee & Fleming 2002	Davies & Kamp 2008
Babisch 2006b	EEA 2010	Leventhall 2003	
Barrowcliffe et al. 2006	ERM 2008	Mestre 2008	
Berglund & Lindvall 1995	EU 2004	Miedema et al. 2003	
Berglund et al. 1999	Fields 1992	Porter et al. 1998	
Berry 2008	HCE 1994	Roberts & Roberts 2009	
Berry & Flindell 2009a	HCE 2004	Schneider et al. 2005	
Berry & Flindell 2009b	Holland 1997	Smith & Broadbent 1991	
Berry & Porter 2004	Horonjeff & William 1997	Stansfeld et al. 1997	
Bistrup 2001	HPA 2009	Suter 1991	
Bly et al. 2001	Ising et al. 2004	Swift 2010	
Boesch et al. 2008	Jones 2009	WHO 2005	
Colby et al. 2009	Jones 2010a	WHO 2009	
den Boer & Schroten 2007	Jones 2010b	WHO 2011	

ANNEX D. LIST OF ENNAH PARTNERS'AFFILIATIONS

Affiliation key	Affiliation
ARPAP	Environmental Protection Agency of Piemonte Region
ARPAT	Environmental Protection Agency of Tuscany Region
ASL	Azienda Unita' Sanitaria Locale Roma
BEL	Berry Environmental Limited
BU	University of Belgrade
CAA	Civil Aviation Authority (UK)
CU	Cardiff University
CUB	Comenius University of Bratislava
HMGU	Helmholtz Zentrum Munchen
IC	Imperial College London
IFADO	Dortmund University
IFFSTAR	French Institute of Science and Technology devoted to Transport planning and networks (IFFSTAR), France
IVZRS	Institute of Public Health of the Republic of Slovenia
JRC	European Commission - Joint Research Centre
KI	Karoliska Institute
MEM	Memoxil Environmental Consultant
MMU	Manchester Metropolitan University
NIOM	Nofer Institute of Occupational Medicine
NKUA	National and Kapodistrian University of Athens
QMUL	Queen Mary University London
RIHP	Republic Institute for Health Protection (Macedonia)
RIVM	National Institute for Public Health and the Environment (Netherland)
USheffield	Sheffield University
STI	Institute for Social and Preventive Medicine at the Swiss Tropical Institute
SU	Stockholm University
TNO	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek
TOI	Institute of Transport Economics (Norway)
UBA	Federal Environment Agency (Germany)
UGävle	University of Gävle
UGent	Universiteit Gent
UGöteborg	Göteborg University
USTUTT	Stuttgart University
USouthampton	University of Southampton
Urome	La Sapienza, University of Rome

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Abstract

The ENNAH project (The European Network on Noise and Health) was funded by the European Union's 7th Framework Program (FP7-ENV-2008-1, project no.226442) to establish a research network of experts on noise and health in Europe. The network brought together 33 European research centres from 16 countries to establish future research directions and policy needs for noise and health in Europe. ENNAH focused on the study of environmental noise sources, in particular transport noise. This network facilitated high level scientific communication and encouraged productive interdisciplinary discussion and exchange through a series of workshops and reports.

An important aspect of the ENNAH Network has been identifying gaps in noise and health research while at the same time assessing, prioritizing and integrating the future research orientation into policy development which would lead to an efficient investment of resources allocated to noise and health research. Noise maps produced under the direction of the Environmental Noise Directive (2002/49/EC) are potentially a very useful resource for noise and health research. We have reviewed the advantages and disadvantages of current noise maps and recommended future changes that would make these maps more appropriate for noise and health research. We have also considered possible new methods for acoustic measurement and modelling which will help to develop innovative exposure measurement techniques in future noise and health studies.

Primarily, ENNAH focused on outlining new priorities for research on environmental noise and health which will hopefully feed into future calls for funding on environment and health matters from the EU. In some areas this means strengthening the evidence on existing exposure effect relationships and using more robust methods such as longitudinal rather than cross sectional studies. This is particularly relevant to the research on environmental noise and hypertension and coronary heart disease and on studies of noise and children's learning. Increasingly relevant for policy is new research that tests whether interventions to reduce noise are effective and also whether they have an impact on health. This is of great practical importance because it can suggest what interventions are efficient and cost optimized.

Last but not least, a further important area identified is to assess where new investment in noise research should be placed, whether this relates to previously non- or poorly studied health outcomes or improvements in the noise and health methodological framework.

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