From: Coral Beach Lodge <info@coralbeachlodge.com>
Sent: Thursday, 12 August 2021 5:30 PM
To: Enquiries
Subject: Objection to D.A MCUC 2021_4231/1 (1024546) - Heliport on Port St. Port Douglas
Attachments: Dear Douglas Council.pdf; FAA 04nov-30-rtc[1].pdf; WHO Comnoise-1.pdf; WHO VGood noise-guidelines-exec-sum-eng.pdf; AU Gov health-effects-Environmental-Noise-2018.pdf; EnvReport2019-WhitePaper-Noise.pdf

Dear Sir or Madam,

Please find the attached objection plus reports supporting the objection the Morris Aviation plan to build a heliport in Port St. Port Douglas.

Thanks

Tom Quealy
Coral Beach Lodge
1-7 Craven Close. Port Douglas.

Coral Beach Lodge
1-7 Craven Close
Port Douglas QLD 2877
12th August 2021

Objection to the heliport development proposed by Morris Aviation. Port St Port Douglas

Dear Douglas Council,

Have you ever wondered why all helicopter pilots, ground crew and passengers have to wear ear protection? It's to prevent permanent ear damage, it's to prevent the operators from being sued. Our residence, guests and staff will not be afforded such a luxury.

I am one of 3 co-owners of Coral Beach Lodge located less than 200 metres from the proposed heliport. We are a small business and have invested everything in rebuilding Coral Beach Lodge.

During the peak season we have a 95% occupancy ratio, meaning anywhere between 90 and 120 guests. These are made up of 50% medium term guests who stay for 2 to 6 months' and work in Port Douglas as housekeepers, kitchen hands, cleaners etc. The remainder are holiday makers looking a peaceful local, lower-cost resort to spend their down time. We employ 3 full time and 8 part time staff and contract 10-12 local tradies for specialised repairs and maintenance. We pay our taxes and bills on time. We are very good citizens.

The heliport development will destroy our business, our guests and our staff. But it's not just about the noise, it's about what the noise does to people, to buildings and to the animals with whom we share our environment. It is proven to cause every from nausea to mental and coronary issues.

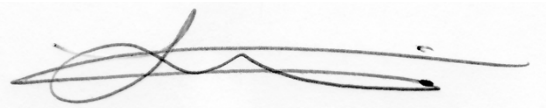
There are endless reports (several attached) highlighting the issues of noise particularly helicopter noise. Quoted below is one commissioned by our own Federal government in 2018 and one by the World Health Organisation. The complete documents are attached to this email.

I beg the council, please study the reports, look at the location and do the sums. Should one man's desire to fly his toys in and around the suburban streets and the waterways of Port Douglas out weight the needs of the many who are entitled to peaceful the enjoyment of their homes and their businesses?

The application speaks of 20 flights per day, that is a minimum of 40 movements, takeoffs and landings shaking Coral Beach Lodge's buildings, their neighbours, their staff and guests. Its 40 movements per day proven to cause heart disease, learning disorders, the destruction of relationships and the damaging of hearing. Its 40 movements a day that will decimate the wildlife of the mangroves, the crabs, the crocs, the crustaceans and the mangroves themselves. And its 40 movements a day that will destroy Coral Beach Lodge

Port street Port Douglas is no place for a heliport.

Regards



Thomas Quealy (Co-Owner)
Coral Beach Lodge
1-7 Craven Close. Port Douglas. QLD 4877

I 2018 the Australian Department of Health handed down a report on "Health Effect From Environmental Noise"

Summary of findings

There is sufficient evidence of a causal relationship between environmental noise and both sleep disturbance and cardiovascular disease to warrant health based limits for residential land uses:

- *• During the night-time, an evidence based limit of 55 dB(A) at the facade using the $L_{eq,night}$, or similar metric and eight-hour night-time period is suggested.*
- *• During the day-time, an evidence based limit of 60 dB(A) outside measured using the $L_{eq,day}$, or similar metric and a 16 hour day-time period is suggested.*

  There is some evidence that environmental noise is associated with poorer cognitive performance. However findings were mixed and this relationship requires further investigation.

  It is plausible that aircraft, rail and road traffic noise have differential effects on sleep quality and cardiovascular health ……

  Research on the health impacts of environmental noise in the Australian context should be a priority. There is a particular lack of research on environmental noise exposure and health impacts in rural areas. Intervention studies examining the effects of change in noise exposure on changes in population health are also needed

In a World Health Organisation report titled "Environmental Noise Guidelines"

"Recommendation

For average noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft below 45 dB L_{den}., as aircraft noise above this level is associated with adverse health effects.

For night noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft during night time below 40 dB L_{night}., as night-time aircraft noise above this level is associated with adverse effects on sleep.

To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions the GDG recommends implementing suitable changes in infrastructure.

Strength

Strong Strong Strong "

Federal Aviation
Administration

REPORT TO CONGRESS

Nonmilitary Helicopter Urban Noise Study

Washington, DC 20591

December 2004

**Report of the
Federal Aviation Administration
to the United States Congress
Pursuant to Section 747 of the
Wendell H. Ford Aviation
Investment and Reform Act for
the 21st Century (AIR-21)**

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LIST OF ABBREVIATIONS

AGL	Above Ground Level
ANCA	Airport Noise and Capacity Act
ANSI	American National Standards Institute
ASEL	A-weighted Sound Exposure Level
ASNA	Aviation Safety and Noise Abatement Act
AStar	Eurocopter (former Aerospatiale) helicopter
ATC	Air Traffic Control
BVI	Blade Vortex Interaction
B206	Bell 206 Helicopter
B&K	Brüel & Kjær
CAEP	Committee on Aviation Environmental Protection
CFR	Code of Federal Regulations
CPA	Closest point of approach
dB	Decibel
dGPS	Differential Global Positioning System
DAT	Digital Audio Tape
DNL	Day-Night Sound Level
DOT	Department of Transportation
EC	Eurocopter Corporation
EGA	Excess Ground Attenuation
EMS	Emergency Medical Services
ENG	Electronic News Gathering
EPA	Environmental Protection Agency
EPNL	Effective Perceived Noise Level
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FICAN	Federal Interagency Committee on Aviation Noise
GPS	Global Positioning System
HNM	Helicopter Noise Model
HP	Hewlett Packard
HSI	High Speed Impulsive noise
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
INM	Integrated Noise Model
INMrv	INM Research Version
LAAS	Local Area Augmentation System
LEQ	Equivalent Sound Level
Lmax	Maximum A-Weighted Sound Level
LSP	Liberty State Park, New Jersey
MD	McDonnell Douglas
MDHI	McDonnell Douglas Helicopters Incorporated
NAS	National Airspace System
NASA	National Aeronautics and Space Administration

NEPA	National Environmental Policy Act
NOTAR	No Tail Rotor
NRTC	National Rotorcraft Technology Center
NYC	New York City
PNLT	Perceived Noise Level Tone Corrected
R&D	Research and Development
RITA	Rotorcraft Industry Technology Association
SAE	Society of Automotive Engineers
SEL	Sound Exposure Level
SIL	Speech Interference Level
SPL	Sound Pressure Level
SS	Sight Seeing
S-76	Sikorsky Model S-76 Helicopter
TSPI	Time Space Position Information
UNC	Uncontrolled Condition
UTC	Universal Coordinated Time
VFR	Visual Flight Rules
VOR	Very High Frequency Omni-directional Range
VTOL	Vertical TakeOff and Landing
vTSPI	Video Time Space Position Information
WAAS	Wide Area Augmentation System
WHO	World Health Organization

1.0 Executive Summary

In response to public concerns about nonmilitary helicopter noise impact on densely populated communities, the United States Congress directed the Secretary of Transportation to investigate and develop recommendations on reducing helicopter noise effects. Legislative guidance was developed and specified in the FAA authorization act entitled "Wendell H. Ford Aviation Investment and Reform Act for the 21st Century" (Public Law 106-181) under Section 747 - Nonmilitary Helicopter Noise. The Federal Aviation Administration (FAA) carried out this study on behalf of the Secretary.

The FAA outlined a three-step approach to perform this study. The first step of the FAA approach was a comprehensive literature review of current noise effects on human beings. The review identified several socio-acoustic concerns addressed in the report. These were:

- Noise-induced hearing impairment;
- Interference with speech communication;
- Effects of noise on performance;
- Sleep disturbance;
- Cardiovascular and physiological effects;
- Mental health effects; and
- Effects of noise on residential behavior and annoyance.

Second, FAA solicited public input through Federal Register notices and two public workshops.[1] This generated numerous comments from private citizens, elected officials, civic group representatives, and the helicopter industry. The comments were categorized into operational and non-operational issues. The operational issues most frequently expressed were:

- Minimum altitude for overflight and hover;
- Operational routes & routing design guidelines;
- Hover duration time;
- Retirement of noisiest helicopters;
- Visible identification markings;
- Frequency of helicopter operations (number of flights);
- Time frame of helicopter operations (hours of operation);
- Heliports/airports operations (i.e., ground run-up duration);
- Noise abatement procedures;
- Noise certification limit stringency; and
- Implementation of noise reduction technology (i.e., helicopter "hushkits").

The nonoperational issues most frequently expressed were:

- Effectiveness of voluntary "Fly Neighborly" program;
- Redundancy of Electronic News Gathering (ENG) flights;

[1] 65 FR 39220 (June 23, 2000) and 65 FR 49630 (August 14, 2000).

- Acceptance of public service helicopter operations; i.e., law enforcement, emergency medical services (EMS), and fire fighters;
- Visual Flight Rule (VFR)/Instrument Flight Rule (IFR) Air Traffic Control (ATC) operations access for helicopters;
- Empowerment of local municipalities with airspace control;
- Accounting for military helicopter impact;
- Need for a socio-acoustic (psychoacoustic) study relating medical and health effects;
- Tracking of helicopter traffic growth and noise measures to quantify impact of noise sensitive community sites (parks, hospitals, neighborhoods, etc);
- Utilization of differential Global Positioning Systems (dGPS) approach/departure for noise abatement operations; and
- Insensitivity of A-weighted measurements in accounting for low-frequency noise impact of helicopters.

The third part of the FAA approach involved the acquisition of helicopter noise measurements to quantify noise levels in a densely populated metropolitan area. This was done by taking sets of noise measurements within the urban center of New York City. The FAA's preliminary *in-situ* noise measurements showed that increasing operational altitude does reduce noise from helicopters (see Section 7.2 and Appendix G), corroborates operational noise measurements reported in the New York City Master Plan Report, and supports the industry's voluntary operational guidance to "fly higher" altitudes.

Conclusions and Recommendations:

The FAA offers the following conclusions and recommendations based upon the study:

- Additional development of models for characterizing the human response to helicopter noise should be pursued. Civil helicopter annoyance assessments utilize the same acoustic methodology adopted for airplanes with no distinction for a helicopter's unique noise character. As a result, the annoyance of unaccustomed, "impulsive" helicopter noise has not been fully substantiated by a well-correlated metric. Comments from both the helicopter industry and the public strongly recommended that further socio-acoustic investigations be pursued. Additional civil helicopter annoyance studies may help refine current noise measurement analysis methodology that would lead to improved noise mitigation effectiveness. The Federal Interagency Committee on Aviation Noise (FICAN) should charter a technical study to focus on low frequency noise metric to evaluate helicopter annoyance, including performance of multi-year socio-acoustic (noise) studies to correlate helicopter annoyance and health effects of urban helicopter operations. In the meantime, the FAA will continue to rely upon the widely accepted Day-Night Sound Level (DNL) as its primary noise descriptor for airport and heliport land use planning. The FAA will also continue the use of supplemental noise descriptors for evaluation of helicopter noise issues.

  To date, this recommendation has been incorporated into the Rotorcraft Research and Development Initiative for Vision 100 – Century of Aviation Reauthorization Act (Public Law 108-176) under Sec. 711. For Sec. 711, NASA, FAA, and the rotorcraft industry defined a 10-year rotorcraft research and development (R&D) plan that included the study of Psychoacoustics. The research proposes to determine human annoyance levels due to helicopter noise, both in its native condition and synthetically modified. Studies would be conducted to uncover neglected characteristics of noise and develop a refined metric more representative of the true human response.

- Further operational alternatives that mitigate noise should be explored. A number of operational alternatives, proposed by the public and industry, have the potential to mitigate urban nonmilitary helicopter noise and preserve the safe and efficient flow of air traffic. In particular, the FAA found:

  - Noise reduction benefits can be achieved with higher altitude flight. With more conclusive demonstrations addressing safety, such noise mitigation approaches could be integrated within the ATC design planning in specific urban airspaces;

  - Optimal helicopter route planning to avoid noise sensitive areas will require comprehensive evaluation for each specific region of concern;

  - The promotion of noise abatement procedures should be pursued on two fronts – with helicopter pilots and air traffic control personnel. The FAA will continue training ATC personnel to increase awareness of noise abatement procedures that best mitigate noise over communities; and

  - The use of advanced technologies, such as dGPS, aids in helicopter approach and departure procedures do show to be beneficial for noise abatement operations. Preliminary dGPS/noise research sponsored by the National Rotorcraft Technology Center (NRTC)/ Rotorcraft Industry Technology Association (RITA) has indicated promising noise reductions using more precise procedures.

  The implementation of any of these alternatives would require comprehensive evaluation, and demonstration where appropriate on a case-by-case basis, in accordance with all applicable FAA orders and regulations. Also, careful consideration would have to be taken of any ATC changes to an urban segment of the National Airspace System (NAS) that could impact the heavily utilized and highly burdened large commercial transport sector. Finally, funding levels required to develop and explore the technology and procedures listed above will be significant.

  Similarly under the 2004 Vision 100 Rotorcraft R&D plan, operational noise reduction studies were defined to aid in the noise mitigation of legacy helicopters, such as the Sikorsky S-76 and Bell helicopter products. The expansion of noise abatement flight techniques would be tested for consistency with safety and passenger comfort for several classes of rotorcraft: light, medium and advanced configurations. At the R&D program conclusion, the compilation of noise mitigation technology and abatement operational procedures is to be integrated and demonstrated in a selected single flight vehicle for noise and system validation.

Also, under the Vision 100 plan, there is the “Zero ceiling/Zero visibility” operational goal that addresses advances in navigational system such as wide area augmentation system (WAAS) and local area augmentation system (LAAS) and moving to a comprehensive differential global position system (dGPS) precision navigation capability. Such research applications have proven beneficial to noise mitigation and are expected to enhance the noise abatement operational procedures development.

- Emergency helicopter service should be exempt from restrictions. A key outcome of the FAA-hosted workshops was the mutual agreement among public and industry participants that emergency helicopter service (air medical, law enforcement, fire-fighting, public services, etc.) should be exempted from any proposed limitations or restrictions considered by Congress following this study. These services are time-critical and provide a “noise-excusable” public service.

- Helicopter operators and communities should develop voluntary agreements to mitigate helicopter noise. Federal, state, and local governments encourage voluntary mutual cooperation by helicopter operators, the community, and local authorities in the establishment of a “noise response” process. Federal, state and local governments establish business incentives that encourage the “pooling” of helicopter operations, especially for redundant ENG operations.

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2.0 Introduction

Helicopters serve specialized functions and important roles in the Nation's commerce and transportation system. Helicopters are a versatile and valued segment of the multimodal transportation infrastructure. The helicopter's unique hovering, vertical takeoff and landing capabilities fulfill a broad range of missions. Helicopters support vital roles including air ambulance services; Federal, state, and local law enforcement patrol; flexible corporate shuttle services; news coverage; parcel distribution; aerial tourism; firefighting; and heavy lift capability.

Over the past several decades, significant technological advances have been made in aviation noise reduction. However, research and development activities have succeeded primarily in reducing the noise levels associated with commercial transport jet airplanes. Much of the scientific investments for rotorcraft has benefited in physical understanding and phenomenon modeling, such as Blade Vortex Interaction (BVI) and High Speed Impulsive (HSI) noise during approach and high speed cruise, respectively. A Congressional Report on "Quiet Aircraft Technology for Propeller-Driven Airplanes and Rotorcraft" identified the technical status of the United States Research and Technology (R&D) for the rotorcraft sector. The 1996 report concluded that, in general, quiet rotorcraft technology was immature and too slow to market.

A notable "low noise" technological success was achieved with the non-conventional NOTAR (NO TAil Rotor) anti-torque design by MDHI (formerly McDonnell Douglas Helicopters Incorporated). Yet, a major challenge continues to exist in balancing cost to implement low noise technology within an overall affordable market cost to users and operators.

The FAA and the International Civil Aviation Organization (ICAO) continue to assess and revise rotorcraft noise certification requirements for increased noise stringency that are based upon reasonably achievable noise reduction technology. The noise certification process establishes reference conditions for the manufacturer to demonstrate that a design complies with the standard.

In the New York City metropolitan area, there has been an ongoing dispute over helicopter noise. Communities there are concerned that helicopter noise impacts their quality of life. Consequently, New York City launched a comprehensive master plan analysis that studied: 1) the City's heliport "needs", 2) heliport guidelines taking into consideration the environment and socioeconomic issues of the community, 3) future heliport planning, 4) present and future airspace integration issues, and 5) proposed financial planning and implementation schedule.[2]

2.1 Mandate

In response to public concerns about nonmilitary helicopter noise impact on densely populated communities, the U.S. Congress directed the Secretary of Transportation to investigate the effects of helicopter noise and to develop recommendations for reducing the effects.

[2] Edwards and Kelcey Engineering, Inc., "Heliport and Helicopter Master Plan for the City of New York," Final Report, March 1999.

This mandate was specified in Section 747 (Public Law 106-181) of the FAA authorization act entitled “Wendell H. Ford Aviation Investment and Reform Act for the 21st Century.” It states:

Section 747. - Nonmilitary Helicopter Noise

(a) IN GENERAL- *The Secretary shall conduct a study - (1) on the effects of nonmilitary helicopter noise on individuals in densely populated areas in the continental United States; and (2) to develop recommendations for the reduction of the effects of nonmilitary helicopter noise.*

(b) FOCUS- *In conducting the study, the Secretary shall focus on air traffic control procedures to address helicopter noise problems and shall take into account the needs of law enforcement.*

(c) CONSIDERATION OF VIEWS- *In conducting the study, the Secretary shall consider the views of representatives of the helicopter industry and organizations with an interest in reducing nonmilitary helicopter noise.*

(d) REPORT- *Not later than 1 year after the date of the enactment of this Act, the Secretary shall transmit to Congress a report on the results of the study conducted under this section.*

FAA carried out this study on behalf of the Secretary of Transportation.

2.2 Background

New York City has spawned the most extensive utilization of helicopter services of any city in the world. The New York City’s heliports have over 150,000 takeoffs and landings annually. There have also been increasing community noise complaints leading to the formation of anti-helicopter interest groups. In response, the City of New York initiated and prepared a comprehensive assessment of the City’s heliport infrastructure and related helicopter activities to better balance local helicopter industry’s operational needs and the affected communities’ quality of life. Completed in 1999, the City’s master plan outlined a comprehensive framework of developmental planning, review of commerce, economics, and environmental issues and proposed long-term planning guidelines.[3] In addition, New York City has established a policy not to support air tour activities.[4] However, state and local governments do not have the authority to regulate aircraft flight operations. Such authorities lie with the FAA and must be addressed in accordance with all applicable FAA orders and regulations. To minimize their noise liability, state and local governments, acting as airport proprietors, have authority to adopt reasonable nondiscriminatory restrictions on access that do not impose on undue burden on interstate commerce.

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[3] Edwards and Kelcey Engineering, Inc.

[4] R. Grotell, Docket Comment #76: The City of New York: Office of the Mayor,” October 20, 2000.

2.3 FAA Study Process

The FAA used three methods to gather data to complete this study. The methods included: (1) solicit comments via Federal Register notice(s) and at public workshop(s), (2) review current noise effects literature, and (3) measure helicopter source noise in a densely populated metropolitan area.

The FAA hosted two public workshops and opened a docket for submission of written comments after soliciting information in the Federal Register. The comment period was extended to provide sufficient time for public responses.

2.4 Report Format

This report presents the urban helicopter noise study information that the FAA was required to prepare pursuant to Section 747 of the Wendell H. Ford Aviation Investment and Reform Act for the 21^{st} Century.

Section 1 is the Executive Summary.

Section 2 presents an introduction including the general background on the circumstances that led to this legislative mandate. It also outlines the approach implemented by the FAA to perform the study; i.e., seek public input, literature review, and urban source noise measurements.

Section 3 presents the current state of scientific research on noise effects on individuals based on past socio-acoustic study findings. Where appropriate, it relates the criteria to aviation noise and more specifically helicopter noise.

Section 4 is a compilation of the helicopter noise reduction comments offered by the public and helicopter industry. The information is summarized and presented as an issues list with a synopsis of responses.

Section 5 presents the ATC procedures and regulations that support safe helicopter operations. Specific helicopter noise issues that relate to ATC operations are discussed. The needs of law enforcement and other emergency services are addressed.

Section 6 takes into consideration the views expressed by the public and industry. It offers the FAA's response to each of the issues identified.

Section 7 presents the FAA sponsored helicopter source noise measurements recorded in a densely populated metropolitan urban area. This noise data consists of a limited sample of *in-situ* noise measurements. In addition, a technical assessment of the noise-altitude sensitivity for a broad range of helicopters is discussed.

Section 8 summarizes the conclusions and recommendations for helicopter noise reduction on individuals in densely populated (urban) areas.

3.0 Noise Effects on Individuals

In this section, current scientific research concerning noise effects on individuals has been compiled and summarized.

3.1 Health Effects - Introduction

In a recent report, the World Health Organization (WHO) offers guidance on the potential health effects due to community noise exposure. The report categorizes the effects as follows:

- Noise-induced hearing impairment;
- Interference with speech communication;
- Effects of noise on performance;
- Sleep disturbance;
- Cardiovascular and physiological effects;
- Mental health effects; and
- Effects of noise on residential behavior and annoyance.[5]

The WHO study considered both environmental and occupational settings. Noise-induced hearing impairment is normally associated with occupational settings. Only when the 24-hour equivalent level exceeds 70 dB does the threat of environmental noise-induced hearing impairment arise.[6] Helicopters rarely produce 24-hour equivalent levels that exceed 70 dB. In fact, such worst case, high noise levels only occur near very busy military airfields operating heavy lift helicopters and frequent flights. Thus, noise-induced hearing impairment due to nonmilitary helicopters operations in urban environments is an unlikely condition.

3.2 Noise Effects on Communications and Performance

The WHO, based upon a study by Lazarus (1998), suggests that "noise interference with speech comprehension results in a large number of personal disabilities, handicaps and behavioral changes." The report goes on to say: "Problems with concentration, fatigue, uncertainty and lack of self-confidence, irritation, misunderstandings, decreased working capacity, problems in human relations, and a number of stress reactions have all been identified. Particularly vulnerable to these types of effects are the hearing impaired, the elderly, children in the process of language and reading acquisition, and individuals who are not familiar with the spoken language."

Nearly all information on this topic relates to the workplace or the classroom setting. The FICAN position on research in effects of aircraft noise on classroom learning states: "Research on the effects of aircraft noise on children's learning suggests that aircraft noise can interfere with learning in the following areas: reading, motivation, language and speech acquisition, and memory." No such data exist in other environmental noise settings. WHO (2000) states: "However, there are no published studies on whether environmental noise at home also impairs cognitive performance in adults."[7] Thus, at the present time, little can be said of environmental noise effects on communications and performance except as it relates to the classroom setting.

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[5] WHO 2000 - "Guidelines for Community Noise," edited by Berglund, B., Lindvall, T., Schwela, D., and Goh, K., World Health Organization/Ministry of the Environment, 2000.
[6] WHO 2000.
[7] WHO 2000.

Since at least the 1970s, research results have shown that environmental noise—primarily aircraft or road traffic—can adversely affect classroom learning.[8,9,10] Recent work near Heathrow airport and near the new and old Munich airports show similar results.[11,12,13,14] These studies treat the entire population of students in a cohort group as one single population. The study results generally show small but statistically significant effects. Masser (1970) showed larger effects by splitting the cohort groups into three sub-groups- the high achievers, the low achievers, and a middle group.[15] His studies showed that it was primarily the low achievers that were adversely affected by environmental noise. There was little effect from noise on the middle or high achiever groups. Thus, the small effects found in other studies maybe the result that mainly the low achievers are adversely affected but less discriminating within the unaffected majority of the population.

While the general effects of noise on learning have been demonstrated, there are also sub-groups of students that may be more affected than others. Students with hearing impairments, students for which English is a second language, music classes, and foreign language classes are all thought to be particularly susceptible to extraneous noise.[16,17]

To avoid the adverse effects of noise in classrooms, WHO (2000) recommends an indoor equivalent level in classrooms of 35 dB.[18] Similarly, a draft American National Standard that is being developed primarily with the noise from heating and ventilating equipment in mind also recommends an indoor classroom equivalent level of 35 dB.[19] With respect to helicopter noise in urban areas, it can be expected that, where flights are frequent, the indoor equivalent level from

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[8] S. Cohen, D.A. Glass, and J.E. Singer, 1973, "Apartment Noise, Auditory Discrimination, and Reading Ability in Children," *J. of Experimental Social Psychology*, 9, 407-422.

[9] A. Bronzaft, and D. McCarthy, 1975, "The effects of elevated train noise on reading ability," *Environment and Behavior*, **7**, 517-527.

[10] K.B. Green, 1980, "The Effects of Community Noise Exposure on the Reading and Hearing Ability of Brooklyn and Queens School Children," Ph. D. Thesis, Program in Environmental Health Sciences, Faculty of the Graduate School, New York University, New York, NY.

[11] S. Hygge, G.W. Evans, and M. Bullinger, 1996, "The Munich Airport noise study: cognitive effects on children from before to after the change over the airports," *Inter-Noise 96 Proceedings*, 2189-2194, Liverpool, England.

[12] S. Hygge, and G.W. Evans, 2000, "The Munich Airport noise study—Effects of chronic aircraft noise on children's perception and cognition," *Inter-Noise 2000 Proceedings*, in publication, Nice, France.

[13] S. Standfeld, M. Haines, J. Head, B. Berry, M. Jiggins, S. Brentnall, and R. Rhiannon, 2000, "Aircraft noise at school and child perform and health: Initial results from the west London schools study," *Inter-Noise 2000 Proceedings*, in publication, Nice, France.

[14] P. Lercher, G. Brauchle, W. Kofler, U. Widmann, and M. Meis, 2000, "The assessment of noise annoyance in schoolchildren and their mothers," *Inter-Noise 2000*, in publication, Nice, France.

[15] A. Masser, circa 1970, Private communications with P. Schomer re Highline School District vrs Sea-Tac Airport, School System Psychologist, Highline School District, Highline, WA.

[16] H. Lazarus, 1998, Noise and Communication: The present state. In N.L. Carter and R.F.S. Job (Eds.) Noise as a Public Health Problem, Vol. 1, pp. 157-162, Noise Effects '98 PTY Ltd., Sidney, Australia.

[17] WHO 2000.

[18] WHO 2000.

[19] ANSI, 2000, American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound—Part 6: Methods for Measurement of Awakenings Associated with Noise Events, ANSI S12.9-1996—Part 6, Draft—to be circulated for 30-day review prior to final adoption, American National Standards Institute (ANSI), New York, NY.

helicopter noise may exceed 35 dB. It is also highly probable that other urban noise sources, such as street traffic and subway trains, would exceed this threshold more frequently than helicopter operations.

3.3 Sleep Disturbance

The effects of noise on sleep disturbance remain the subject of much debate.[20,21] Studies performed in laboratories generally show effects of noise such as awakening at relatively low noise levels. However, the laboratory subject is in unfamiliar surroundings and connected to probes. In contrast, field studies near major airports found that behavioral awakenings occur only when the sound levels of individual events get very loud. Based on over 10,000 subject-nights in field studies, the percent of awakenings, P, is given by American National Standards Institute (ANSI) 2000:

$$P = 0.13\ \text{ASEL} - 6.64 \qquad (1)$$

where A-weighted Sound Exposure Level (ASEL) is in decibels.[22] Equation 1 suggests that there is no behavioral awakenings until the indoor sound exposure level exceed 51 dB. At 60 dB indoors, there is the probability that 1 percent will be awakened.

To further point out the difference between laboratory and field results in this area, Figure 3-1 shows separate regression lines fit to laboratory and field data for behavioral awakenings.[23] It is clear that the laboratory data and the *in-situ* data are not measuring the same effects. Most would agree that the field data represent what is actually happening to people in their homes while the laboratory data must be confounded by other variables such as adaptation, the presence of probes connected to the subject, unfamiliarity with the noise, and unfamiliarity with the surroundings. Nevertheless, the WHO (2000) has chosen to concentrate on the laboratory data and largely ignore the field data.

The FAA supports the FICAN* recommendation of a new dose-response curve for predicting awakening, based on field data[24]. The FICAN took the conservative position that, because the adopted curve represents the upper limit of the field data, it should be interpreted as predicting the "maximum percent of the exposed population expected to be behaviorally awakened" or the "maximum % awakened" (see Figure 3-2).

* FICAN - Federal Interagency Committee on Aviation Noise was formed in 1993 to provide forums for debate over future research needs to better understand, predict and control the effects of aviation noise, and to encourage new technical development efforts The Department of Defense (DOD), the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) are the primary agencies responsible for addressing aviation noise impacts through general R&D activities.

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[20] K. Pearsons, D. Barber, B. Tabachnick, and S. Fidell, 1995, Analysis of the predictability of noise-induced sleep disturbance," *Journal of the Acoustical Society of America*, **97**, 331-338.
[21] S. Fidell, K. Pearsons, R. Howe, L. Silvati, and D. Barber, 1995, "Field study of noise-induced sleep disturbance," *Journal of the Acoustical Society of America*, **98**, 1025-1033.
[22] ANSI 2000.
[23] ANSI 2000.
[24] "Effects of Aviation Noise on Awakenings from Sleep," Federal Interagency Committee on Aviation Noise, June 1997.

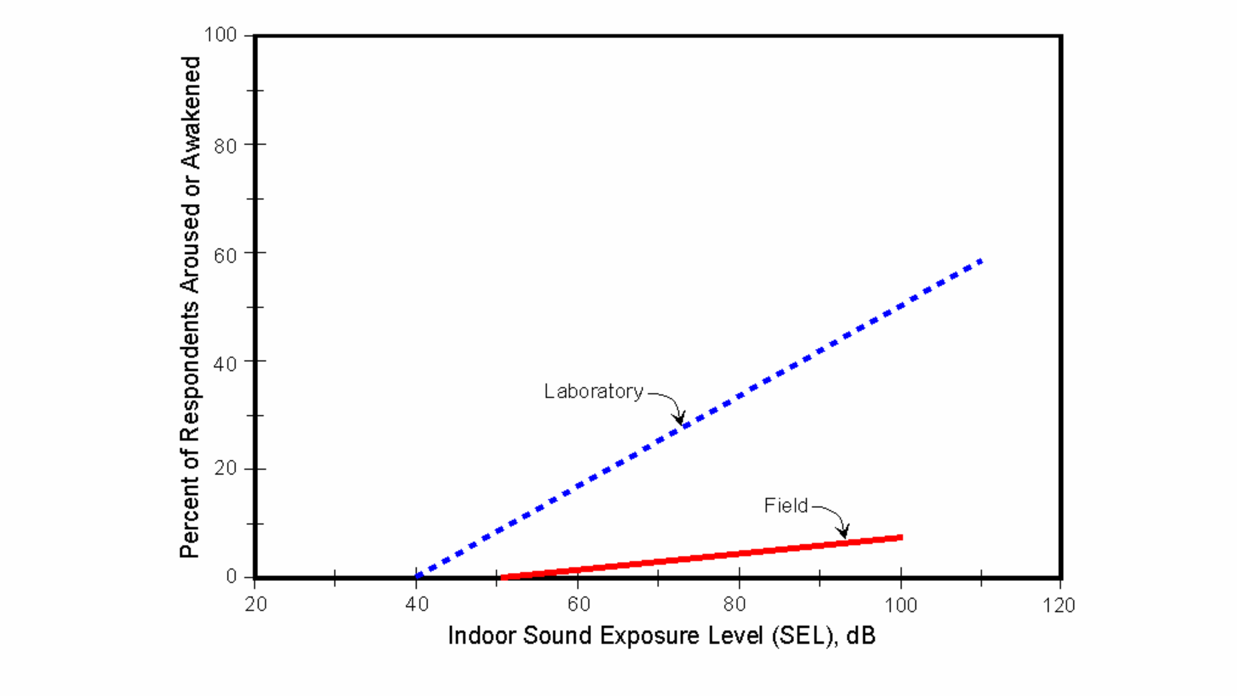

Figure 3-1. Behavioral awakening results: laboratory and field studies (ANSI 2000)

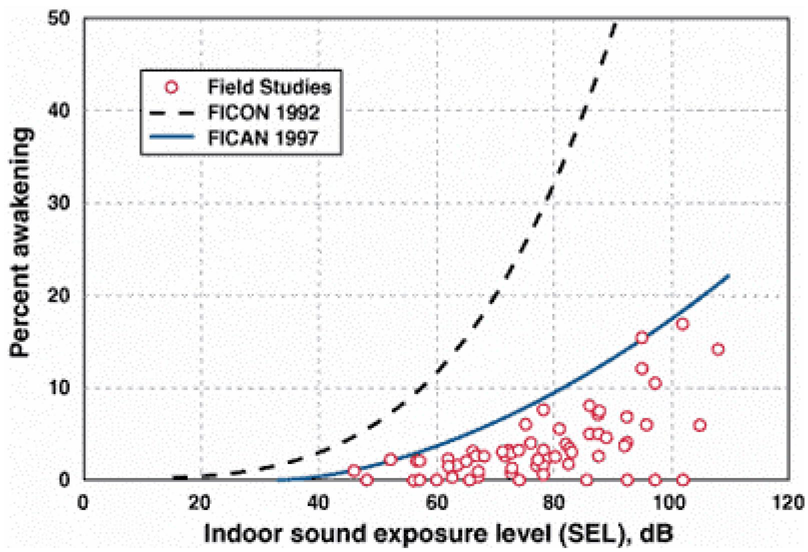

Figure 3-2. FICAN Recommended Sleep Disturbance Dose-Response Relationship

3.4 Cardiovascular and Other Physiological Effects

The WHO states: "The overall conclusion is that cardiovascular effects are associated with long-term exposure to 24-hour equivalent level values in the range of 65-70 dB or more, for both air- and road-traffic noise. However, the associations are weak…"[25] Reporting on results from the Health Council of the Netherlands, Passchier-Vermeer gives a 24-hour equivalent level of 70 dB as the "observation threshold of an effect for which the causal relationship with noise exposure is

[25] WHO 2000.

judged to be sufficient."[26] The term "observation threshold" is not defined but one can assume that it represents a small fraction of the total population. In any case, urban helicopter noise will not normally exceed a 24-hour equivalent level of 65 to 70 dB. These types of levels can be found only near the busiest of military airfields. Thus, one can conclude that urban helicopter noise does not represent a threat with respect to cardiovascular and other physiological effects.

3.5 Annoyance - Introduction

The assessment of helicopter noise has been the subject of much study over the past 30 years. Most NATO countries use the ASEL to assess helicopter noise. An alternative measure is the Effective Perceived Noise Level (EPNL). When using ASEL, the noise events over a period of time are combined into an equivalent level (LEQ). For daytime flights, Fields and Powell (1987) demonstrated a strong relationship between average LEQ and average annoyance over the range of 1 to 32 flights per 9 hours. In the Fields and Powell study, annoyance was flat up to an LEQ of 47 dB and then grew as a linear function of LEQ up to 59 dB.[27] No one has carried out a similar experiment for nighttime noise. Schomer found that the traditional 10 dB nighttime penalty, used in the determination of DNL, is consistent with community attitudinal data.[28]

During the 1970s, there was a widespread belief among environmental noise scientists in the U.S. Department of Defense that a given LEQ from rotary-wing is more annoying than an equal LEQ from fixed-wing aircraft. This belief was reflected in official policy through the imposition of a 7 dB penalty to be added "to meter readings obtained under conditions where Blade-Slap was present until and unless meters are developed which more accurately reflect true conditions."[29] Blade-Slap or BVI noise occurs during the descent condition for landing. It is the result of interaction by a rotor blade with previously shed tip vortices. These interactions generate a complex unsteady pressure field that propagates below the rotor as high impulsive noise.

The need for a Blade-Slap penalty was based primarily on laboratory studies. Leverton (1972) conducted one of the first studies comparing the A-weighted sound level from helicopter operations with and without Blade-Slap. The study, conducted in a simulated living room, found that the presence of Blade-Slap increased the subjects' annoyance to helicopter noise by the equivalent of 4-8 dB.[30] Other researchers who found that there was a need for a Blade-Slap correction included Man-Acoustics (1976), Lawton (1976), Wright and Damongeot (1977), Galanter *et al*., (1977), Galloway (1978), Klump and Schmidt (1978), and Sternfeld and Doyle (1978).[31,32,33,34,35,36,37]

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[26] W. Passchier-Vermeer, and W.F. Passchier, 2000, "Noise Exposure and Public Health," *Environmental Health Perspectives*, **108** Supplement 1, 123-131, March 2000

[27] J.M. Fields and C.A. Powell, 1987, "Community reactions to helicopter noise: Results from an experimental study," *Journal of the Acoustical Society of America*, **82**, 479-492

[28] P.D. Schomer, 1983b, "A Survey of Community Attitudes Toward Noise Near a General Aviation Airport," *Journal of the Acoustical Society of America*, **74**, 1773-1781

[29] DOD, 1977, Department of Defense Instruction 4165.57, 8 November 1977, "Air Installations Compatible Use Zones."

[30] J.W. Leverton, 1972, "Helicopter Noise – Blade-Slap, Part 2, Experimental Results," NASA Technical Report CR1983, March 1972.

[31] Man-Acoustics & Noise, Inc., 1976, "Certification Considerations for Helicopters Based on Laboratory Investigations," Report prepared for U.S. Department of Transportation, FAA-RD-76-116, July 1976.

Other laboratory studies suggested that a simple measure of impulsivity does not capture the unique annoyance of helicopter noise. Berry *et al*. (1975) found subjects to be more responsive to the “roughness” quality of the sound than to the Blade-Slap, per se.[38] Similarly, Galloway (1977) found the annoyance to be related to the rate of impulses.[39] Ohshima and Yamada (1987), using a variable high pass filter, concluded that low-frequency energy below 50 Hz did not contribute to the annoyance, but that low-frequency energy between 50 and 200 Hz did contribute.[40]

Subsequent field studies failed to produce support for a Blade-Slap penalty. In a U.S. Army study, listeners judged the annoyance of overflights by different helicopters and a control fixed-wing aircraft heard outdoors. The study found that their annoyance judgments correlated with A-weighting without the need for further correction.[41] Although the U.S. Army researchers concluded that a 2 dB penalty was consistent with the results, they asserted, “no correction for Blade-Slap was found which improves the prediction of annoyance.” In a NASA study, listeners compared the annoyance of helicopter and propeller aircraft flights heard both indoors and outdoors. Annoyance was accurately predicted by SEL.[42] In a subsequent community noise study of Fields and Powell (1987), unsuspecting residents reacted similarly to the flights of two helicopter types that had very dissimilar noise signatures.[43]

There is general agreement among a wide range of experts that adding a penalty to the A-weighted SEL to account for the annoyance of Blade-Slap is not justified.[44,45,46,47,48,49,50] In spite

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[32] B.W. Lawton, 1976, “Subjective Assessment of Simulated Helicopter Blade-Slap Noise,” NASA Langley Research Center, NASA TN D-8359, December 1976.
[33] S.E. Wright, and A. Damongeot, 1977, “Psychoacoustic Studies of Impulsive Noise,” Paper #55, Third European Rotorcraft Powered Lift Aircraft Forum, Aeronautical and Astronautic Association of France, September 1977.
[34] E. Gallanter, R.D. Popper, and T.B. Perera, 1977, “Annoyance scales for simulated VTOL and CTOL overflights,” Paper given at the 94th meeting of the Acoustical Society of America, Miami, Florida, December 1977.
[35] W.J. Galloway, 1978, “Review of the Development of Helicopter Impulsive Assessment Proposals by ISO TC43/SC1/WG2 – Aircraft Noise,” Memorandum Report, January 1978.
[36] R.G. Klump and D.R. Schmidt, 1978, “Annoyance of Helicopter Blade-Slap,” Naval Ocean Systems Center Technical Report 247, 3 July 1978.
[37] H.M. Jr. Sternfeld, and L.B. Doyle, 1978, “Evaluation of the Annoyance Due to Helicopter Noise,” NASA Contractor Report 3001, June 1978.
[38] B.G. Berry, A.J. Renie, and H.C. Fuller, 1975, “Rating Helicopter Noise: The Feasibility of an Impulsive Noise Correction,” National Physical Memorandum for ISO/TC43/SC1/WG2, October, 1975.
[39] W.J. Galloway, 1977, “Subjective Response to Simulated and Actual Helicopter Blade-Slap Noise,” Bolt, Beranek and Newman Report No. 3573 for NASA, December 1977.
[40] T. Ohshima and I. Yamada, 1987, “The evaluation of normal take-off/landing helicopter noise,” *Inter-Noise 87*, 1037-1041.
[41] J.H. Patterson, Jr. B.T. Mozo, P.D. Schomer, and R.T. Camp, 1977, “Subjective Ratings of Annoyance Produced by Rotary-Wing Aircraft Noise,” U.S. Army Medical Research and Development Command, USAARL Report, No. 77-12, May 1977.
[42] C.A. Powell, 1978, “A Subjective Field Study of Helicopter Blade-Slap Noise,” National Aeronautics and Space Administration, Langley Research Center, NASA Technical Memorandum 78758, July 1978.
[43] J.M. Fields and C.A. Powell, 1987.
[44] ICAO, 1981, Loughborough University of Technology, Studies of Helicopter Noise Perception: Background Information Paper, ICASo Committee on Aircraft Noise, Working Group B, December 1981.

of the objective evidence that helicopter noise, at a given A-weighted decibel level, is no more annoying than fixed-wing aircraft noise, there is survey evidence that the public reacts more negatively to helicopter noise than to fixed-wing aircraft noise. This phenomenon is discussed below.

3.5.1 Heightened reaction to helicopter noise

Typical of heightened reaction to helicopter noise is the experience of the U.S. Navy at Miramar Marine Corps Air Station. Miramar had long been a naval air station famed for its Top Gun School and its F-14 Tomcats. But with Top Gun moving to Fallon, Nevada, and the Tomcats being assigned to other bases, Miramar was turned over to the Marine Corps in 1997, which brought in helicopter and F-18 operations. Almost from the beginning, residents have complained about noise and pollution and expressed concerns over possible helicopter crashes. Yet, the noise contour map is not significantly different from when the F-14 aircraft were operating.[51] In addition, the contribution of helicopter operations to the overall DNL is much less than that of the F-18 operations.

An example of heightened reaction to helicopters at a general aviation airport was published by Schomer (1983b).[52] At an airport where the noise exposure was dominated by fixed-wing aircraft and with less than two helicopter operations per week, 7 percent of the people exposed to a DNL of 66 dB reported themselves to be “highly annoyed” by helicopters. A 1982 study from the United Kingdom also found a heightened reaction to helicopter noise.[53,54,55] In the community of Lower Feltham, the contribution of fixed-and rotary-wing aircraft to the overall noise exposure was about equal. However, the percentages of people who considered helicopters more disturbing than fixed-wing aircraft were 2 to 2.5 times as large as the percentages that considered helicopters less disturbing. In the communities of Esher and Epsom, where the numbers of helicopters and a fixed-wing aircraft were about equal, the disturbance due to helicopter noise was 2.5 times as large as that due to fixed-wing aircraft noise. People were more annoyed by the helicopters even though, on average, the fixed-wing aircraft were 5.0 dB louder.

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[45] J.A. Molino, 1982, “Should Helicopter Noise Be Measured Differently from Other Aircraft Noise?,” NASA Contractor Report No. 3069, Wyle Laboratories, Crystal City, VA.

[46] J.B. Ollerhead, 1982, “Laboratory Studies of Scales for Measuring Helicopter Noise,” NASA Contractor Report 3610, November 1982.

[47] W. Passchier-Vermeer, 1994, “Rating of Helicopter Noise was Respect to Annoyance,” English Version, TNO-Report 94.061, Leiden, The Netherlands.

[48] T. Ohshima, and I. Yamada, 1993, "Psycho-Acoustic Study on the Effect of Duration on the Annoyance of Helicopter Noise Using Time Compressed or Expanded Sounds," *Inter-Noise 93*, 1087-1090.

[49] T. Gjestland, 1994, “Assessment of helicopter noise annoyance: A comparison between noise from helicopters and from jet aircraft,” *Journal of Sound and Vibration*, **171**, 453-58.

[50] G. Bisio, U. Magrini, and P Ricciardi, 1999, “On the helicopter noise: A case history,” *Inter-Noise 99*, 183-188.

[51] Wyle Research Report WR 94-25, 1995, Aircraft Noise Study for Marine Corps Air Station Miramar, CA, Wyle Laboratories, Arlington, VA, August 1995.

[52] P.D. Schomer, 1983b.

[53] C.L.R. Atkins, 1983, “1982 Helicopter Disturbance Study: Tabulations of the Responses to Social Surveys,” London Civil Aviation Authority, DR Communication 8302.

[54] C.L.R. Atkins, P. Brooker, and J.B. Critchley, 1983, “1982 Helicopter Disturbance Study: Main Report,” London: Civil Aviation Authority, DR Report 8304.

[55] P. Prescott-Clarke, 1983, “1982 Aircraft Noise Index Study and 1982 Helicopter Disturbance Study: Methodological Report,” Social and Community Planning Research, London.

In general, there are a number of possible explanations for heightened community response to helicopter noise. The possible explanations, which are not mutually exclusive, include the following:

- A subsection of the population may be more sensitive to the low-frequency helicopter noise than is the majority of the population;
- A-weighting is possibly not the most appropriate metric with which to assess helicopter noise because A-weighting attenuates the low-frequency noise component;
- Noise-induced building vibration and rattle has been shown to significantly increase noise annoyance and helicopter sound is rich in low-frequency content;
- There is some evidence that suggests helicopter noise is slightly more annoying than fixed-wing aircraft noise at the same sound exposure level;
- Helicopter noise may be more noticeable because of its periodic impulsive characteristic;
- There is the possible phenomena of “virtual noise” in which a set of non-acoustical factors, such as bias (a personal judgment that the helicopter does not need to fly here) and fear (of crashes/injury/death), greatly enhances people’s negative attitudes; and
- The way helicopters are operated can influence reactions, i.e., stationary hover and flexible low altitude flight capability.

3.5.2 Low-frequency sensitivity

Over the past 30 years there have been a series of papers describing a subset of the population that is especially sensitive to low-frequency noise. In general, low-frequency noise includes the range from about 16 Hz to about 100 Hz. Apparently, a subset of the population is very sensitive to noises in this frequency range and is quite bothered and disturbed by this noise almost as soon as it crosses the threshold of audibility.[56,57,58,59] The size of this subset is not known. Patterson *et al.* (1977) used 25 subjects to study the subjective ratings of annoyance produced by rotary-wing aircraft noise. In an outdoor setting, the subjects judged the sounds from many types of military helicopters performing level flyovers climbs, descents, and turns. A numerical rating scheme was used and a DC-3 aircraft served as the control sound source. Statistical correlations were performed using A, B, C, and D-weighting and various forms of EPNL. Most of the 25 subjects had subjective ratings that correlated well with A-weighted measures. However, 11 of the subjects had subjective ratings that correlated well with C-weighted measures. For three of

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[56] S. Yamada, 1982**,** “Occurrence and control of low frequency noise emitted from an ice cream storehouse, *Journal of Low Frequency Noise and Vibration*, **1**(1), 19-21.
[57] W. Tempest, 1985**,** “Discussion at end of 3rd International Conference on Low Frequency Noise and Vibration, London, September 1985,” *Journal of Low Frequency Noise and Vibration*, **4**(4), 168-180.
[58] S. Yamada, T. Watanabe, T. Kosaka, and N. Oshima, 1987**,** “Construction and analysis of a database of low frequency noise problems,” *Journal of Low Frequency Noise and Vibration*, **6**(3), 114-118.
[59] M. Mirowska, 1998**,** “An investigation and assessment of annoyance of low frequency noise in dwellings,” *Journal of Low Frequency Noise and Vibration*, **17**(3), 119-126.

these, the correlation with C-weighting was better than the correlation with A-weighting, and for one, the correlation is much better.[60] Thus this study appears to have discovered a subset of individuals who are more sensitive to the low-frequency energies than are the majority.

3.5.3 Is A-weighting the optimum weighting for assessing helicopter sound?

As discussed above, there is some evidence that the A-weighting metric may not fully characterize human reactions to noise events with substantial low-frequency content. With the focus on industrial noise sources, ANSI S12.9 Part 4 provides a supplemental measure to A-weighting for the assessment of sounds with strong low-frequency content. This measure combines the sound energies in the 16, 31, and 63 Hz octave bands.[61] Both Germany and Denmark have special low-frequency sound measures that utilize sound energy in the 16, 31, and 63 Hz octave bands and Denmark adds energies in the 125 Hz band. As a possible alternate to A-weighting (which changes only with frequency), Schomer (2000) suggested the use of the equal-loudness level contours as a weighting function that changes with both amplitude and frequency. He showed that the 2 dB adjustment that possibly should be applied to helicopter sounds compared with fixed-wing aircraft sounds can be derived from the known functions of human hearing.[62]

As noted above, low-frequency noise complaints begin at the threshold of hearing. Further, small increases (decreases) in low-frequency noise levels can yield large increases (decreases) in annoyance. Møller (1987) measured both equal loudness and equal annoyance functions at low-frequencies (4, 8, 16, and 31.5 Hz). At these frequencies, changes of 2, 3, 4, or 5 dB yielded the same change in annoyance as a 10 dB change in sound level at 1000 Hz. That is, a 2 dB change in level at 4 Hz yields the same change in annoyance as a 10 dB change at 1000 Hz.[63]

For throbbing low-frequency noise, the complaint threshold can be below the threshold of audibility. The throbbing noise or distinctive rhythmic low-frequency helicopter sound is an inherent consequence of the main rotor blades periodic motion. Vercammen (1989) suggests a 5 dB adjustment for throbbing noise.[64] The Schomer paper (May 2000) explains this effect. The hearing function reacts to a 2 to 5 dB change in level as if it were a change in loudness of 10 dB. When throbbing occurs at low-frequencies, the actual loudness is greater than that predicted by the equivalent level. Stated another way, even though the equivalent level of a sound may be below the threshold of audibility, the sound is audible. The mistake is using the equivalent level at low-frequencies.[65] Schomer and Bradley (2000) have confirmed this effect using independently gathered data.[66]

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[60] J.H. Patterson, B.T. Jr. Mozo, P.D. Schomer, and R.T. Camp, 1977.

[61] ANSI, 1996, American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound—Part 4: Noise Assessment and Prediction of Long-Term Community Response, ANSI S12.9-1996—Part 4, American National Standards Institute (ANSI), New York, NY.

[62] P.D. Schomer, 2000, "Loudness-Level Weighting for Environmental Noise Assessment," *Acustica—Acta Acustica*, **86**, 49-61, January 2000.

[63] H. Møller, 1987, "Annoyance of audible infrasound," *Journal of Low Frequency Noise and Vibration*, **6**(1), 1-17.

[64] M.L.S. Vercammen, 1989, "Setting limits for low frequency noise," *Journal of Low Frequency Noise and Vibration*, **8**(4), 105-109.

[65] P.D. Schomer, 2000.

[66] P.D. Schomer and J.S. Bradley, 2000, "A test of proposed revisions to room noise criteria curves," *Noise Control Engineering Journal*, **48**(4), 124-129, (July/August 2000).

3.5.4 Noise induced building vibrations and rattles

In a study by Schomer and Neathammer (1985), subjects made judgments of the annoyance of helicopter flights while outdoors, in the living room of a new mobile home, and in an old frame house. During the tests, the supervising technician judged the amount of rattle during each flyover. The annoyance judgments were grouped by whether no rattle had been present, a little rattle had been present, or a lot of rattle was present. Clear differences emerged. When there was a little rattle, annoyance increased by an equivalent 10 dB. When there was a lot of rattle, annoyance increased by an equivalent 20 dB.[67] When the same experiments were repeated using better-built military housing, the annoyance due to rattle was quite reduced.[68]

In a study by Schomer and Averbuch (1989), subjects judged the annoyance of simulated blast sounds created using a giant (3 by 4 meter) woofer. Two groups of subjects responded in the same facility to the same set of test sounds using the same control sounds. The only difference was a small source of rattle on one window in the test house in which the subjects were situated. Although the rattle sounds were virtually unmeasurable at the ears of the test subjects compared with the blast sound itself, the mere presence of these rattle sounds raised the equivalent annoyance by about 6 to 13 dB depending on blast sound level.[69] The evidence seems to support the notion that annoyance increases on the order of 10 dB when there are noticeable rattle sounds over the annoyance predicted based on measures of just the sound itself. If the helicopter sound produces noticeable rattles, then the study results suggest that it is likely that the annoyance will be significantly greater than that predicted on the basis of just the A-weighted measures.

The C-weighting has been used in the United States for almost 30 years to assess blast noise and sonic booms in order to account for the noise-induced rattles generated by these sounds, and currently, several other countries also use the C-weighting for this purpose. It is primarily the sound energies in the 10 to 30 Hz ranges that induce wall vibrations. The C-weighting could be used to identify those helicopter sound energies that will induce wall vibrations.

3.5.5 Helicopter noise is more annoying than fixed-wing aircraft noise

Some studies have shown no increase in annoyance for helicopter noise as compared with fixed-wing aircraft noise. Others have shown a small adjustment. The most realistic studies are those that use subjects outdoors or in real houses with real helicopters to create the stimulus. Unfortunately, most studies are performed in the laboratory using simulated sounds. As discussed above, Patterson *et al.* (1977) used 25 subjects to study the subjective ratings of annoyance produced by real rotary-wing aircraft noise. On a per event basis, he found a +2 dB adjustment for the annoyance of helicopter sounds as compared with fixed-wing aircraft sound producing the same A-weighted sound exposure level.[70] In a similarly constructed experiment using real helicopters and a fixed-wing aircraft as the control, Powell (1981) placed subjects both

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[67] P.D. Schomer, and R.D. Neathammer, 1985.
[68] P.D. Schomer, B.D. Hoover and L.R. Wagner, 1991, "Human Response to Helicopter Noise: A Test of A-Weighting," Technical Report N-91/13, USA Construction Engineering Research Laboratory, November 1991.
[69] P.D. Schomer and A. Averbuch, 1989, "Indoor human response to blast sounds that generate rattles," *Journal of the Acoustical Society of America*, **86**(2), 665-673, August 1989.
[70] J.H. Patterson, B.T. Jr. Mozo, P.D. Schomer, and R.T. Camp, 1977.

outdoors and inside real houses. He found a 3 to 5 dB adjustment of the EPNL for subjects situated indoors and no adjustment for subjects situated outdoors.[71]

3.5.6 Helicopter sounds may be more readily noticeable than other sounds

At the same A-weighted sound exposure, a helicopter may be much more noticeable than a fixed-wing aircraft because of the impulsive blade-slap sound. Schomer and Wagner (1996) performed an *in-situ* study in respondents' homes. Clusters of subjects were chosen and an outdoor sound monitor was used to measure ASEL and to record the times at which they occurred. The three sources studied were helicopters, fixed-wing aircraft, and trains. For the same ASEL, helicopter sounds were not found to generate any greater *annoyance per event* than did the other two sounds. *Rate of response* was used as the main indicator of noticeability. Rate of response is defined as the ratio or relative order of magnitude of percent average noticeability comparing two unique sources of noise. In this case, helicopter noise was compared to fixed-wing airplane and train noise. The *rate of response* function for helicopter sounds grew at three times the *rate of response* functions found for airplanes and trains. This paper showed that sound noticeability may be a significant variable for predicting human response to noise. The character of the sound was a key ingredient to noticeability. Helicopters, with their distinctive sound character, appeared to be more noticeable than other sounds for the same A-weighted sound exposure level.[72]

3.5.7 Attitudes—non-acoustic factor

The community attitudes towards the noise source can be an important influence on the degree of annoyance. The Environmental Protection Agency (EPA) in 1974 suggested that the measured noise level can be adjusted downward by 5 dB when the party that generates the noise maintains very good community relations and convinces the community that everything possible that can be done is being done to reduce the noise.[73] Further study is needed to confirm EPA's result in this regard. The meta-analyses of Fields (1993) confirmed that community attitude is an important modifier of annoyance. This was one of five attitudes confirmed as important by the study. In addition to "noise prevention beliefs," Fields listed "fear of danger from the noise source," "beliefs about the importance of the noise source," "annoyance with non-noise impacts of the noise source," and "general noise sensitivity."[74]

In a more detailed study of attitudes, Staples *et al* (1999) combined elements of Fields' "noise prevention beliefs," "beliefs about the importance of the noise source," and "annoyance with non-noise impacts of the noise source" into a 10-item Environmental Noise Risk Scale. Their 351 subjects were living in the 55 to 60 dB DNL zone of a former military airfield that had been converted for civil use. They found that the environmental noise risk scale accounted for

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[71] C.A.Powell, 1981, "Subjective Field Study of Response to Impulsive Helicopter Noise," NASA Technical Paper 1833, April 1981.

[72] P.D. Schomer and L.R. Wagner, 1996, "On the Contribution of Noticeability of Environmental Sounds to Noise Annoyance," *Noise Control Eng. J.*, **44**(6), 294-305, Nov-Dec 1996.

[73] EPA, 1974, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," US Environmental Protection Agency, Office of Noise Abatement and Control (ONAC), Rpt. EPA550/9-74-004, Washington D.C.

[74] J.M. Field, 1993, "Effect of Personal and Situational Variables on Noise Annoyance in Residential Areas," *Journal of the Acoustical Society of America*, **93**, 2753-2763.

36 percent of the variation in individual disturbance from noise. Particularly powerful was a statistical factor that they labeled, "appraisal of one's neighborhood as inadequately protected and vulnerable to future increases in noise."[75]

Several of the attitudinal factors described above appear in the written submissions to the FAA. There is the belief that helicopters used for transportation of corporate executives, sightseeing, or ENG are unimportant. There is also the fear factor associated with helicopter overflights. There is the perception that helicopters could fly higher than they do and over less noise-sensitive areas. People feel that their privacy is being invaded when a helicopter flies low or hovers near their residence. Ollerhead and Jones (1994) noted the importance of privacy, noise prevention beliefs, and fear of crashes in neighborhoods around the Battersea Heliport. Ollerhead and Jones (1994) suggested people feel that a helicopter is "a rich man's toy."[76]

3.5.8 Vertical TakeOff/Landing (VTOL) capability

In contrast to fixed-wing aircraft, helicopters have additional flight capabilities, such as hover and vertical operations. These additional operational degrees of freedom can produce uniquely different noise signatures due to the varying complex source noise mechanisms. Noise generated over an extended period of a hover operation can lead to low-frequency droning that could enhance annoyance. Where fixed-wing aircraft require an airport with sizable runways for landings and takeoffs, helicopters can operate on much smaller landing sites that could be relatively close to residential communities. This creates an immediate local environment of higher noise levels that can be further compounded by the other dynamic helicopter noise effects. Related operational approaches for noise mitigation regarding VTOL capabilities are discussed in detail in Section 6.1.

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[75] S.L. Staples, R.R. Cornelius, and M.S. Gibbs, 1999, "Noise disturbance from a developing airport: Perceived risk or general annoyance," *Environment and Behavior*, **31**(5), 692-710.
[76] J.B. Ollerhead and C.J. Jones, 1994, "Social Survey of Reactions to Helicopter Noise," London: Civil Aviation Authority.

4.0 Public Input on Noise Reduction

In this section, responses to the FAA's request for information are summarized. Suggested noise reduction approaches and concerns expressed by the public are presented. Written comments were solicited by publication of notices in the Federal Register. The FAA held two public workshops in Washington, DC to obtain additional comments. The compiled study information (comments and workshop presentations) are accessible on the FAA's Office of Environment and Energy website:

http://www.aee.faa.gov/
under the link: "Section747-Nonmilitary Helicopter Noise"

As the result of a thorough review, the issues were grouped as either operational or non-operational. These issues were then sub-categorized according to applicable FAA regulations creating the following outline:

A. Operational Issues **–**

[related to 14 CFR part 91 - General Operating and Flight Rule]

1) Minimum altitude for overflight and hover;
2) Operational routes & routing design guidelines;
3) Hover duration time;
4) Retirement of noisiest helicopters;
5) Visible identification markings;

[related to:
14 CFR part 150 regulation – Airport Noise Compatibility Planning and
14 CFR part 161 regulation -Notice and Approval for Airport Noise & Access Restrictions

6) Frequency of helicopter operations (number of flights);
7) Time frame of helicopter operations (hours of operation);
8) Heliports/airports operations (i.e., ground run-up duration);
9) Noise abatement procedures;

[related to with 14 CFR part 36 - Noise Standards: Aircraft Type and Airworthiness Certification]

10) Noise certification limit stringency;
11) Implementation of noise reduction technology (i.e., helicopter "hushkits?");

B. Non-operational Issues **–**

12) Industry's voluntary "Fly Neighborly" program effectiveness;
13) ENG redundant flights;
14) Acceptance of public service helicopter operations; i.e., law enforcement, EMS, and fire fighters;
15) VFR/IFR ATC operations access for helicopters;
16) Empowerment of local municipalities with airspace control;

(Note: military helicopters are not addressed because they are outside of the mandate scope)

Supporting Technology Initiatives-

17) Socio-acoustic (psychoacoustic) study relating medical and health effects;
18) Tracking helicopter traffic growth and noise measures to quantify impact of noise sensitive community sites (parks, hospitals, neighborhoods, etc);
19) Utilize GPS approach/departure for noise abatement operations; and
20) Insensitivity of A-weight measurements to low-frequency noise impact of helicopters.

4.1 Synopsis of Responses

Views from representatives of the helicopter industry and organizations with an interest in reducing nonmilitary helicopter noise were sought, reviewed, and are presented in this section.

The organizations offering input were as follows:

Helicopter Noise Coalition of New York City - New York City, NY
League of the Hard of Hearing - New York City, NY
W400 Block Association - New York City, NY
Fifteenth Street Block Association (represents the West 200 Block) - New York City, NY
Federation of Citywide Block Associations - New York City, NY
Vinegar Hill Neighborhood Association - Brooklyn, NY
Community Board 7 - New York City, NY
The City College of the City University of New York - New York City, NY
Weehawken Environment Committee - Weehawken, NJ
Coalition to Quiet Our Neighborhood - West Orange, NJ
Noise Pollution Clearinghouse - Montpelier, VT
The MARCH Coalition Fund, Inc. - Poway, CA
Homeowners of Encino - Encino, CA
Sherman Oaks Homeowners Association (SOHA) - Sherman Oaks, CA
Lake Balboa Neighborhood Association - Van Nuys, CA
West Hill Property Owners Association (WHPOA) - Encino, CA .
Citizens for a Quiet Environment - Corrales, NM
Federation of University Neighborhoods - Albuquerque, NM
South Broadway Action Team - Albuquerque, NM

Similarly, the helicopter industry was represented by:

American Helicopter Society (AHS) International, VA - technical society
Helicopter Association International, VA - national operators association
Bell Helicopter Textron Inc., TX - manufacturer
Robinson Helicopter Co., CA- manufacturer
Whisper Jet Inc., FL - retrofit manufacturer
Eastern Regional Helicopter Council, PA - operators’ affiliate

Congressional representatives and local governments also contributed their comments and recommendations. Other specialized related aviation industry representatives, such as the helicopter law enforcement, helicopter medical services, and airports, also provided information and comments. The specific affiliation and concerns expressed are summarized in Table 4-1.

4.2 Scoping Questions

The FAA published a notice in Federal Register [Docket No. 30086: Report to Congress on Effects of Nonmilitary Helicopter Noise on Individuals in Densely Populated Areas in the Continental United States (65 FR 39220)] on June 23, 2000, requesting information from people concerned with nonmilitary helicopter noise. The request for information was confined to the context of the effects of nonmilitary helicopter noise on individuals in densely populated areas of the continental United States. The following four questions were posed:

- What are the types of helicopter operations (law enforcement, electronic news gathering, sightseeing tours, etc.) that elicit the negative response by individuals in densely populated areas?
- What air traffic control procedures are applicable in addressing helicopter noise reduction? Why?
- What impacts could restrictive air traffic control procedures have on operation of:
  - Law enforcement helicopters?
  - Electronic news gathering (ENG) helicopters?
  - Sightseeing tour helicopters?
  - Emergency medical services (EMS) helicopters?
  - Corporate executive helicopters?
- What are the recommended solutions for reduction of the effects of nonmilitary helicopter noise?

Although the comments received were not always directly responsive to the four questions, responses were grouped to the extent practical according to the questions. An overall summary of the responses is presented in Table 4-1. The responses are described in detail below.

TABLE 4-1. SUMMARY OF COMMENTS IN RESPONSE TO REQUEST: LISTED IN ORDER OF RECEIPT

	Question #		Current Concerns						Suggested Solutions												
#	Respondent		Low AGL	Hours	Route	Hover	Struct Vib/ Dam.	Operation Type*	Curfew	Min AGL	Max SPL	Spec Route	Visible ID	Limit # Ops	Limit Hover	Pool Ops	Hush Kit	Stage 3	Part 91	Heliport	#
1	Ontario Police Dept.	CA	<500'	X																	1
2	MARCH Coalition	CA						Mil		X		X									2
3	Individual, Springfield	VA	<1000'	X			X	PD, Mil, EMS		X									X		3
4	Individual, Sherman Oaks	CA	X					ENG	X	X		X			X					X	4
5	Individual, Juneau	AK						SS	X												5
6	Individual, Portland	OR	X	X		X		ENG		X	X			X					X		6
7	Hayward Airport	CA	X		X			PD, ENG,PT, EMS		X		X								X	7
8	Robinson Helicopter	CA								X	X										8
9	Seattle Council on Airport Affairs	WA	X	X		X		All	X	1500'		X	X								9
10	Clark Co. Dept Aviation	NV								1000'/500'								X			10
11	Hel. Noise Coalition NY City (O)	NY			X		X	All	X	X		X	X		X	X		X		X	11
12	Assoc. Air Medical Services	VA																			12
13	Representative Carolyn Maloney (O)	NY						All	X	X			X								13
14	AHS International (O)	VA						Indeter		1000-2000'		X									14
15	City of Portland	OR								2000'									X		15
16	Bell Helicopter/Textron	TX	X					Indeter									X				16
17	Helicopter Assoc. International (O)	VA						Indeter		1000-2000'											17
18	Individual, NY City	NY		X					X	1500'		X	X		X	X				X	18
19	Individual, Sherman Oaks	CA		X			X	ENG, PD	X	X						X					19
20	Jones Farm HOA, Hillsboro	OR	X	X	X			PT						X						X	20
21	Whisper Jet, Inc., Sanford (O)	FL								X							X				21
22	Lake Balboa Neigh. Assoc, Van Nuys	CA	X	X	X		X	ENG, SS	X	X		X		X						X	22
22A	Fairway Park Neigh, Assoc., Hayward	CA						None													22A
23	Individual, Sherman Oaks	CA	X	X	X			ENG										X			23
24	Eastern Region Helicopter Council (O)	PA		X	X			Indeter		2000'		X									24
25	Individual, Chester	VA	X		X					1000'+									X		25
26	Individuals, Portland	OR	X					ENG		X				X							26
27	Individuals, Portland	OR	X	X				ENG		X											27
28	Individuals, Portland	OR	X	X			X	ENG,EMS,Taxis		X								X			28
29	Homeowners of Encino (NHNC) (O)	CA	X	X	X			All	X	1500'		X	X	X	X	X		X	X		29
30	Individual, Torrance	CA	X		X					X		X		X				X			30
31	Individual, San Lorenzo (Hayward) (O)	CA	X	X	X	X		ENG,PT,PD		X			X					X		X	31
32	Member Community Board 7, NYC	NY						All	X	1500'		X	X		X	X		X			32
33	Airport Commission, San Francisco	CA	X			X				1000'					X						33
34	Wrong docket																				34
34A	NY State Senator T. Duane	NY						All	X	X		X	X		X	X					34A
34B	President, Borough of Manhattan	NY																			34B
34C	Representative Adam Smith	WA																			34C
34D	Council Member C. Quinn, City of NY	NY																			34D
35	Individuals, Encino (O)	CA	X	X	X		X	ENG, SS	X	X		X		X		X				X	35

TABLE 4-1. (CONT). SUMMARY OF COMMENTS IN RESPONSE TO REQUEST: LISTED IN ORDER OF RECEIPT (CONTINUED)

Question #			Current Concerns						Suggested Solutions												
#	Respondent		Low AGL	Hours	Route	Hover	Struct Vib/ Dam.	Operation Type*	Curfew	Min AGL	Max SPL	Spec Route	Visible ID	Limit # Ops	Limit Hover	Pool Ops	Hush Kit	Stage 3	Part 91	Heliport	#
36	Individual, City College	NY						All		1500'		X	X	X	X	X					36
36A	Individual, Brooklyn	NY																			36A
37	Individual, Brooklyn	NY	X	X		X	X	ENG, SS, Com												X	37
37A	Individual. NY City	NY		X				All													37A
37B	Air Methods Corp, Englewood	CO								1000-2000'											37B
38	Individuals, NY City	NY		X		X								X							38
39	Individual, NY City	NY	X			X		PD,ENG,SS Film		X		X				X					39
40	W400 Block Assoc.	NY	X			X						X		X	X						40
41	Individual, NY City	NY			X							X									41
42	Individual, Puunene	HI																			42
43	Hel. Noise Coalition NY City (O)	NY																			43
44	League for the Hard of Hearing	NY																			44
45	Individual, Hoboken	NJ		X		X		SS. Com. ENG						X				X			45
46	Individual, Brooklyn	NY		X	X			Corp. Gov	X			X		X							46
47	Federation of University Neighborhoods	NM	X	X		X		ENG. EMS		2000'		X			X						47
48	Individual, Brooklyn	NY		X	X	X		ENG. SS. Corp						X							48
49	Individual, NY City	NY	X			X		SS.ENG.PD.Corp.Film						X						X	49
50	Individual, NY City	NY	X	X			X	Corp. SS		X				X	X	X		X			50
51	Individual, Brooklyn	NY	X	X		X		Corp. ENG		X			X								51
52	Noise Pollution Clearinghouse	VT	X	X	X	X				3000'		X						X		X	52
53	Individual, NY City	NY	X	X	X	X	X	SS.ENG.Corp.Com													53
54	Council Member K.Fisher, City of NY	NY		X	X		X	ENG. Corp		X		X		X		X					54
55	Representative Jerrold Nadler (O)	NY	X	X				SS.ENG.Corp		X		X			X			X			55
55A	Individual, NY City	NY	X	X		X		ENG		X		X			X	X					55A
56	Individual, NY City	NY	X	X	X	X	X	ENG		X				X	X	X					56
56A	WestHillsPropOwnerAssoc/HOEncino(O)	CA	X	X	X			ENG	X	1500'		X	X	X	X	X		X	X	X	56A
57	Individuals, Brooklyn	NY		X		X		ENG		X											57
58	Individual, Pleasant Hill	CA						PT													58
59	Individual, El Segundo (O)	CA				X		ENG		X				X	X			X			59
60	Individual, NY City	NY			X						X										60
61	Individual, NY City	NY	X																		61
61A	NY Assembly Member R Gottfried	NY																			61A
61B	Weehawken Environment Committee	NJ																			61B
62	Individual, NY City	NY			X	X				X			X	X							62
63	Fifteenth Street Block Assoc.	NY										X			X	X					63
64	Individual, Albuquerque	NM		X	X	X		PD. ENG			X										64
65	NY Assembly Member E Connelly	NY			X			ENG													65
66	Representative Jerrold Nadler	NY																			66
67	NY Assembly Member R Gottfried	NY				X		ENG.SS		X		X	X							X	67
68	Individual, NY City	NY																		X	68
69	Weehawken Environment Committee (O)	NJ	X	X	X	X	X	SS.ENG.Corp	X	X		X		X	X	X		X			69
70	Individuals, NY City	NY	X	X		X		ENG		X		X			X						70

TABLE 4-1. (CONT). SUMMARY OF COMMENTS IN RESPONSE TO REQUEST: LISTED IN ORDER OF RECEIPT (CONTINUED)

	Question #		Current Concerns						Suggested Solutions												
#	Respondent		Low AGL	Hours	Route	Hover	Struct Vib/ Dam.	Operation Type*	Curfew	Min AGL	Max SPL	Spec Route	Visible ID	Limit # Ops	Limit Hover	Pool Ops	Hush Kit	Stage 3	Part 91	Heliport	#
71	Individual, Brooklyn	NY	X	X		X		ENG		X		X									71
71A	Mayor, City of El Segundo	CA						ENG. Corp		X									X		71A
72	Individuals, Sherman Oaks	CA	X	X				ENG	X					X		X					72
73	Sherman Oaks Homeowners Assoc. (O)	CA	X	X				All	X	X		X		X	X						73
74	Individual, NY City	NY																			74
75	Vinegar Hill Neighborhood Assoc.	NY	X		X	X	X			X		X		X							75
76	Office of Mayor, NY City	NY	X	X				ENG. SS.													76
76A	Coalition to Quiet Our Heighborhood (O)	NJ	X	X			X		X	1500'		X									76A
77	Individual, NY City	NY						ENG.SS.Corp													77
77A	Regional Commission on Airport Affairs	WA																			77A
77B	Regional Commission on Airport Affairs	WA																			77B
77C	Citizens for a Quiet Environment	NM		X		X		ENG.PD.SS.Corp		2000'	X	X	X					X			77C
77D	Individual, San Lorenzo	CA																			77D
77E	Inidividual, NY City	NY																			77E
77F	Inidividual, NY City	NY																		X	77F
77G	City Councillor, Cambridge	MA	X	X		X		ENG				X									77G
77H	S. Broadway Action Team, Albuquerque	NM		X		X		PD, ENG													77H
78	Air Methods Corp, Englewood	CO																			CO
79	MD Helicopters, Inc	AZ	X	X		X		PD				variable									AZ
80	Individual, NY City	NY		X	X	X	X	COMM,SS													NY
81	Individual, Las Vegas	NV		X	X			SS	X	X		X		X							NV
82	Citizens for a Quiet Environment	NM	X					ENG,PD		2000'	55dBA		X				X				NM
83	Individual, Brooklyn	NY	X		X		X	ENG, SS		2500'		mandatory		X							NY
84	Individual, Lake Balboa	CA	X		X																CA
85	Metro NY Aircraft Noise Mitigation Commi	NY	X			X				X		X			X	X					NY
86	Individual, Brooklyn	NY	X	X			X	PD													NY
87	Individual, NY City	NY		X	X		X							X							NY
88	Individual, NY City	NY												X							NY
89	Individual, NY City	NY			X									X							NY
90	Individuals, NY City	NY	X	X	X	X		MIL, SS, FIL													NY
91	Individual, NY City	NY		X		X															NY
92	Individual, San Francisco	CA		X	X			SS						X							CA
93	Individual, Valley Village	CA	X	X	X			ENG, PD,EMS,COM	X	X		X	X	X	X	X					CA
94	Individual, Philadelphia	PA	X			X		SS,ENG,COM,PD													PA
95	Individual, Hoboken	NJ		X	X	X		SS,ENG,COM,PD	X			X		X		X					NJ
96	Individual, Locust	NJ					X	COM	X	X		X									NJ
97	Metro NY Aircraft Noise Mitigation Commi	NY								X				X	X	X					NY
98	City of NY Community Brd Six Manhattan	NY							X			X	X								NY
99	Individual, Brooklyn	NY	X	X																	NY
100	Individual, NY City	NY						COM													NY
101	NY Assembly Member Scott Stringer	NY																			NY
102	Individual, Brooklyn	NY	X	X					X	X		X									NY
103	Individual, Brooklyn	NY	X	X		X		PD, ENG		X											NY
104	Community Board 7 Manhattan	NY	X	X	X			PD, ENG, COM	X	X		X			X						NY
105	City of NY, Community Board 2 Manhattan	NY	X			X		PD,ENG, FILM,SS	X	X		X		X		X					NY
106	Brooklyn Heights Association, Inc	NY		X		X								X							106
107	Individual, Brooklyn	NY		X				ENG,COM						X							NY
																					0
	Total Count @ #107	122	56	57	36	39	19		26	64	6	46	17	36	24	22	3	16	7	18	
		%	46	47	30	32	16		21	52	5	38	14	30	20	18	2	13	6	15	

* **Mil = Military: PD = Police/Fire Dept.: EMS = Emergency Medical Service: ENG = Electronic News Gathering: SS = Sightseeing: Taxis = Helicopter Taxis: PT = Pilot Training: Indeter = Unable to determine: Com = Commuter: Film = Filming: Corp = Corporate/Business: Gov = Non-emergency governmental**

(O) denotes was represented also by oral presentation at one of the two hearings at FAA Headquarters.

4.3 Respondents

After adjusting for duplicate submissions, a total of 122 independent responses were recorded. The breakdown of the respondents by group is given in Table 4-2.

TABLE 4-2: BREAKDOWN OF RESPONDENTS BY GROUP

Group	Number of Respondents	Percentage of Total
Individual Citizens	67	54.9%
Homeowners' Associations	10	8.2%
Citizens' Associations	16	13.1%
Elected Officials	15	12.3%
Helicopter Manufacturers and Technical Associations	5	4.1%
Helicopter Operators' Associations	2	1.6%
Emergency Service Operators and Associations	3	2.5%
Police Departments	1	0.8%
Airport Operators	3	2.5%
Total	122	100%

The distribution of the respondents by state of residence, operation or office location is given in Table 4-3.

In the case of New York and New Jersey, all 67 (54.9 percent) respondents reside in the New York City area. In the case of California, 23 (18.9 percent) respondents reside in the Los Angeles area, and 5 of the 6 (4.9 percent) respondents from Oregon reside in the city of Portland.

Two (1.6 percent) responses came from states (Alaska and Hawaii) that are outside the contiguous United States, but they are included in the analysis for completeness. In addition, one response (from California) is concerned solely with military helicopters. That response is also included for completeness.

Sixteen individuals who submitted written comments also attended and testified at the public workshops. The respondents at the two public workshops consisted of three individuals, three homeowners' associations, three citizens' associations, two elected officials, two helicopter manufacturers and technical associations, two helicopter operators' associations, and one EMS operator.

TABLE 4-3: DISTRIBUTION OF RESPONDENTS BY STATE

State	Number of Respondents	Percentage of Total
Alaska	1	0.8%
Arizona	1	0.8%
California	23	18.9%
Colorado	2	1.6%
Florida	1	0.8%
Hawaii	1	0.8%
Massachusetts	1	0.8%
New Jersey	5	4.1%
New Mexico	5	4.1%
Nevada	2	1.6%
New York	62	50.8%
Oregon	6	4.9%
Pennsylvania	2	1.6%
Texas	1	0.8%
Virginia	5	4.1%
Vermont	1	0.8%
Washington	3	2.5%
Total	122	100%

4.4 Helicopter Operations Eliciting Negative Response

The respondents were asked to identify the types of helicopter operations that elicit negative reaction. Eleven specific types of operation were cited by 63 of the respondents and 9 other respondents stated that all helicopter operations were of concern. The 11 specific types of operation and the number of citations for each type of operation are identified in Table 4-4.

Four respondents were unable to determine the nature of the operations and one respondent stated that there was no noise problem associated with helicopter operations. The remaining 45 respondents did not respond to the question. The specific operations identified by each of the respondents can be found in Table 4-1.

There is strong sentiment among individual citizens, homeowners associations, and citizen associations that ENG operations and sightseeing operations create the most adverse reactions and are the least justifiable.

Several respondents distinguished between police, fire, and medical services. If the operations are truly emergencies, the majority of these respondents indicated that they accept such operations as beneficial to the community. However, routine police patrols and return flights from an emergency are viewed more strictly as non-emergency operations.

TABLE 4-4: TYPES OF HELICOPTER OPERATIONS ELICTING NEGATIVE RESPONSE

Type of Operation	Number of Citations
Electronic News Gathering (ENG)	47
Sightseeing (SS)	24
Corporate/business (Corp)	19
Police (PD)	17
Pilot training (PT)	4
Emergency medical services (EMS)	5
Commuter (Com)	10
Filming (Film)	4
Military (Mil)	2
Helicopter taxis (Taxi)	1
Non-emergency governmental (Gov)	1
All Operations	9

4.5 Operations of Concern

Five specific concerns - low flight altitude, hours of operation, flight routes, hovering, and structural vibration and damage - were given as the main reasons for negative reaction to helicopter operations in urban areas. These concerns are listed in Table 4-1 under the column headings “Low AGL,” “Hours,” “Route,” “Hover,” and “Struct. Vib/Dam,” respectively.

4.5.1 Low Flight Altitude

Low flight altitude was cited by 56 (46 percent) respondents (see Table 4-1), although in only two cases were flight altitudes quoted -- 500 and 1,000 feet Above Ground Level (AGL). Several responses attributed the low flight altitudes, at least in part, to FAA or ATC procedures which either do not specify minimum flight altitudes for helicopters or do not encourage the use of higher flight altitudes for noise abatement. In particular, several respondents referred to FAR Part 91, Section 91.119(d), because it does not specify minimum flight altitudes for helicopters. Section 91.119 exempts helicopters from the altitude restrictions that are imposed on fixed-wing aircraft flights over congested areas. The minimum altitude restriction for fixed-wing aircraft is “1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft.” The regulation requires that helicopters be operated without hazard to persons or property on the surface and that the operator should comply with any routes or altitudes specifically presented for helicopters by the FAA Administrator.

4.5.2 Hours of Operation

Helicopter operations early in the morning and late at night were cited by 57 (47 percent) respondents as causing negative response. The concern cited most frequently was the loss of sleep. Several types of operations were cited, including early morning ENG flights and nighttime police surveillance flights. Respondents from both New York City and Los Angeles claim that ENG helicopter operations begin as early as 5 a.m.

4.5.3 Flight Route

Helicopter flight routes are of concern to 36 (30 percent) respondents, but there is a divergence of opinion regarding the nature of the problem. Some respondents stated that concentrating helicopter flight routes along specific corridors, such as along freeways, unfairly exposes certain residents to even higher noise levels than they endure from freeway traffic. In addition, the helicopters tend to fly over residential areas to the left and right of the freeway rather then directly over the freeway. These respondents suggested that the routes be directed towards open space or industrial areas. Other respondents expressed the concern that helicopter flights followed routes of maximum convenience to the operator, such as following the shortest distance between two points, without regard to residents below. They requested more control over the flight routes. Some respondents recognized that changing the helicopter flight routes to reduce noise levels in one community would probably result in an increase in noise in another community.

There is a divergence of opinion in the responses to the effectiveness of voluntary flight route restrictions. Helicopter operators cite examples where voluntary changes to flight routes have reduced noise exposure of residents of New York City. However, citizen associations claim that helicopters do not always follow voluntary rules.

4.5.4 Hovering

Helicopter's hovering for long durations was the cause of concern for 39 (32 percent) respondents. ENG and police operations were cited as the cause of the majority of the hovering occurrences. There was particularly strong negative reaction to the tendency of ENG helicopters to congregate over a particular incident and hover, as a group, for extended periods of time.

4.5.5 Structural Vibration and Damage

Nineteen (16 percent) respondents stated that helicopter operations caused building structures and fixtures to vibrate and rattle. Several of the responses also claimed that there was a potential for damage to the structures and contents due to the low-frequency vibration. One respondent claimed that actual damage to property had occurred due to helicopter noise.

5.0 Helicopter Air Traffic Control Procedures

In this section, general ATC procedures applicable to helicopters are discussed. Also, the consideration of helicopter law enforcement and other public emergency services are addressed regarding needs and public response.

The NAS is confronted by demand of record growth in passenger volume and flight operations.[77] As a result, ATC operations are at times strained and encountering congestion and delays. As changes to meet capacity needs are continual, ATC procedures are complex in nature and influence a multitude of interrelated factors. For example, the airspace in and around New York City is one of the busiest urban metropolitan areas with the most complex ATC environments in the country. Heavy volume of air traffic is managed for multiple international airports (LaGuardia, JFK, and Newark), numerous general aviation airports, multiple heliports, and the several exclusion corridors. Defining, managing, and altering the procedures in this airspace will require a comprehensive FAA review. An ATC aircraft operational change, whether for helicopter or small fixed-wing airplane, is certain to pose an impact to large fixed-wing transport during en route, approach, and/or departure operations. Changes must be carefully considered and demonstrated before implementation to fully assess the impact to the overall NAS safety.

5.1 ATC Discussion

The helicopter industry stated that the FAA ATC limited helicopter altitude operations (see Section 5.2 "VFR and IFR Operations") could benefit noise abatement operations.[78] FAA believes that current helicopter high altitude boundaries are flexible enough to facilitate noise abatement if desired and requested by pilots. Current helicopter route charts for several major metropolitan areas, such as Boston, Chicago, and New York, were established in collaboration with industry operators to identify "voluntary" operational corridors for safe and minimal noise flights over sensitive areas. The study team reviewed the eight metropolitan helicopter charts and identified more than appropriate upper altitude bounds that would allow for higher altitude noise reduction flight if desired by helicopter operations. For example, within the New York City metropolitan area, the Class B airspaces, surrounding Kennedy/LaGuardia/Newark airports, are controlled from ground surface to 7,000 feet AGL and are available for utilization upon ATC request. Under the lateral boundaries and beneath any available floor of the Class B airspace, VFR operations may be utilized. The opportunity to request higher altitudes for operations, in the interest of noise abatement, is unconstrained by regulation.

Within the metropolitan area of New York City, voluntary noise mitigation operational procedures have been negotiated and established between the FAA and helicopter industry operators. Such procedures endorse general operations along waterway corridors and limitations over specified areas, such as parks. These recommended guidance are published on the Helicopter Route Charts. Eight (8) metropolitan areas have established helicopter route charts. These metropolitan areas are Baltimore-Washington, Boston, Chicago, Dallas-Fort Worth, Houston, Los Angles, New York, and U.S. Gulf Coast.

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[77] Aviation Week & Space Technology magazine, "Commercial Aviation on Ropes," September 18, 2000, pp. 46-51.
[78] Docket Comment #17 by Helicopter Association International, VA, July 24, 2000.

A related ATC comment stated "helicopter IFR operations are limited by the FAA that could otherwise offer noise abatement operations."[79] IFR flight was not established as a noise reducing operational mode but as an operational airspace utilization mode. The principal ATC priority is to uphold safety considerations while minimizing delays in aviation system. This gives greater priority to large fixed-wing transports that move more passengers and require higher operating speed within the airspace. Helicopters are relatively slower and carry few passengers. To avoid conflict with IFR fixed-wing aircraft, helicopters have an alternative flight profile of flying to high altitudes in visual flight rules/uncontrolled condition (VFR/UNC) airspace. This helicopter alternative averts slowing down large transports aircraft and decreases demand on the ATC system.

14 CFR part 91 regulations - General Operating and Flight Rule

FAA regulations addressing helicopter ATC procedures are specified in the Part 91 for "Air Traffic and General Operating Rules." Presently, in Part 91 under Subpart I- "Operating Noise Limits," noise regulations are specified primarily for fixed-wing transport aircraft and do not address helicopters and small airplanes.

5.2 Law Enforcement and Other Public Emergency Services

Law enforcement operations support air patrol for crime prevention of highways and communities, crowd control observation, and immediate response to ground base officers. The needs of law enforcement, like many specialized public services, operate over extended business hours if not around the clock 24 hours a day. For example, one California helicopter police unit responded that it operates daily from 7:30 a.m. to 3:00 a.m., except weekends when it operates from 5:00 p.m. – 3:00 a.m. "Establishment of altitude restrictions beyond safety requirements could **seriously** inhibit the conduct of airborne law enforcement operations," as expressed by a law enforcement respondent.[80]

Several other public emergency services, such as fire fighting and EMS, employ the helicopter's versatility to provide critical life saving and time sensitive operations. One service provider of emergency medical transportation systems and services has served an estimated 200,000 missions among 40 hospitals across the country.[81]

In the Federal Register notice, scoping questions (in Section 4.2) were proposed to assess helicopter noise concerns by functional type of operations. Respondents recognized role of law enforcement helicopters. This sentiment was also expressed for other emergency services, including medical, fire fighting and limited specialized public services. Such services are regarded

[79] Docket Comment #17.
[80] Docket Comment #1 by Ontario Police Dept., CA, July 5, 2000.
[81] Docket Comment #78 by Air Methods, CO, September 14, 2000.

as vital community needs.[82,83] FAA concurs and recommends that these public services be exempt from any consideration of proposed ATC procedures that would otherwise impose operational limitations.

[82] August 16, 2000 Public Workshop Transcript #1.
[83] October 20, 2000 Public Workshop Transcript #2.

6.0 Consideration of Views (Public/Industry Comments)

In this section, the primary issues of concern are identified and reviewed based upon the public comments received. They are assessed with regard to technical merit (safety and effectiveness) and applicability within statutes, laws and regulations. The issues are broadly categorized either as operational, relating to aircraft/airspace operational issues, or non-operational. Operational issues are further grouped and discussed in context with the appropriate FAA regulation. Each issue is individually discussed to examine the potential for noise mitigation benefits.

6.1 Operational Issues

Five operational issues were identified that relate to "General Operations and Flight Rule" specified under 14 CFR Part 91. These operational issues are: 1) minimum altitudes, 2) noise sensitive route and design guidelines, 3) hover duration time, 4) retirement of noisiest helicopters, and 5) visible identification markings requirements. Preceding the discussion is a brief description of the Part 91 regulation.

Part 91 Regulation

Helicopters have unique VTOL capability that allows them to operate at variable altitudes, low speeds, and hover. The helicopter's versatility is well established in public services such as law enforcement, EMS, fire fighting missions, and heavy lift. In many cases, these operations are highly warranted and only viable by helicopters.

Except during takeoff and landing, Section 91.119 mandates that, when flying over congested areas, aircraft maintain an altitude of at least 1,000 feet above the highest obstacle and a horizontal radius of at least 2,000 feet from another aircraft. In other than congested areas, aircraft are required to maintain an altitude of at least 500 feet above the surface over open water or sparsely populated areas. Over open water or sparsely populated areas, aircraft may operate at less than 500 feet above the surface, provided that they do not fly closer than 500 feet to any person, vessel, vehicle, or structure.

Helicopters may be operated at less than these minimum altitudes provided that they are conducted without hazard to persons or property on the surface.

In comments received, several respondents recommended that Section 91.119 be amended to establish a minimum flight altitude for helicopters similar to that for fixed-wing airplanes. Such a change would require that helicopters in urban areas maintain an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the helicopter. One respondent stated that public safety helicopters should be exempted from the minimum altitude restriction.

6.1.1 Minimum Altitude for Overflight and Hover

The noise reduction solution suggested by the majority of the respondents proposed the establishment of a minimum altitude AGL regulation for helicopters. The solution was contained in 64 responses, or 52 percent of the total number of responses received, and was the most prevalent recommendation. Minimum flight altitudes were suggested in 18 responses (see Table 1), with the majority suggesting a minimum altitude above ground level ranging from

1,000 to 2,000 feet. Neither the police department respondent nor the helicopter industry respondents were in favor of this regulatory solution.

A similar noise reduction solution suggested by five respondents proposed the establishment of regulation limiting the allowable maximum sound pressure level (SPL) on the ground. Such an approach can serve to standardize the noise impact threshold on ground observers. One respondent suggested that this approach would be more customary and consistent with existing noise ordinances for other ground-based noise sources like cars, radios, and human disturbances. Three respondents propose this approach principally be implemented for noise sensitive areas, such as hospitals. Two respondents proposed it applicable for all helicopters. Individual helicopter models generate different noise level. As such, the establishment of a noise level on the ground becomes a function of overflight altitude. So noisier helicopters would be required to fly higher to maintain the same noise level emitted to the ground.

Both suggested solutions apply relative altitude or stand off distance as the primary mechanism for attenuating the noise. By establishing a fixed minimum altitude to limit overflight operations spatially over the public, noise levels are likely to fall. Different model helicopters generate different noise levels. Depending on the absolute minimum altitude selected, the noise from different helicopters, although lower in level, may still vary by the ground observer's perception. By prescribing a noise limit on the ground, conceptually the perceived noise reduction becomes a constant allowable noise level with the variability imposed on the helicopters operational altitude. In practice it would place the onus on the aircraft manufacturers to noise test and identify the relative minimum altitude or stand off distance that satisfies the established SPL_{max} criteria on the ground. Both concepts require further research to assess the noise benefits and establish as operational process, procedures, and/or regulation.

Noise reductions are achieved by operating at greater altitude for overflight. This is supported by historical helicopter noise measurements (Newman et al. (1979)) and the present urban *in-situ* noise measurements. Notwithstanding the noise benefits, instances of heavy traffic volume in complex urban airspace regions may trigger an overriding recognition for greater aircraft separation distance for safety. To preserve separation, ATC may accede to alter its priority and limit higher altitude helicopter flight in lieu of the voluntary high altitude low noise flight alternative. Any new procedures or redesign of airspace will require integration of a "keep aircraft high" philosophy. The challenge to optimize airspace utilization continues. Changes can potentially affect other areas of the NAS. Any proposed procedural changes will receive careful consideration and will require testing for feasibility prior to implementation.

6.1.2 "Noise sensitive" Routes & Routing Guidelines

Aviation routes are established to provide for safe and efficient flow of air traffic. The FAA attempts to establish routes over non-noise sensitive areas. It is not practical for aircraft to avoid overflights of some residential communities between their point of departure and destination. This issue is more pronounced for helicopters as most heliports and vertiports are situated within densely populated areas with limited real estate to buffer noise. Forty-six (38 percent) of the respondents recommended changes to the routes flown by helicopters in urban areas. The most frequent recommendation (21 respondents) was that helicopter flight be directed away from residential areas. Some of the respondents suggested that preference be given to helicopter flight routes over commercial and industrial areas. It was also recommended that careful analysis be made of land uses with comments requested from the affected communities prior to the designation of specific flight routes.

The FAA helicopter route charts for several urban areas show helicopter routes along major highways. Respondents disagreed with this approach because of the potential concentration of helicopter noise in residential areas. One respondent specifically called for helicopter routes that were more spread out. Respondents from urban areas along major rivers recommend that actual helicopter operations be flown over the river center rather than along the riverbanks.

One respondent recommends that VFR routes be reexamined, as they have not always been chosen with environmental considerations. The revisions should take into account requirements for high angle-of-bank turns that cause increases in noise level.

The respondents state that routes should be mandated and the rules enforced. They claim that voluntary compliance does not work. It is generally accepted that emergency services be exempted from flight route restrictions.

Identification of optimum helicopter route planning for avoidance of noise sensitive areas should be incorporated and emphasized specifically within the overall planning and development process for an urban airspace design process. Pursuit and implementation of any proposed ATC procedure would require comprehensive evaluation in accordance with all applicable FAA orders and regulations. It would include but not be limited to the environmental and economic review processes.

6.1.3 Limit Hover Duration

Twenty-four respondents or 20 percent presented concepts for limiting hover operations. Twenty proposed limiting the time spent by helicopters in hover for specific sites. Two respondents made the general suggestions for the reductions of hover duration for all operations. Sixteen of the respondents recommended that strict time limits be imposed on the duration of hover. Two examples of such limitations are (a) no more than 5 minutes hover in any hour or (b) no hover period should exceed 2-3 minutes. Two respondents recommended an outright ban on hover operations.

Current flight regulations offer operational flexibility for helicopter operators to exercise voluntary procedures and judgment for hover operations. The FAA strongly encourages that voluntary criteria for minimum hover duration be instituted. FAA encourages operators to increase pilot awareness training for noise mitigation procedures that would include limiting hover duration where possible. Voluntary hover guidelines could state hover duration be kept to a minimum to mitigate noise over populated areas unless the hover operation qualifies as an emergency.

6.1.4 Retire Noisiest Helicopters

Sixteen respondents or 13 percent recommended that quieter helicopters be introduced in urban areas. Ten respondents called for a phased out of service or retirement of helicopters that could not meet a newly defined Helicopter Stage 3 criteria by some specified data; i.e., 2005.

The current civilian helicopter fleet is categorized as either Stage 1 or Stage 2 based upon its compliance to the noise certification limit under Part 36. Helicopters, for which application for issuance of type certificate in primary, normal, transport, or restricted category was made prior to March 6, 1986, are Stage 1. Numerous Stage 1 helicopters continue to offer a productive service that otherwise might be cost prohibitive. The suggested retirement or phase out of any helicopters would require a comprehensive study of environmental benefit and economical impact under rulemaking. Pursuit and implementation of a new Stage 3 standard would require rulemaking under Part 36. FAA would be authorized to phase out Stage 1 and Stage 2 helicopters only if through a rulemaking action it was determined economically reasonable or technically practical under 49 U.S.C. 44715.

Currently, several factors complicate the assessment of a helicopter technology “phase-out” evaluation study. These factors are: 1) the lack of comprehensive operational usage and representative flight profile data for most helicopters, 2) modeling complexity (not simply “point A to point B” flight operations as airplanes) due to helicopters dynamic operational flexibility, and 3) the lack of an up-to-date helicopter noise model database for impact assessment. Until such information and data can be established, a present “phase-out” assessment of noise is unsubstantiated. The FAA is establishing an update of the helicopter noise database with recent technology flight test measurements under the auspices of Society of Automotive Engineers 21 Committee on Aircraft Noise.

6.1.5 Visible Identification

Seventeen respondents or 14 percent suggested that helicopters be prominently marked with visible identification that is readable by ground observers. Concepts proposed consider utilizing the existing N-numbers issued by the FAA, or other identifiers, placed on the belly of the helicopter. Lights were also recommended for identification luminescent at night. The discrimination of police, fire, and other emergency helicopters users was proposed. It called for a flashing blue light installed beneath the helicopter. This is similar to sirens on fire trucks for public acknowledgement, safety, and avoidance. The suggested markings and visual identification proposals sought the identification of helicopters causing negative noise impacts or violating any regulatory flight procedures.

Most helicopters are not appreciably sizable in surface area to display a far-visible, distinctive identification. Some helicopters can be visually recognizable due to unique commercial painted designs used primarily for advertising recognition. Although aircraft are required to display a registration number, the mark display requirements, as specified 14 CFR Section 45.29, ranges from 2 to 12 inches in height. The relatively small sized mark display can result in limited long distance recognition. A more fundamental limitation of this approach includes no guarantee that the helicopter of concern will operate within a reasonable relative distance or line of sight.

Land Use/Access

Three operational issues were identified with relationships to "Airport Land Use Planning Compatibility/Airport Noise and Access Restrictions" specified under Part 150/161. These issues are frequency of operations, time frame of operations, and topics associated with heliports/airports (i.e., ground run-up duration). Also presented is the aim of noise abatement procedures. The background leading to Part 150 and Part 161 regulations is briefly discussed.

Part 150/161 Regulations

Proposing to minimize number of aircraft operations and establish a curfew of operational time frame implies airport/heliport access and usage restrictions. These measures are within the interest of the airport operator. Airport access and use restrictions include such topics as hours of airport operation, types of aircraft allowed to utilize the airport, and limits on number of aircraft operations or passenger enplanements. However, the FAA restricts airport operators from establishing policies which impact safety that are unreasonable, unjustly discriminatory, impose an undue burden on interstate commerce, or interfere with Federal regulations.

Background

The FAA has provided technical and financial support for airport noise compatibility planning since 1976. The 1976 Aviation Noise Abatement Policy encouraged airport proprietors and others to consult with FAA about their plans and proposals and to suggest innovative ways to meet the noise problem in their communities. Airport proprietors were encouraged to consult and review proposals to restrict use with airport users and the FAA before implementation.

In 1979, Congress enacted the Aviation Safety and Noise Abatement (ASNA) Act to encourage airport operators to adopt noise abatement plans on a voluntary basis and to provide Federal grants-in-aid for approved plans. This voluntary program was enacted through FAA's issuance of Federal Aviation Regulation Part 150 "Airport Noise Compatibility Planning." ASNA directed the FAA to establish by regulation a single system for measuring aircraft noise exposure, to identify land uses that are normally compatible with various noise exposure levels, and to receive voluntary submissions of noise exposure maps and noise compatibility programs from airport proprietors. Based on the noise exposure maps, strategies are developed and evaluated to reduce noise exposure and non-compatible land uses around an airport.

In 1990, the Airport Noise and Capacity Act (ANCA) was enacted partly in recognition of growing constraints that local airport noise and access restrictions were imposing on the national aviation system. The ANCA affirmed pre-existing law obligating airport operators to not impose restrictions that would, among other things, place an undue burden on interstate or foreign commerce or the national aviation system. In 1991, the FAA established Federal Aviation Regulation Part 161 "Notice and Approval of Airport Noise and Access Restrictions," to implement the requirements under ANCA relating to airport restrictions. Part 161 established requirements for notice, analysis, and review of local Stage 2 aircraft restriction proposals and notice, analysis, and Federal approval of Stage 3 aircraft restriction proposals. The FAA determined that Part 161 should cover operations by all Stage 2 aircraft, including those weighing less than 75,000 pounds that were not subject to the Stage 2 "phase out" requirement.

Part 161 also applies to proposals to restrict operations by helicopters that are certified as Stage 2. Part 161 applies to federally funded airports and heliports or those that plan to seek Federal funding for development projects.

Noise or access restrictions are defined in Part 161 as restrictions affecting access or noise that affect the operations of Stage 2 or Stage 3 aircraft, such as limits on the noise generated on either a single event or cumulative basis; a limit on the total number of aircraft operations; a noise budget or noise allocation program that includes Stage 2 or Stage 3 aircraft; a restriction imposing limits on hours of operations; a program of airport-use charges that has the direct or indirect effect of controlling airport noise; and any other limit on Stage 2 or Stage 3 aircraft that has the effect of controlling airport noise. The rule does not apply to aircraft operational procedures that must be submitted for adoption by the FAA, such as preferential runway use, noise abatement approach and departure procedures and profiles, and flight tracks. Other noise abatement procedures, such as taxiing and engine run-ups, are not subject to Part 161 unless the procedures imposed limit the total number of aircraft operations, limit the hours of aircraft operations, or affect aircraft safety at the airport or heliport.

For Stage 2 aircraft, Part 161 requires that airports provide a cost-benefit analysis concerning proposals to restrict operations and a public notice and opportunity for comment. The analysis must include costs and benefits of the proposal, a description of alternative measures considered, and comparative cost-benefit analyses of these alternative measures. The notice and analysis required must be completed at least 180 days prior to the effective date of the restriction, with a minimum 45-day comment period.

ANCA provides a regulated means through which airport operators, users, and communities could work together to reach solutions which would reduce incompatibility of airport-generated noise with sensitive land uses while ensuring that the airport's role in the national aviation system is not jeopardized. The FAA also encourages airport proprietors to seek to enter into voluntary agreements with users. Voluntary agreements are not subject to ANCA and may include agreed-upon enforcement mechanisms that are consistent with Federal law.

6.1.6 Frequency of Operations

The 36 respondents (or 30 percent of the total comments) recommended limiting the frequency or number of helicopter operations. This issue also encompasses the suggestion for pooling helicopter utilization to reduce number of flight operations. These recommended solutions cover a wide range of options, including, in an increasing order of severity:

(a) Limiting the number of ENG and traffic helicopters;
(b) Reducing the number of operations by Sightseeing (SS)/tour and ENG helicopters;
(c) Permitting ENG helicopters only for specific events;
(d) Eliminating SS helicopters;
(e) Eliminating SS helicopters, and reducing the number of ENG helicopters;
(f) Eliminating SS and non-essential flights;
(g) Permitting only emergency operations; and

(h) Banning all helicopter flights over densely populated areas.

Such proposals to limit, ban, or eliminate the frequency or number of helicopter flights require federally funded airport/heliport operators to comply with Part 161 procedures for implementing restrictions. Such restrictions must establish claim that it would not affect aircraft safety, be unjustly discriminatory, impose an undue burden on interstate commerce, or interfere with Federal regulations.

6.1.7 Time Frame of Operations

Twenty-six respondents or 21 percent proposed instituting helicopter operational curfews. In some cases the curfews were proposed in a general sense without specificity of function of operator. In other cases, the proposed curfews were restricted to either SS or ENG operations or to both. Seven respondents recommended specific curfew time frames. The proposed starting time for a curfew ranges from 9:30 p.m. to 11 p.m. and the proposed ending time is either 7 a.m. or 8 a.m. It was suggested that exemptions be permitted for emergency flights or flights with special justification.

The more stringent proposal specified SS flights operations only from 12 noon to 5 p.m. on weekdays with a total ban during weekday nights and during the entire weekend. All other operations are limited to daylight hours with one recommendation that there be no corporate operations after 6 p.m. on weekdays and no operations on weekends.

Similarly, such proposals to limit helicopter time frame of operation requires federally funded airport and heliport operators to comply with Part 161 procedures for implementing restrictions. Such restrictions must establish claim that it would not affect aircraft safety, be unjustly discriminatory, impose an undue burden on interstate commerce, or interfere with Federal regulations.

A prototype system for aircraft tracking and management of low altitude air traffic in an urban area was demonstrated during the 1996 Centennial Olympic Games in Atlanta, Georgia. Under Operation Heli-STAR (Helicopter Short-Haul Transportation and Aviation Research), a Heli-STAR tracking system was tested in the proof-of-concept evaluation of National Aeronautics and Space Administration's (NASA) AGATE Advanced General Aviation Transportation Experiment Program requirements and temporarily utilized to allow cargo hauling operations of time critical goods.[84] The ADS-B (Automatic Dependent Surveillance-Broadcast) tracking system demonstrated a promising technology that could offer a VFR tracking solution to support the concerns of this study. More R&D investment is required to prepare and fully demonstrate the system for commercialization and field implementation.

6.1.8 Airports and Heliports

Eighteen respondents or 15 percent addressed the operation of helicopters in the neighborhood of airports and heliports. The recommendations covered a wide range of options:

(a) Curfews for arrivals and departures;

[84] Stephen T. Fisher *et al*, "Operation Heli-STAR – Summary and Major Findings," DOT/FAA/ND-97/9 Report, September 1997.

(b) Prescribed arrival and departure routes;
(c) Limits on the number of helicopters based at an airport or heliport;
(d) Limits on the number of helicopter operations at an airport or heliport;
(e) Noise abatement procedures for takeoff and landing at an airport or heliport;
(f) Restrictions on ground operations such as idling and run-up time for helicopters and limitations on pilot training time; and
(g) FAA rules to allow local government to restrict or ban the placement of helicopter landing and takeoff facilities in urban areas.

One respondent addressed the use of IFR and GPS for helicopter operations at heliports in lieu of ground-based precision approach aids. It was further recommended that the FAA develop, and implement, GPS point-in-space approaches to heliports and GPS IFR departure procedures that recognize the full range of helicopter operational capabilities.

Once again, such proposals to limit airport/heliport operations require federally funded airport and heliport operators to comply with Part 161 procedures for implementing restrictions. Such restrictions must establish claim that it would not affect aircraft safety, be unjustly discriminatory, impose an undue burden on interstate commerce, or interfere with Federal regulations. Concerns regarding idling and run-up time for helicopters may not require compliance with Part 161 if it does not affect total number of hours of operations or affect aircraft safety, but are addressed through voluntary operational guidance of noise awareness pilot training.

6.1.9 Noise Abatement Procedures

Noise abatement procedures are designed to lessen the impact of aircraft noise on communities. These procedures depict or describe geographic areas to avoid, approach and departure paths to follow, or limit direction to certain times of day. Noise abatement procedures may also specify rate of climb, altitude restrictions, or power settings. They may provide techniques for ground operations such as use of reverse thrust, reverse thrust back-ups, and maintenance run-ups. The FAA ensures that ATC personnel are cognizant of and do not issue control instructions contrary to noise abatement procedures to the extent they do not impact aircraft safety or air traffic efficiency. Airport sponsors are responsible to ensure pilot compliance with these measures.

Two operational issues were identified with relationships to "Noise Standards: Aircraft Type and Airworthiness Certification" specified under Part 36.

Part 36 Regulations

Under Part 36, Noise Standards: Aircraft Type and Airworthiness Certification, noise certification regulations for helicopters are in subpart H with references to Appendix H, Noise Requirement for Helicopters, and Appendix J, Alternative Noise Certification Procedure for Helicopters. It directly addresses limiting allowable noise levels by setting certification noise limits based on achievable noise reduction and aviation technology and reasonable economic basis. Under the noise certification process, helicopters must demonstrate under strict standards

and test procedures that its worst case maximum noise emission can satisfy established noise limit requirements prior to aircraft production or modification for operations. Helicopters that demonstrated noise levels, at or below the set limits, are in noise compliance and are subject to satisfying applicable airworthiness regulations.

6.1.10 Helicopter Stage 3 limits

Sixteen respondents or 13 percent recommended a requirement that only quieter helicopters may operate in urban areas. In some cases, the recommendation was made in general terms for all operations and unspecific to only urban areas. Ten respondents made specific reference to the categorization of helicopters into Stages 1, 2, and 3 in a manner similar to fixed-wing airplane usage. Two respondents recommended setting new quieter helicopters standards and termed them Stage 4 for helicopters. Internationally, aviation environmental policy is heavily stressing noise stringency (strict limitation on noise) and actively pursuing harmonization of international noise guidelines. The United States is a leading member of ICAO and participates in continued harmonization of noise regulations in the preservation of environmental concerns. Under the Fifth Session of the Committee on Aviation Environmental Protection (CAEP5), a proposal to increase stringency of ICAO Annex 16 noise guidelines for helicopters was adopted within the ICAO steering committee. Proposed stringency would affect the existing regulations by reducing noise limit curves: -4.0 dB for overflight, -3.0 dB for takeoff, and -1.0 dB for approach conditions. Consistent with ICAO council approval, the FAA will promulgate the stringency proposal for U.S. regulatory adoption under 14 CFR Part 36.

6.1.11 Source Noise Reduction (hushkit?)

Three respondents or 2 percent recommended reduction of helicopter noise at source. Some noise reduction is achievable by retrofitting existing helicopters either with a “quiet cruise kit” (response #16) or the installation of a “hushkit” (response #21)[85,86]. In general, respondents identified the need for the development of quieter helicopters and the phasing out of noisier helicopters.

Presently, helicopter “hushkits” do not exist in a generic retrofit process like that of fixed-wing aircraft “hushkits.” Yet, Vertical Aviation Technology, Inc., successfully retrofits a vintage Sikorsky S-55 helicopter primarily for noise reduction. The noise reduction methods applied are uniquely helicopter model dependent and cannot simply be applied to all types of helicopters. The retrofit cost and market demand has not stimulated the larger manufacturers’ technology investment. Major manufacturers find it much more cost effective to build the noise technology into new aircraft rather than retrofit existing aircraft. The $10 million invested by Vertical Aviation Technology Inc. was very specifically aimed at meeting the sightseeing/tour operator needs. This was in anticipation of the impending noise restrictions in national park areas being proposed.

Investments and implementation of noise reduction technology has not completely been a recognized priority by all manufactures. Internationally harmonized requirements for stricter noise certification regulation will compel implementation of noise reduction technology. More aggressive manufacturers are promoting their development of quieter helicopters in the market

[85] Docket Comment #16: by Bell Helicopter Textron Inc., TX. July 24, 2000.
[86] Docket Comment #21: by Whisper Jet Inc., FL. July 25, 2000.

place. Public recognition for advocating “quiet” helicopters and consumer/operator awareness is gradually changing the buyer/operator “lowest purchase price” paradigm for helicopter to one of community friendly/environmentally compatibility. The U.S. helicopter industry highly recommended the infusion of Government basic research and development funding for “quiet” rotorcraft technology to equally compete with foreign entities.

6.2 Non-operational Issues
In the following, non-operational issues are presented. These are issues not mutually exclusive but are, rather, interrelated. Note that military helicopter operations are not addressed because they are outside of the scope of this mandate.

6.2.1 Voluntary Rules
There is consensus among individual respondents, homeowners’ associations and citizens’ associations that voluntary restrictions on helicopter operations in urban areas do not work. However, respondents from helicopter operators’ associations dispute this conclusion. Eastern Region Helicopter Council of operators has quoted examples where New York City route changes to mitigate noise exposure on residents have resulted in complaint reductions. The helicopter operators also referred to their “Fly Neighborly” as an effective voluntary program to minimize noise levels in urban communities.

For helicopters, special voluntary routes are established making full use of the VTOL operating characteristics that would otherwise constrain flight corridors due to miss matches in speed criteria with fixed-wings. Although use of these routes is not mandatory, it is recommended by FAA for its mutually established benefits, i.e., avoidance of noise sensitive areas and reduction in general flight corridor traffic.

6.2.2 Pooling of Operations
Twenty-two respondents or 18 percent suggested that there be pooling of ENG helicopters so that there is only one helicopter flying to cover a particular event. Television and radio stations would share the signal transmitted from that pool helicopter. The responses ranged from recommendations of voluntary participation to recommendations of mandatory regulations.

With specific application to the reporting of traffic problems, it was recommended that ground-based systems be used instead of ENG helicopters for the reporting of traffic problems; i.e., cameras installed along the freeways by Caltrans in Southern California.

Pooling of operations, specifically of ENG helicopter operations, is a concept targeted at limiting the number of operations which could reduce the frequency (number) of noise events and accumulation (amplification) from multiple helicopters simultaneously operating at the same event and concentrated airspace.

Although outside of the FAA purview, one suggestion is that business incentives for “pooling” ENG helicopter operations among operators be considered. By pooling ENG operations, it reduces the noise that otherwise is generated by multiple operations covering the same incident. Such a proposed program is encouraged for state/city governments and/or local municipalities and businesses desiring to retain ENG operations while also mitigating noise for their area.

6.2.3 Exempt Law Enforcement and Emergency Medical Services

For the noise reduction alternatives suggested, several could inhibit public service helicopter operations. However, the public expressed supported for exemption from noise restriction alternatives for services in performance of emergency operations. Yet, they still recommended adherence when operating in a non-emergency response condition; i.e., returning to base station.

As a specific concern outlined under the mandate, the discussion regarding law enforcement and EMS is given in Section 5.2, Law Enforcement and Other Public Emergency Services.

6.2.4 VFR and IFR Operations

The helicopter industry recommends that the FAA revise current VFR corridors and checkpoints to minimize noise exposure in urban areas. They also seek that ATC be more aggressive in assigning helicopter flight altitudes for minimum noise whether or not requested by the helicopter flight crew. In addition, the FAA and ATC should develop a better understanding of the helicopter noise problem in urban areas and devise better techniques and training with respect to the unique characteristics of helicopters.

The helicopter industry also recommends that the FAA develop easier access for helicopters to the IFR system with approach and departure capability to and from the actual heliport facilities. It was stated that the changes would eliminate the current lower altitude VFR transitions between the current heliports and the IFR access points. The operators project that there would be higher use of the IFR system by operators that currently opt for lower altitude VFR operations rather than face the delays and uncertainties of the current IFR environment.

Further discussions regarding the VFR,UNC, and IFR operations are addressed in more depth in Section 5.0, Helicopter Air Traffic Control Procedures.

6.2.5 Airspace Control

Local legislative and city authorities commented on requesting authority for determinations of noise and airspace control decisions. However, Federal law outlines the FAA as the agency with jurisdiction and responsibility for airspace control with necessary adherence to environmental policy.

One commenter summarized FAA's options to regulate helicopter traffic and stated that, regardless of whether the best solution is to turn control over to state and local governments or to the FAA to impose strict controls, thousands of urban residents are awaiting a comprehensive and well-reasoned environmentally responsible document. In the past, FAA has worked with local communities and helicopter operators in the New York area and other areas of the country to establish memoranda of understanding designating voluntary noise abatement routes and

procedures, such as for helicopter sightseeing in the vicinity of the Statue of Liberty. FAA is willing to continue to facilitate voluntary solutions to address community concerns. While the FAA's exclusive statutory responsibility for noise abatement through regulation of flight operations and aircraft design is broad, the noise abatement responsibilities of state and local governments through exercise of their police powers are circumscribed. Local governments are currently preempted from regulating overflights, in part because of the national need for uniform regulation of the navigable airspace. A patchwork quilt of state and local government airspace regulations would impose an undue burden on interstate commerce. State and local governments play a critical role in protecting their citizens from unwanted noise using their powers of land use control. FAA continues to study the issue in order to abate aircraft noise to protect public health and welfare.

6.2.6 Military Helicopters

Military helicopters were specifically excluded from the current study. However, several respondents observed that the general public could not differentiate between civilian and military helicopters. Military helicopters flying over urban areas are usually performing transit operations that are similar to those performed by civilian helicopters. Thus, respondents recommended that military helicopters be included in the study.

Military helicopters utilize the same airspace system, making it difficult to determine the influence the sector that contributes to the public's disturbance. Many military helicopters are not designed to civil noise standards in order to satisfy stringent mission performance requirements. In the long term, it would be beneficial for both sectors, civil and military, to resolve such issues mutually for any future noise solutions to be more effective (and possibly more economical). One proposal is that the Department of Defense consider assimilation of civil noise standards for military rotorcraft in order to address noise reduction in a unified national strategy that mitigates noise from all types of helicopter operations.

Technology Research Initiatives

Respondents identified several topics for further research to better understand the impact of helicopter noise on residents of urban areas and to foster the development of quieter helicopters.

6.2.7 Socio-Acoustic (Psycho-Acoustic) Survey

Ten respondents or eight percent, inclusive of the helicopter industry's support, recommended that a socio-acoustic survey of the people living and working in urban communities exposed to helicopter noise be conducted. The survey should include determination of the types of operation and the noise characteristics that the public find annoying. "Psycho-acoustic" experts in the field of environmental health should design it. Public comments encouraged that any implemented noise methodology be subject to peer review by members of the scientific and medical communities to ensure that it is unbiased. The results of the survey would be used in the development and implementation of methods to reduce the effects of helicopter noise in urban areas. Socio-noise author Professor Bronzaft recommends that Congress consider allocation of funds to support a multi-year, socio-acoustics study at an approximate cost of $150,000 annually to capable universities.[87]

6.2.8 Flight Tracking and Noise Monitoring System

Workshop respondents raised the concern the FAA does not formally track number of operations, normally considered by takeoffs and landings, for helicopters as well as overflights through a given area. This concern was incited in the acceptance of quantifiable helicopter

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[87] Communications with Bronzaft, 2000.

statistics that are currently retained by operators. Communities argued this information was unreliable, without through traffic noise effects and biased, when seeking to gauge noise impact. Hence, recommendations were made for the FAA to track helicopter operations and also perform noise monitoring to quantify the impact, in particular, for specific noise sensitive sites such as parks, hospitals, and neighborhoods.

The FAA does not formally track the number of helicopter operations (takeoffs and landings) nor does the FAA actively monitor noise in metropolitan areas. No process exists for tracking VFR flights below radar controlled airspace. For helicopter operations within the ATC controlled airspace, the radar tracking system records such approved operations. The current VFR procedures are structured for independent operational tracking that helicopters greatly utilize given their vertical short takeoff and landing capabilities. The priority for tracking focuses primarily on IFR controlled airspace and commercial transport operations. The FAA main priority is dedicated to maintaining the IFR system functions. FAA has limited infrastructure tracking resources and budget to expand capabilities to VFR operations.

6.2.9 Global Positioning System approach/departure Noise Abatement Technology

"Spin-off" GPS technology, from an effort to improve radar guided landing and takeoff operations for bad weather, holds the prospect of mitigating noise. By prescribing approach and departure profiles using GPS guidance technology, helicopters can be flown or directed to avoid the high noise generating aircraft states or minimize operations through them.

Under NRTC/RITA activities, preliminary research and testing has indicated the promise of reducing approach noise. However, further development is required to validate a commercially viable system. This new technology offers another alternative for enhancing the capability of operational noise abatement procedures.

6.2.10 Improved Helicopter Noise Metric

Several respondents claim that there is no adequate metric for measuring the response of humans to helicopter noise. Studies indicate the metrics developed for airplane noise are not completely adequate for helicopters. There is a need for further development of appropriate annoyance metric with improved correlation for helicopters.

As discussed in "effects on individuals" (Section 3), there are multiple noise metrics utilized to assess noise (EPNL, ASEL, DNL, etc). However, civil helicopter annoyance assessments utilize the same acoustic methodology adopted for airplanes with no distinction for helicopter's unique noise character. As a result, the annoyance of unaccustomed, impulsive helicopter noise has not been fully substantiated by a well-correlated metric. The FAA favors the chartering a technical effort to focus on low-frequency noise metric to evaluate helicopter annoyance.

6.2.11 Quieter helicopters

Recommendations were made that helicopter manufacturers be encouraged to design quieter helicopters. FAA, NASA, and industry agree it could only be accomplished through stable continued funding of the joint research programs.

Unlike fixed-wing aircraft that benefited from the leap from jet to turbofan technology, helicopter noise reduction technology has not achieved comparative orders of noise reductions. Much of the R&D returns has come from improved understanding and identification of physical mechanisms and phenomenon modeling, such as BVI noise and HSI noise occurring during approach and high speed cruise. Studies have identified "noise reducing" design trades and concepts such as increasing number of blades, reducing tip speed, thin blade tips, high technology airfoils, and a variety of other parameters. Presently, stiff international competition and greater environmental sentiment are making manufacturers more cognizant of their need to invest and implement "quiet" technology into helicopter design.

Noise database

The FAA continues to work with NASA and the aviation industry to identify and create aggressive research programs. There is a strong global awareness for engineering innovations in "quiet" technology for aircraft now and in the future. With the completion of the Advanced Subsonic Technologies Program, many of the concepts await an overall integrated technologies demonstration. NASA has been the Nation's leader in fostering comprehensive helicopter design methods and the establishment of noise test databases for rotorcraft. Together with the FAA, technical studies to bridge the gap between inaccuracies in helicopter predictions, when compared to measurements, require a serious resolution. Overall, the course of our Nation's aviation noise reduction technology effort, especially for rotorcraft, must consider revitalization if significant long-term improvements for noise integration technology are to occur.

7.0 Source Noise Modeling and Sensitivity Assessment

In this section, noise measurements made to establish the helicopter source noise effects with an urban environment are presented. This is followed by a helicopter altitude-noise sensitivity evaluation to consider the benefits of operations at higher altitude.

7.1 Helicopter Source Noise Measurements in an Urban Environment

Figure 7-1. AStar Helicopter Flyby in an Urban Environment (Liberty State Park, NY/NJ)

Helicopter source noise measurements in a densely populated area were necessary to quantify the influences of helicopter noise relative to an urban setting (other noise contributions are automobile traffic, harbor ferry, people, etc.) and understand urban setting effects.

In support of the FAA, the Volpe National Transportation Systems Center Acoustics Facility (Volpe Center) conducted field measurements in the greater New York City area during the week of July 17, 2000. Although the Section 747 mandate is national in scope, the New York City area was chosen for the collection of *in-situ* acoustic data because it was representative of an urban environment exposed to helicopter operations and offered many sites suitable for the collection of such data. Measurements were primarily conducted in New Jersey's Liberty State Park (see Figure 7-2). Additionally, data were collected near one of the downtown heliports, adjacent to the Wall Street financial district. The collected data were studied to identify the urban noise effects relative to conventional common ground conditions and assessed for noise reduction/altitude sensitivities. Similar New York City *in-situ* test data and other available aircraft noise measurements were compared. FAA's Helicopter Noise Model/Integrated Noise Model (HNM/INM) was utilized to model altitude-noise attenuation effects.

Figure 7-2. Liberty State Park - Helicopter Noise Measurement Site

Figure 7-3. Digital Video-based Tracking System

During the measurements, acoustic data were collected using at least one microphone, depending on the site. Additionally, detailed aircraft position data were collected using a digital video-based tracking system (Figure 7-3). Reduction of these data renders time-correlated X, Y, Z and velocity data for each aircraft event. As a backup to the video tracking data, redundant slant range data for the aircraft were collected via 35mm camera-based photo scaling methods as well as using laser range-finding devices. Meteorological data were collected periodically throughout the measurements.

Figure 7-4. An Urban High Density Setting

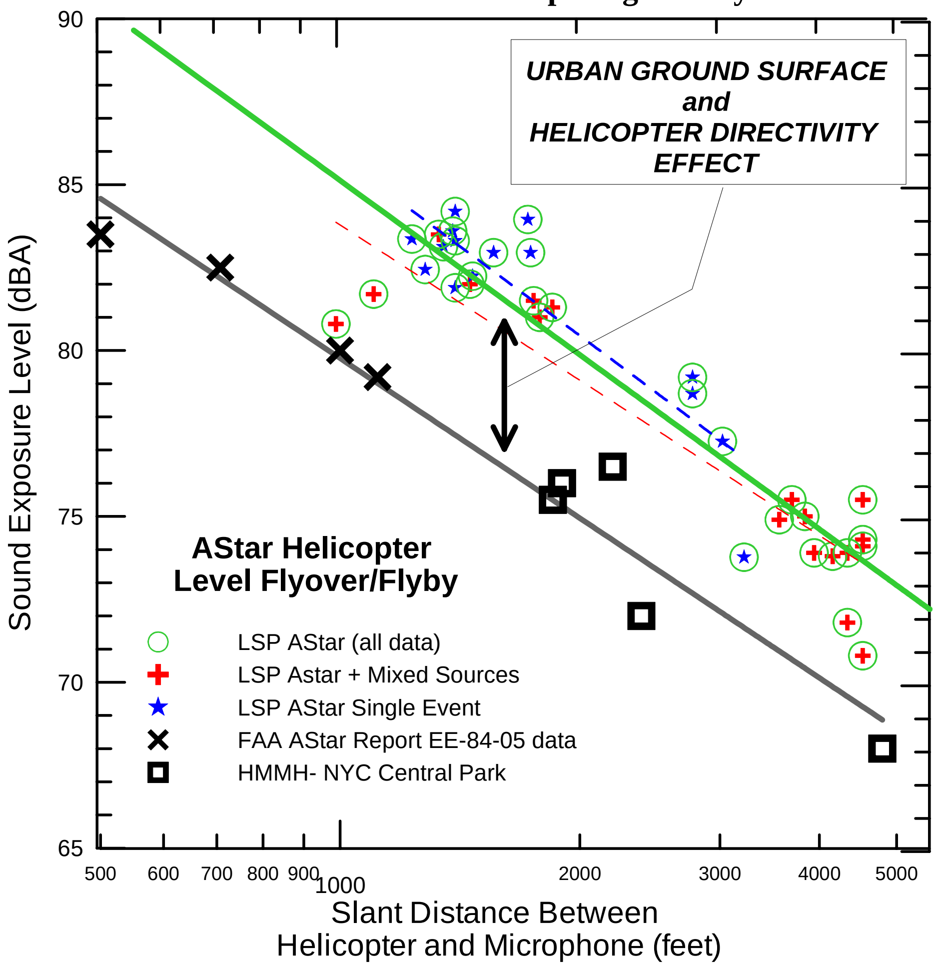
Urban Noise Results

In assessing the acoustical effects of an urban environment, noise data for different ground conditions are investigated. Measured Liberty State Park AStar helicopter noise data are compared with available AStar helicopter noise data from a non-urban setting. In Figure 7-5, SEL and corresponding distance data from Appendix G, Tables (1a) and (1b), are plotted. The single event and mixed helicopter data are depicted as circled star and plus symbols, respectively. It represents helicopter noise over hard ground conditions, characteristic of urbanization, as it was principally measured over calm water. AStar helicopter noise certification data and recent measures from the New York City Master Plan are plotted as “X” and squares, respectively. The latter data were measured over common semi-absorptive ground conditions such as cut grass. Equivalently, the New York City Master Plan noise data are from flights recorded in Central Park.[88]

[88] Edwards and Kelcey Engineering, Inc., *“Heliport and Helicopter Master Plan for the City of New York,”* Final Report, March 1999.

As shown in Figure 7-5, an ASEL difference of approximately +3.5 dB exists between fitted curves for each dataset. Helicopter noise predictions with ground surface noise reflection effects by Leverton and Pike predicted the noise difference being lower than that given by the data. Based on the comprehensive ground reflection analysis, presented in Appendix G, the sound reflections due to hard ground appeared to cause an approximate +2 dB increase in noise levels relative to a semi-absorptive ground conditions. The additional +1.5 dB contribution is possibly due to the helicopter's nonuniformed noise directivity that was a recognizable factor given the *in-situ* measurement situation. In Figure 7-6, the AStar helicopter noise directivity is presented in an azimuthal polar plot. It reveals the higher ASEL at the starboard side as approximately +1.5 dB greater than the port side. The *in-situ* measures distinguish directivity effects that otherwise are averaged lower by multi-microphone measurements. Other factors such as variability in altitude, airspeed, and meteorological effects contribute additional deviations of the data.

Figure 7-5. AStar Noise Measurements Comparing Liberty State Park Noise Effects



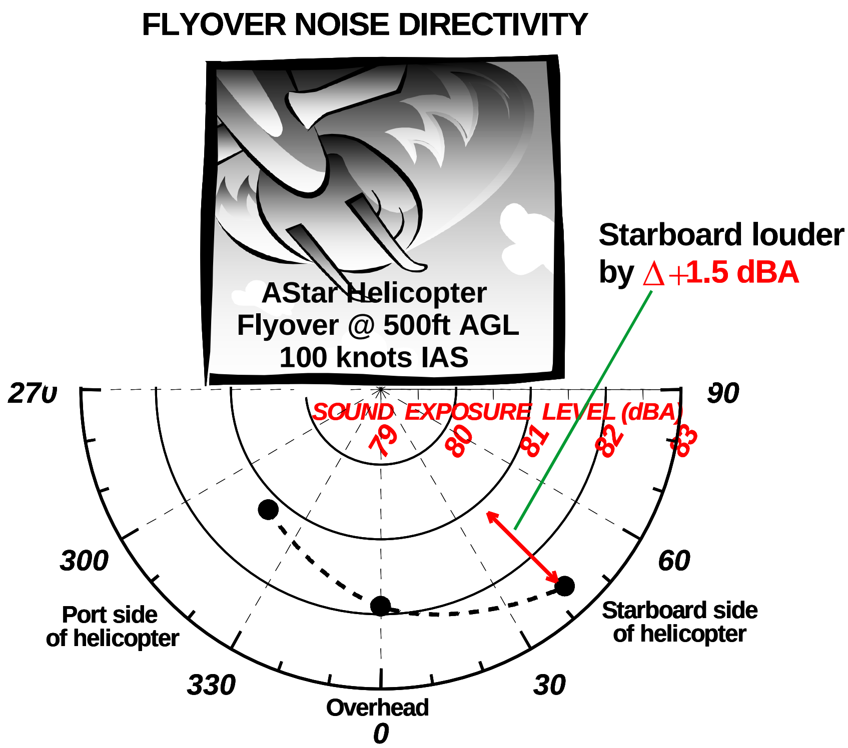


Figure 7-6. Azimuthal Noise Directivity Polar of an AStar Helicopter for 100 knot Flyovers (Ref. FAA-EE-84-05 Report)

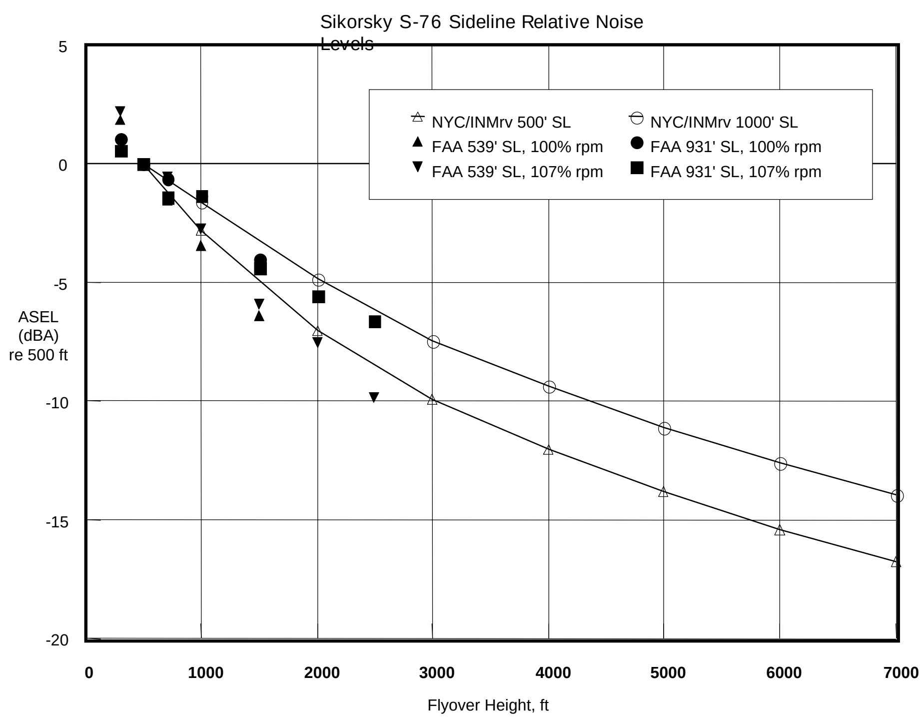


Figure 7-7. S-76 Altitude-Noise Reduction Sensitivity for Liberty State Park

The Research Version of the INM (INMrv) was utilized with Liberty State Park data to model altitude-noise reduction sensitivity effects. The details of the analysis are discussed in Appendix G. Shown in Figure 7-7, the normalized 500-foot Liberty State Park noise results, given by the solid curves, are consistent with past data for lateral sideline noise reduction with increasing altitude. It reveals the possible noise reduction benefit with increased altitude flight for the S-76 given the 500-foot or 1,000-foot lateral observers. The attenuation rates are consistent with previously documented measurements offering high confidence in the data.[89]

In conclusion, an approximate +2.0 dB increase in noise is a result of the noise propagation over a hard ground condition. In this case, it was water. The *in-situ* measurement distinguish directivity effects that otherwise are averaged lower by multi-microphone measurements. Certainly, other factors such as variability in altitude, airspeed, and meteorological effects contribute some deviation to the data. The Liberty State Park data have been checked and revalidated for repeatability. The rates of noise reduction with increasing altitude are consistent whether over common ground or in urban environment. However, the absolute levels should be adjusted to include the +2.0 dB effects of urbanization.

7.2 Altitude-Noise Sensitivity - Introduction

The most highly cited operational issue that was expressed to the FAA requested establishing a minimum altitude for helicopters. The public comprehends the benefit of reducing noise by creating a greater stand off distance and seeks minimum altitude AGL operations. However, there existed some concern that, because of excess ground attenuation effects, sideline noise levels could actually increase as helicopter altitude increased, reaching a maximum for some altitude and then eventually decrease as helicopter altitude is increased further. Several published FAA/industry helicopter noise certification databases have been reviewed in an attempt to address that concern and establish an understanding of altitude-noise sensitivity for observers under the immediate flight path.

Background

It is well known in the certification of transport category and turbojet powered airplanes that values of EPNL measured at takeoff sideline (lateral) locations have a maximum for airplane altitudes of about 1,000 feet although the maximum may not be well-defined in some cases. The explanation is that, during an airplane's takeoff roll and very low altitude lift-off, the effect of excess ground attenuation (EGA) is strongest at shallow incidence angles which contribute a reduction to the sideline noise levels. Shortly after reaching an approximate 1,000 feet altitude, the effect of EGA decreases with incidence angle and the sideline noise levels peak to maximum levels due to spherical spreading dominance. Beyond this point, the sideline noise levels decrease correspondingly with the airplane's increase in relative distance. This sequence of contributing noise effects is identified and depicted in Figure 7-8 for a large transport jet for the three segments of departure.

[89] J.S. Newman, Rickley, E. J., Bland, T. L., Beattie, K. R., "Noise Measurement Flight Test: Data/Analyses Sikorsky S-76A Helicopter", FAA-EE-84-06, September 1984.

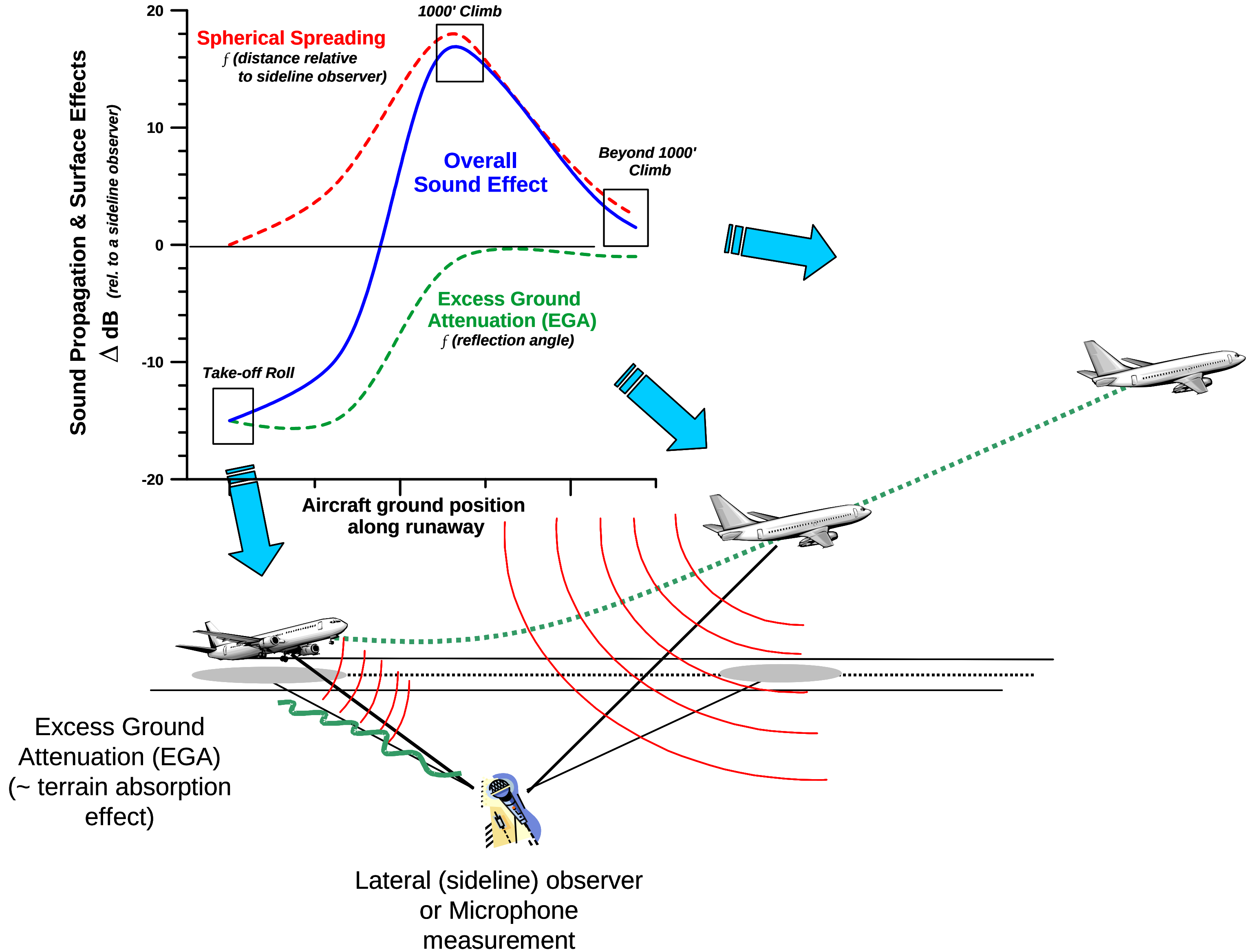


Figure 7-8. Noise Effects For Jet Transport During Departure

Helicopter Noise Database

The FAA has conducted several noise tests on various helicopter types, but most of the tests suffer from the same limitation in that the sideline measuring location is only 492 feet (150 meters) from the flight path.[90,91,92,93,94,95,96,97,98,99,100,101] However, in one case, Newman *et al* made measurements at sideline distances of 539 feet (164 meters) and 931 feet (284 meters). Level flyovers were made at altitudes of 300, 500, 700, 1,000 and 1,500 feet (also 2,000 and 2,500 feet for some helicopters). These combinations of sideline distance and helicopter altitude give elevation angles of 29° to 70° for the 539 feet sideline location and 18° to 58° for the 931 feet sideline location. These elevation angles are greater than those associated with a typical airplane noise certification, but are at least comparable with them in the case of the 931 feet location. Thus, it might be expected that effects of ground attenuation, if any, would be observed in data measured at the 931 feet sideline location.

The measurements reported by Newman *et al* were conducted at the FAA Technical Center (Atlantic City, New Jersey), off the end of the runway. It was reported that there was a cleared circle, approximately 200 feet in diameter, of mowed grass around each microphone location. Low scrub bush and grass bordered each cleared circle. The helicopters tested were Agusta 109, Bell 206L, Sikorsky S-76, and Sikorsky UH-60A Blackhawk. In the case of the Sikorsky S-76, tests were conducted at two engine power settings.[102]

Variation of Noise Level

Data from Newman *et al* are plotted in Figures 7-9 through -13 in terms of the noise level relative to the level measured for a flyover altitude of 300 feet. In some cases, sound levels measured beneath the flight path are included with the sideline data for comparison. The relative

[90] J.S. Newman,and Rickley, E. J., "Noise Levels and Flight Profiles of Eight Helicopters using Proposed International Certification Procedures", FAA-EE-79-03, March 1979.
[91] J.S. Newman, Rickley, E. J., and Ford, D. W., "Helicopter Noise Definition Report: UH-60A, S-76, A-109, 206L", FAA-EE-81-16, December 1981.
[92] J.S. Newman, Rickley, E. J., and Bland, T. J., "Helicopter Noise Exposure Curves for use in Environmental Impact Assessment", FAA-EE-82-16, November 1982.
[93] J.S. Newman, Rickley, E. J., Bland, T. L., and Daboin, S. A., "Noise Measurement Flight Test: Data/Analyses Bell 222 Twin Jet Helicopter", FAA-EE-84-01, February 1984.
[94] J.S. Newman, Rickley, E. J., Daboin, S. A., and Beattie, K. R., "Noise Measurement Flight Test: Data/Analyses Aerospatiale SA 365N Dauphin 2 Helicopter", FAA-EE-84-02, April 1984.
[95] J.S. Newman, Rickley, E. J., Daboin, S. A., Beattie, K. R., "Noise Measurement Flight Test: Data/Analyses Hughes 500D/E Helicopter", FAA-EE-84-03, June 1984.
[96] J.S. Newman, Rickley, E. J., Beattie, K. R., Daboin, S. A., "Noise Measurement Flight Test: Data/Analyses Aerospatiale AS 355F TwinStar Helicopter", FAA-EE-84-04, June 1984.
[97] J.S. Newman, Rickley, E. J., Bland, T. L., Beattie, K. R., "Noise Measurement Flight Test: Data/Analyses Aerospatiale AS 350D AStar Helicopter", FAA-EE-84-05, September 1984.
[98] J.S. Newman, Rickley, E. J., Bland, T. L., Beattie, K. R., "Noise Measurement Flight Test: Data/Analyses Sikorsky S-76A Helicopter", FAA-EE-84-06, September 1984.
[99] J.S. Newman, Rickley, E. J., Bland, T. L., Beattie, K. R., "Noise Measurement Flight Test: Data/Analyses Boeing Vertol 234/CH 47-D Helicopter", FAA-EE-84-07, September 1984.
[100] J.S. Newman, Rickley, E. J., Locke, M., "International Civil Aviation Organization Helicopter Measurement Repeatability Program: U.S. Test Report, Bell 206L-1, Noise Flight Test", FAA-EE-85-6, September 1985.
[101] J.S. Newman, Rickley, E. J., Levanduski, D. A., Woolridge, S. B., "Analysis of Helicopter Noise Data using International Helicopter Noise Certification Procedures", FAA-EE-86-01, March 1986.
[102] J.S. Newman, Rickley, E. J., and Ford, D. W.

noise levels are presented in terms of four parameters: EPNL, SEL, Maximum A-weighted Sound Level (Lmax), and Maximum Perceived Noise Level Tone corrected (PNLTM).

Each set of test data for Lmax or PNLTM has an associated (broken) curve showing the sound level decay according to spherical spreading (inverse square law). For the integrated measures (EPNL and SEL) the estimated level decay is based on the relationship $12.5\log(R_2/R_1)$, where the factor of 12.5 is the net result of adding a factor of 20 for the inverse square law and a factor of –7.5 for the duration correction as applied in Part 36.

The following observations can be made regarding the data in Figures 7-9 through -13. In no case does the noise level increase as helicopter altitude increases. Thus, if EGA is present, it is not very marked for the distances and angles involved with the tests. In most cases, the measured values of PNLTM and Lmax decrease more rapidly than is predicted by spherical spreading as helicopter altitude increases. This implies that excess ground attenuation is negligible.

Integrated measures (EPNL and SEL) show trends similar to those of the instantaneous measures (PNLTM and Lmax), but the rate of decrease of noise level as helicopter altitude increases is slower because of the duration effect.

Whether or not there is any contribution from EGA, the results show that there is only a small reduction in sideline noise level as helicopter altitude increases, until an altitude of about 1,000 feet is reached. For a sideline distance of 931 feet, the integrated noise levels are typically reduced by about 2 dB when the helicopter altitude increases from 300 feet to 1,000 feet, and the PNLTM and Lmax are reduced by about 3 dB.

Discussion

The test data indicate that helicopter sideline noise levels decrease as helicopter altitude increases, at least for sideline distances up to 1,000 feet and elevation angles greater than 18°. The data do not allow conclusions to be drawn for greater sideline distances where the elevation angle of the helicopter would be less than 18°. EGA influences fixed-wing airplane sideline noise levels under Part 36 certification conditions, where the elevation angle is between 11° and 34° (airplane altitudes of 300 to 1,000 feet). However, excess ground attenuation is applied by Newman *et al* only when the helicopter is in hover in the ground effect and the elevation angle is 0° or when the helicopter is in hover out of the ground effect and the elevation angle is near 0° (although "near" is not defined in the reference).[103] Thus, the conditions under which excess ground attenuation would have the greatest influence on helicopter noise propagation are not well defined.

While the role of EGA on helicopter noise propagation over vegetation is not completely defined by the FAA helicopter test data, the results may be indicative of conditions for flight over water. Not defined at all by these data is the effect of helicopter altitude on sideline noise levels in an urban environment with numerous buildings. Thus, the *in-situ* measurements were made as

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[103] J.S. Newman *et al*, FAA-EE-82-16, November 1982.

discussed in Section 7.1, Source Noise Modeling and Sensitivity Assessment, and in Appendix G, *In-situ* Urban Helicopter Noise Measurements (New York City).

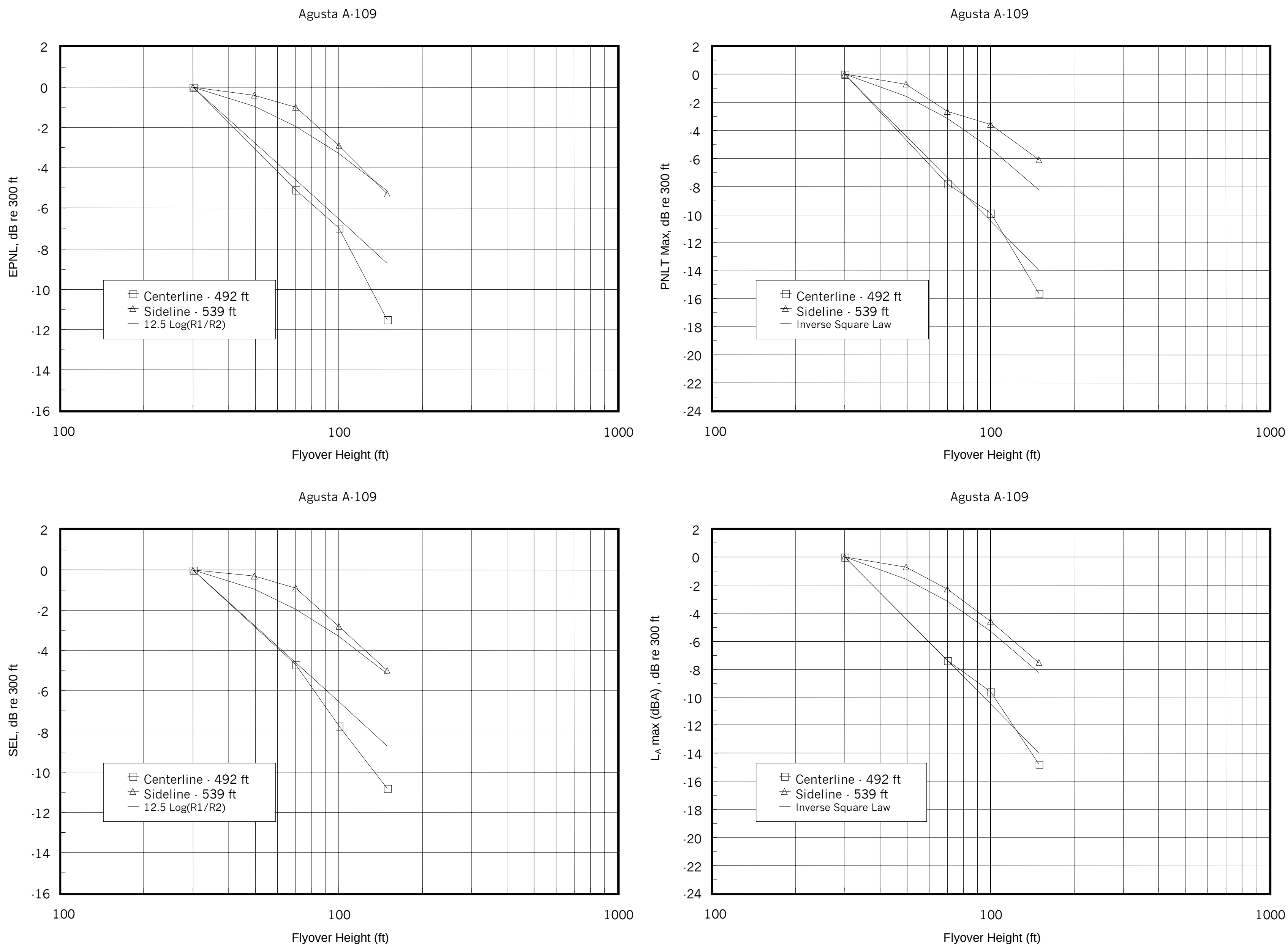

FIGURE 7-9. RELATIVE NOISE LEVELS OF AGUSTA A-109 HELICOPTER AS A FUNCTION OF HELICOPTER ALTITUDE

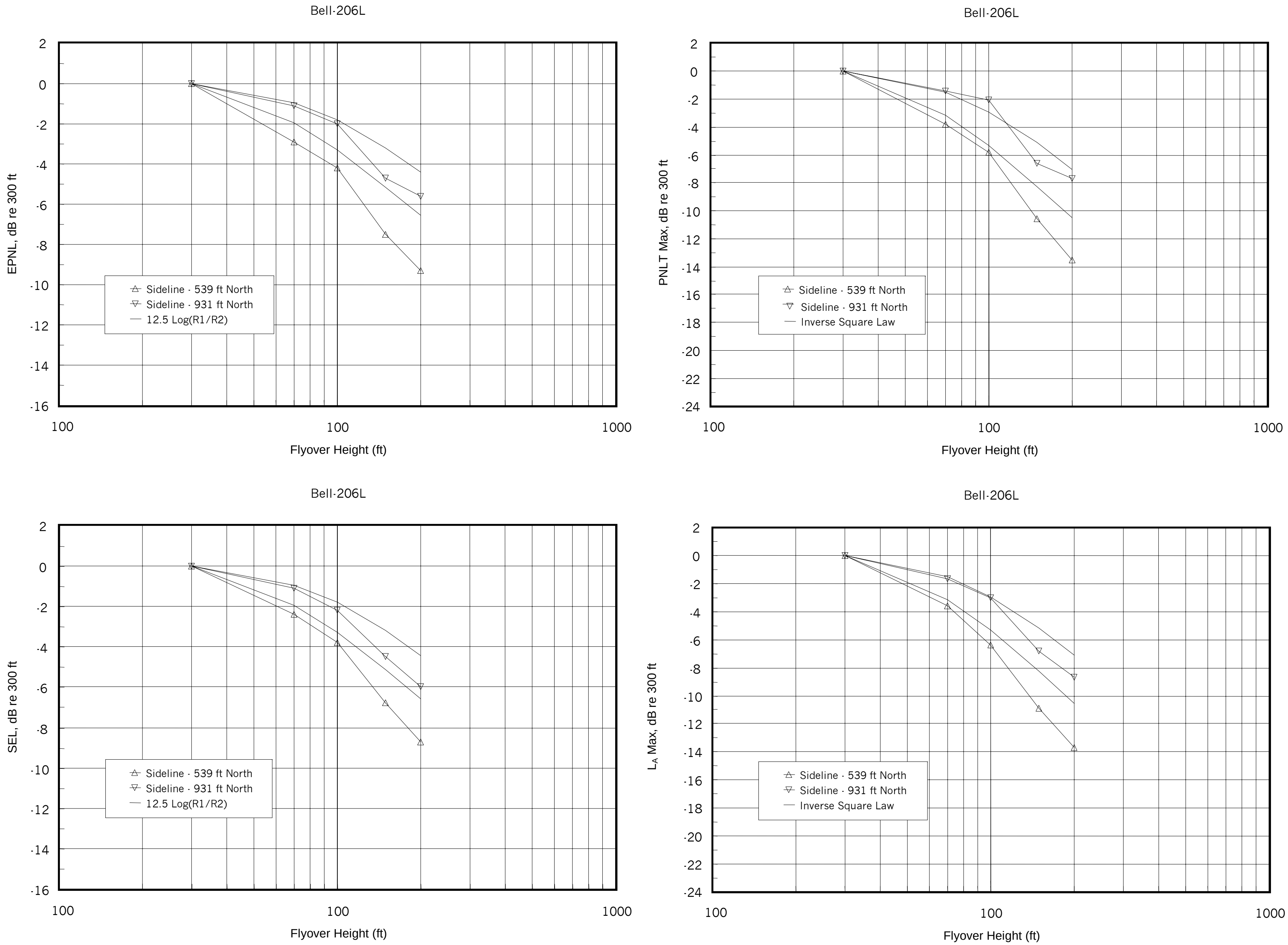

FIGURE 7-10. RELATIVE NOISE LEVELS OF BELL 206L HELICOPTER AS A FUNCTION OF HELICOPTER ALTITUDE

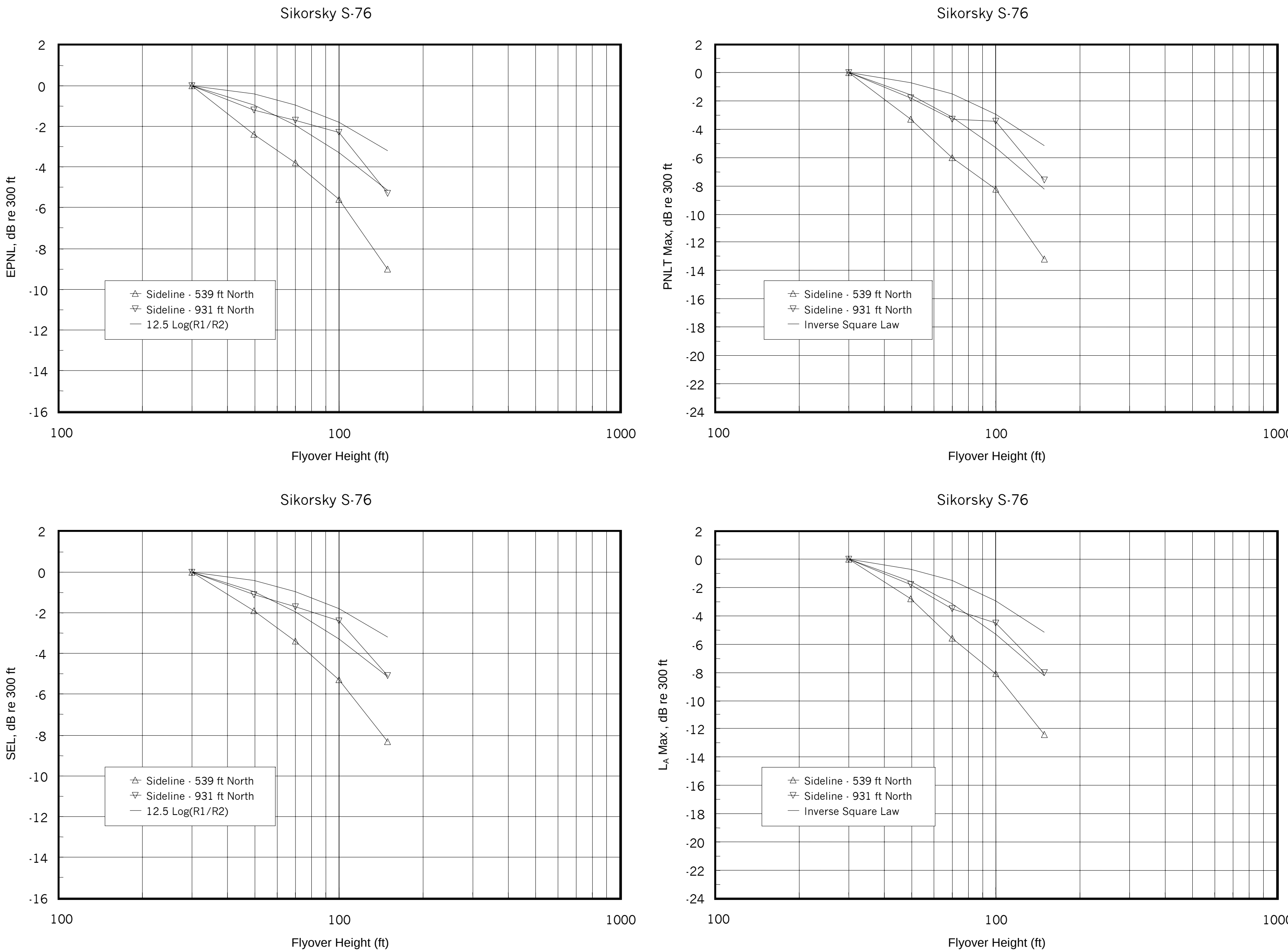

FIGURE 7-11. RELATIVE NOISE LEVELS OF SIKORSKY S-76 HELICOPTER AS A FUNCTION OF HELICOPTER ALTITUDE

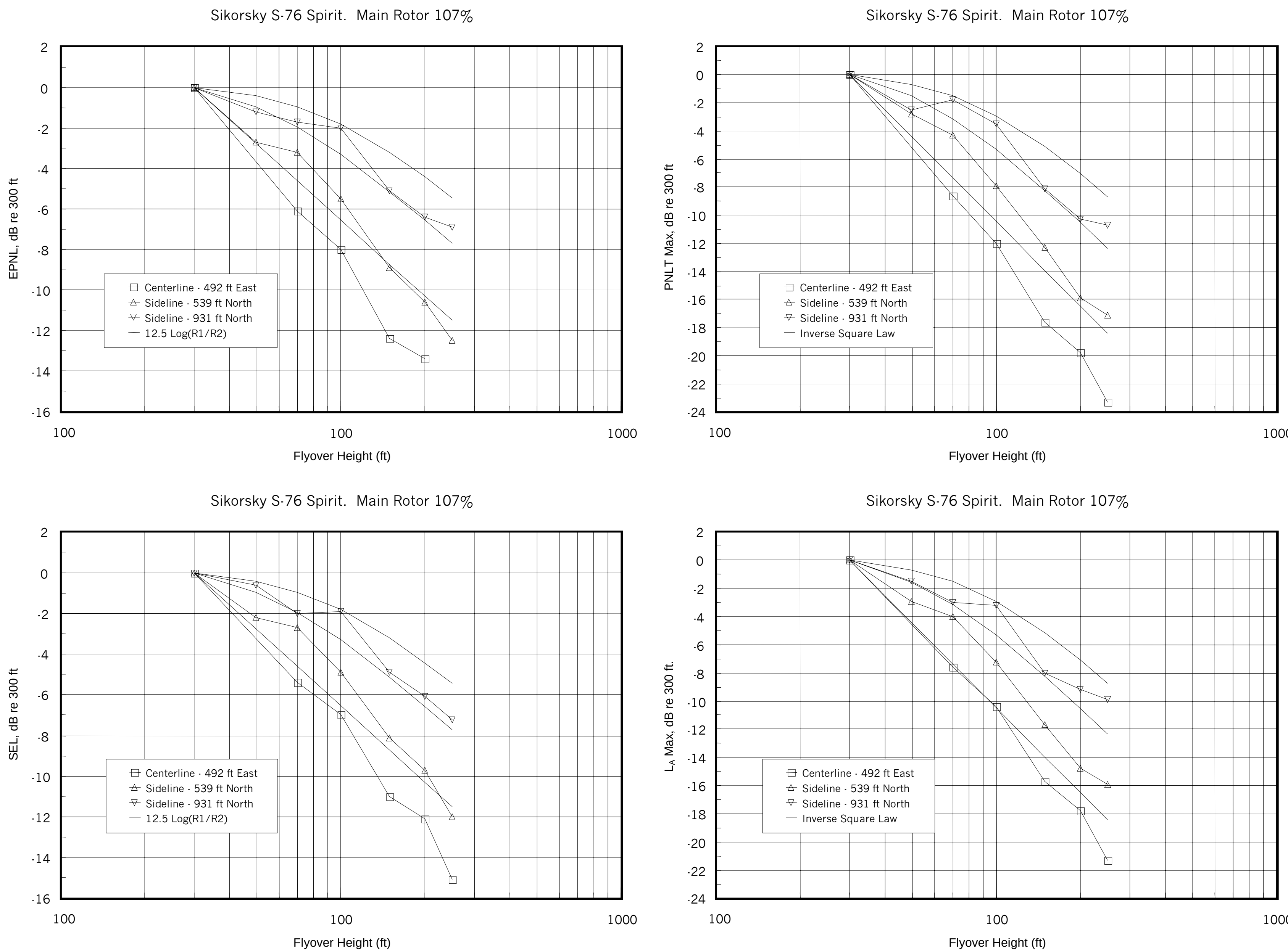

FIGURE 7-12. RELATIVE NOISE LEVELS OF SIKORSKY S-76 (107% RPM) HELICOPTER AS A FUNCTION OF HELICOPTER ALTITUDE

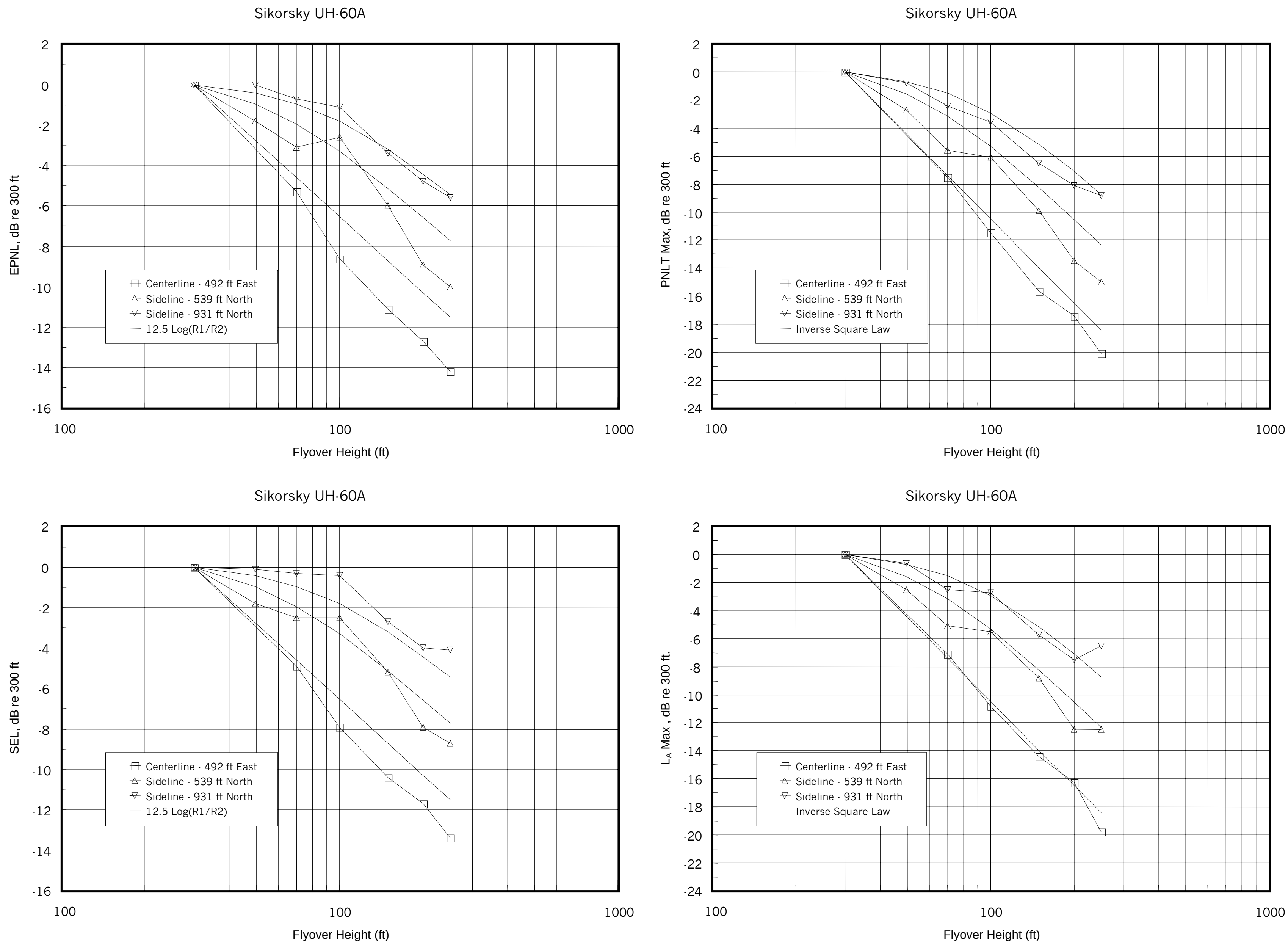

FIGURE 7-13. RELATIVE NOISE LEVELS OF SIKORSKY UH-60A HELICOPTER AS A FUNCTION OF HELICOPTER ALTITUDE

Based upon the FAA's preliminary *in-situ* noise measurements (see Figure 7-14), increasing operational altitude or height AGL does reduce noise from helicopters (for details see Appendix G). Also, the *in-situ* data corroborates operational noise measurements reported in the New York City Master Plan Report. In general, trends support the industry's voluntary operational guidance to "fly higher" altitudes.

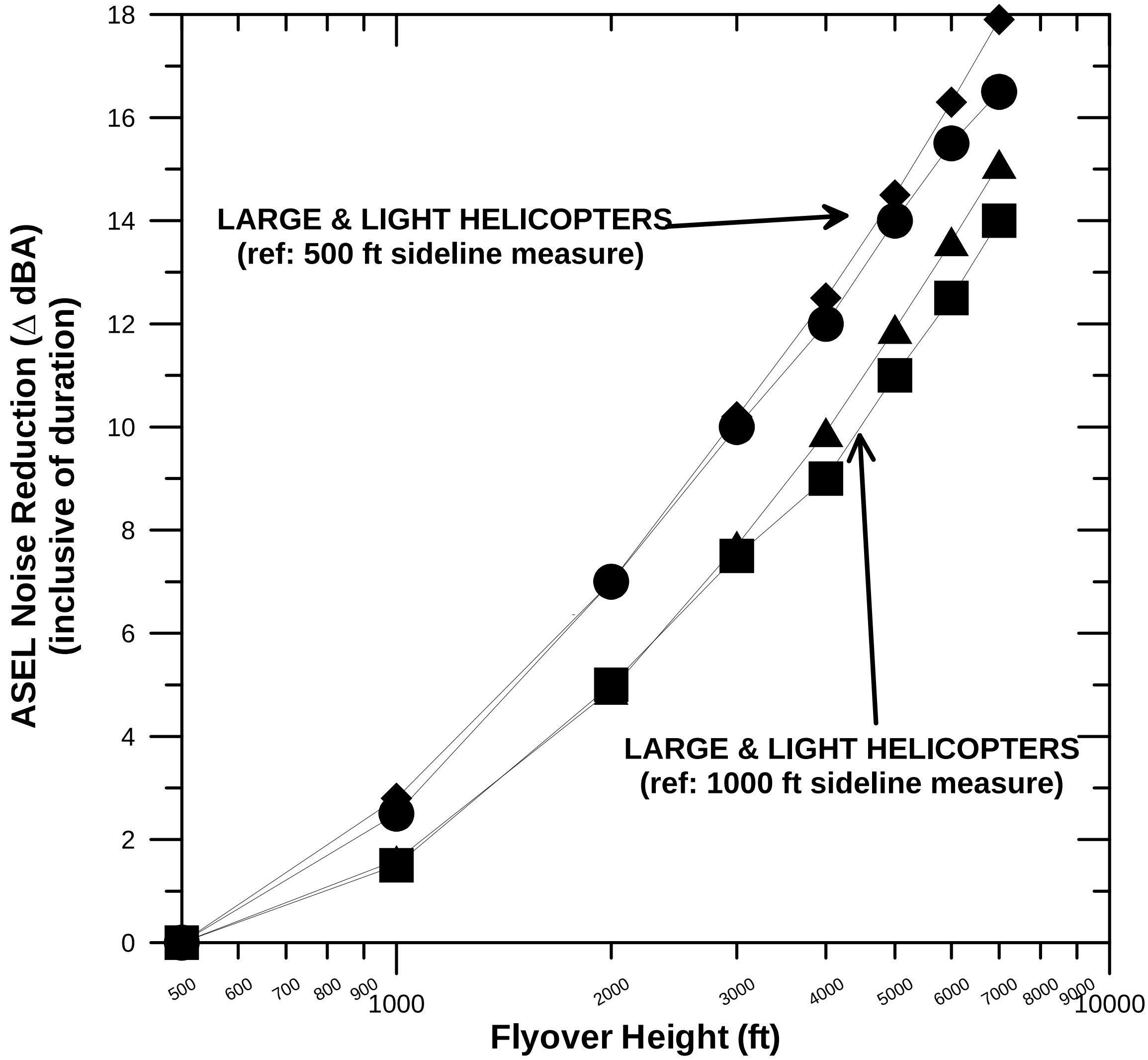

Figure 7-14. Altitude-Noise Reduction Sensitivity for Liberty State Park data

8.0 Summary and Recommendations

8.1 Summary of Noise "Effects on Individuals"

For this study, the background findings on the potential health "effects on individuals" due to community noise exposure, which were discussed in Section 3, are summarized as follows:

- Noise-induced hearing impairment. This is improbable by civil helicopters as they rarely produce 24-hour equivalent levels that exceed 70 dB.

- Noise effects on communications and performance. There is a lack of conclusive effects evidence for an average population. Adverse communication and performance effects has only been identified for under achievers in a classroom environment. But, general alleviation of possible effects is achievable by means of sound proof building construction and HVAC noise reduction sufficient to 35 dB indoor. For urban helicopter noise it can be expected that, where flights are frequent, the indoor equivalent level from helicopter noise may exceed 35 dB. It is also highly probable that other urban noise sources like street traffic and subway trains would similarly exceed this threshold.

- Awakening and sleep disturbance. This is nominally low for steady state sounds of familiarity as indicated by Equation 1 for field data. Yet, it can be likely for close random urban helicopter operations of long duration hover that occur at minimal background noise levels conditions such as early morning and late evening.

- Cardiovascular and physiological effects. When associated with long-term exposure, it does not represent a health threat due to helicopter noise when applying a 24-hour equivalent level that range from 65-70 dB or more criteria.

- Mental health effects. These are not believed to be a direct cause from noise. The notion of noise-induced mental health disorders has been rejected.

- Heighten annoyance factors. Several factors have been identified that relate to heightened community annoyance:
  - **Low- frequency noise susceptible population**.
  - **Non-acoustical effects:** 1) vibration and rattle and 2) *"virtual noise."*
  - **Perception:** 1) helicopter noise characteristics and 2) rate of response.

8.2 Summary of Noise Reduction Conclusions and Recommendations

The FAA offers the following conclusions and recommendations based upon the study:

Additional development of socio-acoustic methodology to deal with helicopter noise should be pursued. Civil helicopter annoyance assessments utilize the same acoustic methodology adopted for fixed-wing airplanes with no distinction for a helicopter's unique noise character. As a result, the annoyance of unaccustomed "impulsive" (spontaneous changing) helicopter noise has not been fully substantiated by a well-correlated metric. Comments from both the helicopter industry and the public strongly recommended that further socio-acoustic investigations be pursued. Additional civil helicopter annoyance studies may help refine current noise measurement analysis methodology that would lead to improved noise mitigation effectiveness. FICAN could charter a technical study to focus on low-frequency noise metric to evaluate helicopter annoyance, including performance of multi-year socio-acoustic (noise) studies to correlate helicopter annoyance and health effects of urban helicopter operations. In the meantime, the FAA will continue to rely upon the widely accepted DNL as its primary noise descriptor for airport and heliport land use planning. The FAA will also continue the use of supplemental noise descriptors for evaluation of helicopter noise issues.

To date, this recommendation has been incorporated into the Rotorcraft Research and Development Initiative for Vision 100 – Century of Aviation Reauthorization Act (Public Law 108-176) under Sec. 711. For Sec. 711, NASA, FAA, and the rotorcraft industry defined a 10-year rotorcraft research and development (R&D) plan that included the study of Psychoacoustics. The research proposes to determine human annoyance levels due to helicopter noise, both in its native condition and synthetically modified. Studies would be conducted to uncover neglected characteristics of noise and develop a refined metric more representative of the true human response.

- <u>Further operational alternatives that mitigate noise should be explored</u>. A number of operational alternatives, proposed by the public and industry, have the potential to mitigate urban nonmilitary helicopter noise and preserve the safe and efficient flow of air traffic. In particular, the FAA found:

  - Noise reduction benefits can be achieved with higher altitude flight. With more conclusive demonstrations addressing safety, such noise mitigation approaches could be integrated within the ATC design planning in specific urban airspaces;

  - Optimal helicopter route planning to avoid noise sensitive areas will require comprehensive evaluation for each specific region of concern;

  - The promotion of noise abatement procedures should be pursued on two fronts--helicopter pilots and air traffic control personnel. The FAA will continue training ATC personnel to increase awareness of noise abatement procedures that best mitigate noise over communities; and

  - The use of advanced technologies, such as GPS, in helicopter approach and departure procedures does show to be beneficial for noise abatement operations. Preliminary GPS/noise research sponsored by the NRTC/RITA has indicated promising noise reductions using more precise procedures.

  The implementation of any of these alternatives would require comprehensive evaluation, and demonstration where appropriate on a case-by-case basis, in accordance with all applicable FAA orders and regulations. Also, careful consideration would have to be taken of any ATC changes to an urban segment of the NAS that could impact the heavily utilized and highly burdened large commercial transport sector. Finally, funding levels required to develop and explore the technology and procedures listed above will be significant.

Similarly under the 2004 Vision 100 Rotorcraft R&D plan, operational noise reduction studies were defined to aid in the noise mitigation of legacy helicopters, such as the Sikorsky S-76 and Bell helicopter products. The expansion of noise abatement flight techniques would be tested for consistency with safety and passenger comfort for several classes of rotorcraft: light, medium and advanced configurations. At the R&D program conclusion, the compilation of noise mitigation technology and abatement operational procedures is to be integrated and demonstrated in a selected single flight vehicle for noise and system validation.

Also, under the Vision 100 plan, there is the "Zero ceiling/Zero visibility" operational goal that addresses advances in navigational system such as wide area augmentation system (WAAS) and local area augmentation system (LAAS) and moving to a comprehensive differential global position system (dGPS) precision navigation capability. Such research applications have proven beneficial to noise mitigation and are expected to enhance the noise abatement operational procedures development.

- <u>Emergency helicopter service should be exempt from restrictions</u>. A key outcome of the FAA-hosted workshops was the mutual agreement among public and industry participants that emergency helicopter service (air medical, law enforcement, fire-fighting, public services, etc.) should be exempted from any proposed limitations or restrictions considered by Congress following this study. These services are time-critical and provide a "noise-excusable" public service.

- <u>Helicopter operators and communities should develop voluntary agreements to mitigate helicopter noise</u>. Federal, state and local governments should encourage voluntary mutual cooperation by operators, the community, and local authorities to establish a "noise response" process; e.g., New York City Heliport Oversight Committee (informal). Also, Federal, state and local governments establish business incentives that encourage the "pooling" of helicopter operations, especially for redundant Electronic News Gathering (ENG) operations.

GUIDELINES

FOR

COMMUNITY NOISE

Edited by

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This WHO document on the *Guidelines for Community Noise* is the outcome of the WHO- expert task force meeting held in London, United Kingdom, in April 1999. It bases on the document entitled "Community Noise" that was prepared for the World Health Organization and published in 1995 by the Stockholm University and Karolinska Institute.

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Foreword

Noise has always been an important environmental problem for man. In ancient Rome, rules existed as to the noise emitted from the ironed wheels of wagons which battered the stones on the pavement, causing disruption of sleep and annoyance to the Romans. In Medieval Europe, horse carriages and horse back riding were not allowed during night time in certain cities to ensure a peaceful sleep for the inhabitants. However, the noise problems of the past are incomparable with those of modern society. An immense number of cars regularly cross our cities and the countryside. There are heavily laden lorries with diesel engines, badly silenced both for engine and exhaust noise, in cities and on highways day and night. Aircraft and trains add to the environmental noise scenario. In industry, machinery emits high noise levels and amusement centres and pleasure vehicles distract leisure time relaxation.

In comparison to other pollutants, the control of environmental noise has been hampered by insufficient knowledge of its effects on humans and of dose-response relationships as well as a lack of defined criteria. While it has been suggested that noise pollution is primarily a "luxury" problem for developed countries, one cannot ignore that the exposure is often higher in developing countries, due to bad planning and poor construction of buildings. The effects of the noise are just as widespread and the long term consequences for health are the same. In this perspective, practical action to limit and control the exposure to environmental noise are essential. Such action must be based upon proper scientific evaluation of available data on effects, and particularly dose-response relationships. The basis for this is the
process of risk assessment and risk management.

The extent of the noise problem is large. In the European Union countries about 40 % of the population are exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB(A) daytime and 20 % are exposed to levels exceeding 65 dB(A). Taking all exposure to transportation noise together about half of the European Union citizens are estimated to live in zones which do not ensure acoustical comfort to residents. More than 30 % are exposed at night to equivalent sound pressure levels exceeding 55 dB(A) which are disturbing to sleep. The noise pollution problem is also severe in cities of developing countries and caused mainly by traffic. Data collected alongside densely travelled roads were found to have equivalent sound pressure levels for 24 hours of 75 to 80 dB(A).

The scope of WHO's effort to derive guidelines for community noise is to consolidate actual scientific knowledge on the health impacts of community noise and to provide guidance to environmental health authorities and professional trying to protect people from the harmful effects of noise in non-industrial environments. Guidance on the health effects of noise exposure of the population has already been given in an early publication of the series of Environmental Health Criteria. The health risk to humans from exposure to environmental noise was evaluated and guidelines values derived. The issue of noise control and health protection was briefly addressed.
At a WHO/EURO Task Force Meeting in Düsseldorf, Germany, in 1992, the health criteria and guideline values were revised and it was agreed upon updated guidelines in consensus. The essentials of the deliberations of the Task Force were published by Stockholm University and Karolinska Institute in 1995. In a recent Expert Task Force Meeting convened in April 1999 in London, United Kingdom, the Guidelines for Community Noise were extended to provide global coverage and applicability, and the issues of noise assessment and control were addressed in more detail. This document is the outcome of the consensus deliberations of the WHO Expert Task Force.

Dr Richard Helmer
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Preface

Community noise (also called environmental noise, residential noise or domestic noise) is defined as noise emitted from all sources except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic, industries, construction and public work, and the neighbourhood. The main indoor sources of noise are ventilation systems, office machines, home appliances and neighbours. Typical neighbourhood noise comes from premises and installations related to the catering trade (restaurant, cafeterias, discotheques, etc.); from live or recorded music; sport events including motor sports; playgrounds; car parks; and domestic animals such as barking dogs. Many countries have regulated community noise from road and rail traffic, construction machines and industrial plants by applying emission standards, and by regulating the acoustical properties of buildings. In contrast, few countries have regulations on community noise from the neighbourhood, probably due to the lack of methods to define and measure it, and to the difficulty of controlling it. In large cities throughout the world, the general population is increasingly exposed to community due to the sources mentioned above and the health effects of these exposures are considered to be a more and more important public health problem. Specific effects to be considered when setting community noise guidelines include: interference with communication; noise-induced hearing loss; sleep disturbance effects; cardiovascular and psycho-physiological effects; performance reduction effects; annoyance responses; and effects on social behaviour.

Since 1980, the World Health Organization (WHO) has addressed the problem of community noise. Health-based guidelines on community noise can serve as the basis for deriving noise standards within a framework of noise management. Key issues of noise management include abatement options; models for forecasting and for assessing source control action; setting noise emission standards for existing and planned sources; noise exposure assessment; and testing the compliance of noise exposure with noise immission standards. In 1992, the WHO Regional Office for Europe convened a task force meeting which set up guidelines for community noise. A preliminary publication of the Karolinska Institute, Stockholm, on behalf of WHO, appeared in 1995. This publication served as the basis for the globally applicable *Guidelines for Community Noise* presented in this document. An expert task force meeting was convened by WHO in March 1999 in London, United Kingdom, to finalize the guidelines.

The *Guidelines for Community Noise* have been prepared as a practical response to the need for action on community noise at the local level, as well as the need for improved legislation, management and guidance at the national and regional levels. WHO will be pleased to see that these guidelines are used widely. Continuing efforts will be made to improve its content and structure. It would be appreciated if the users of the *Guidelines* provide feedback from its use and their own experiences. Please send your comments and suggestions on the WHO *Guidelines for Community Noise – Guideline document* to the Department of the Protection of the Human Environment, Occupational and Environmental Health, World Health Organization, Geneva, Switzerland (Fax: +41 22-791 4123, e-mail: schwelad@who.int).

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Executive Summary

1. Introduction

Community noise (also called environmental noise, residential noise or domestic noise) is defined as noise emitted from all sources except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic; industries; construction and public work; and the neighbourhood. The main indoor noise sources are ventilation systems, office machines, home appliances and neighbours.

In the European Union about 40% of the population is exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB(A) daytime, and 20% are exposed to levels exceeding 65 dB(A). When all transportation noise is considered, more than half of all European Union citizens is estimated to live in zones that do not ensure acoustical comfort to residents. At night, more than 30% are exposed to equivalent sound pressure levels exceeding 55 dB(A), which are disturbing to sleep. Noise pollution is also severe in cities of developing countries. It is caused mainly by traffic and alongside densely-travelled roads equivalent sound pressure levels for 24 hours can reach 75–80 dB(A).

In contrast to many other environmental problems, noise pollution continues to grow and it is accompanied by an increasing number of complaints from people exposed to the noise. The growth in noise pollution is unsustainable because it involves direct, as well as cumulative, adverse health effects. It also adversely affects future generations, and has socio-cultural, esthetic and economic effects.

2. Noise sources and measurement

Physically, there is no distinction between sound and noise. Sound is a sensory perception and the complex pattern of sound waves is labeled noise, music, speech etc. Noise is thus defined as unwanted sound.

Most environmental noises can be approximately described by several simple measures. All measures consider the frequency content of the sounds, the overall sound pressure levels and the variation of these levels with time. Sound pressure is a basic measure of the vibrations of air that make up sound. Because the range of sound pressures that human listeners can detect is very wide, these levels are measured on a logarithmic scale with units of decibels. Consequently, sound pressure levels cannot be added or averaged arithmetically. Also, the sound levels of most noises vary with time, and when sound pressure levels are calculated, the instantaneous pressure fluctuations must be integrated over some time interval.

Most environmental sounds are made up of a complex mix of many different frequencies. Frequency refers to the number of vibrations per second of the air in which the sound is propagating and it is measured in Hertz (Hz). The audible frequency range is normally considered to be 20–20 000 Hz for younger listeners with unimpaired hearing. However, our hearing systems are not equally sensitive to all sound frequencies, and to compensate for this various types of filters or frequency weighting have been used to determine the relative strengths of frequency components making up a particular environmental noise. The A-weighting is most commonly used and weights lower frequencies as less important than mid- and higher-frequencies. It is intended to approximate the frequency response of our hearing system.

The effect of a combination of noise events is related to the combined sound energy of those events (the equal energy principle). The sum of the total energy over some time period gives a level equivalent to the average sound energy over that period. Thus, LAeq,T is the energy average equivalent level of the A-weighted sound over a period T. LAeq,T should be used to measure continuing sounds, such as road traffic noise or types of more-or-less continuous industrial noises. However, when there are distinct events to the noise, as with aircraft or railway noise, measures of individual events such as the maximum noise level (LAmax), or the weighted sound exposure level (SEL), should also be obtained in addition to LAeq,T. Time-varying environmental sound levels have also been described in terms of percentile levels.

Currently, the recommended practice is to assume that the equal energy principle is approximately valid for most types of noise and that a simple LAeq,T measure will indicate the expected effects of the noise reasonably well. When the noise consists of a small number of discrete events, the A-weighted maximum level (LAmax) is a better indicator of the disturbance to sleep and other activities. In most cases, however, the A-weighted sound exposure level (SEL) provides a more consistent measure of single-noise events because it is based on integration over the complete noise event. In combining day and night LAeq,T values, night-time weightings are often added. Night-time weightings are intended to reflect the expected increased sensitivity to annoyance at night, but they do not protect people from sleep disturbance.

Where there are no clear reasons for using other measures, it is recommended that LAeq,T be used to evaluate more-or-less continuous environmental noises. Where the noise is principally composed of a small number of discrete events, the additional use of LAmax or SEL is recommended. There are definite limitations to these simple measures, but there are also many practical advantages, including economy and the benefits of a standardized approach.

3. Adverse health effects of noise

The health significance of noise pollution is given in chapter 3 of the *Guidelines* under separate headings according to the specific effects: noise-induced hearing impairment; interference with speech communication; disturbance of rest and sleep; psychophysiological, mental-health and performance effects; effects on residential behaviour and annoyance; and interference with intended activities. This chapter also considers vulnerable groups and the combined effects of mixed noise sources.

Hearing impairment is typically defined as an increase in the threshold of hearing. Hearing deficits may be accompanied by tinnitus (ringing in the ears). Noise-induced hearing impairment occurs predominantly in the higher frequency range of 3 000–6 000 Hz, with the largest effect at 4 000 Hz. But with increasing LAeq,8h and increasing exposure time, noise-induced hearing impairment occurs even at frequencies as low as 2 000 Hz. However, hearing impairment is not expected to occur at LAeq,8h levels of 75 dB(A) or below, even for prolonged occupational noise exposure.

Worldwide, noise-induced hearing impairment is the most prevalent irreversible occupational hazard and it is estimated that 120 million people worldwide have disabling hearing difficulties. In developing countries, not only occupational noise but also environmental noise is an increasing risk factor for hearing impairment. Hearing damage can also be caused by certain diseases, some industrial chemicals, ototoxic drugs, blows to the head, accidents and hereditary origins. Hearing deterioration is also associated with the ageing process itself (presbyacusis).

The extent of hearing impairment in populations exposed to occupational noise depends on the value of LAeq,8h, the number of noise-exposed years, and on individual susceptibility. Men and women are equally at risk for noise-induced hearing impairment. It is expected that environmental and leisure-time noise with a LAeq,24h of 70 dB(A) or below will not cause hearing impairment in the large majority of people, even after a lifetime exposure. For adults exposed to impulse noise at the workplace, the noise limit is set at peak sound pressure levels of 140 dB, and the same limit is assumed to be appropriate for environmental and leisure-time noise. In the case of children, however, taking into account their habits while playing with noisy toys, the peak sound pressure should never exceed 120 dB. For shooting noise with LAeq,24h levels greater than 80 dB(A), there may be an increased risk for noise-induced hearing impairment.

The main social consequence of hearing impairment is the inability to understand speech in daily living conditions, and this is considered to be a severe social handicap. Even small values of hearing impairment (10 dB averaged over 2 000 and 4 000 Hz and over both ears) may adversely affect speech comprehension.

Speech intelligibility is adversely affected by noise. Most of the acoustical energy of speech is in the frequency range of 100–6 000 Hz, with the most important cue-bearing energy being between 300–3 000 Hz. Speech interference is basically a masking process, in which simultaneous interfering noise renders speech incapable of being understood. Environmental noise may also mask other acoustical signals that are important for daily life, such as door bells, telephone signals, alarm clocks, fire alarms and other warning signals, and music.

Speech intelligibility in everyday living conditions is influenced by speech level; speech pronunciation; talker-to-listener distance; sound level and other characteristics of the interfering noise; hearing acuity; and by the level of attention. Indoors, speech communication is also affected by the reverberation characteristics of the room. Reverberation times over 1 s produce loss in speech discrimination and make speech perception more difficult and straining. For full sentence intelligibility in listeners with normal hearing, the signal-to-noise ratio (i.e. the difference between the speech level and the sound level of the interfering noise) should be at least 15 dB(A). Since the sound pressure level of normal speech is about 50 dB(A), noise with sound levels of 35 dB(A) or more interferes with the intelligibility of speech in smaller rooms. For vulnerable groups even lower background levels are needed, and a reverberation time below 0.6 s is desirable for adequate speech intelligibility, even in a quiet environment.

The inability to understand speech results in a large number of personal handicaps and behavioural changes. Particularly vulnerable are the hearing impaired, the elderly, children in the process of language and reading acquisition, and individuals who are not familiar with the spoken language.

Sleep disturbance is a major effect of environmental noise. It may cause primary effects during sleep, and secondary effects that can be assessed the day after night-time noise exposure. Uninterrupted sleep is a prerequisite for good physiological and mental functioning, and the primary effects of sleep disturbance are: difficulty in falling asleep; awakenings and alterations of sleep stages or depth; increased blood pressure, heart rate and finger pulse amplitude; vasoconstriction; changes in respiration; cardiac arrhythmia; and increased body movements. The difference between the sound levels of a noise event and background sound levels, rather than the absolute noise level, may determine the reaction probability. The probability of being awakened increases with the number of noise events per night. The secondary, or after-effects, the following morning or day(s) are: reduced perceived sleep quality; increased fatigue; depressed mood or well-being; and decreased performance.

For a good night's sleep, the equivalent sound level should not exceed 30 dB(A) for continuous background noise, and individual noise events exceeding 45 dB(A) should be avoided. In setting limits for single night-time noise exposures, the intermittent character of the noise has to be taken into account. This can be achieved, for example, by measuring the number of noise events, as well as the difference between the maximum sound level and the background sound level. Special attention should also be given to: noise sources in an environment with low background sound levels; combinations of noise and vibrations; and to noise sources with low-frequency components.

Physiological Functions. In workers exposed to noise, and in people living near airports, industries and noisy streets, noise exposure may have a large temporary, as well as permanent, impact on physiological functions. After prolonged exposure, susceptible individuals in the general population may develop permanent effects, such as hypertension and ischaemic heart disease associated with exposure to high sound levels. The magnitude and duration of the effects are determined in part by individual characteristics, lifestyle behaviours and environmental conditions. Sounds also evoke reflex responses, particularly when they are unfamiliar and have a sudden onset.

Workers exposed to high levels of industrial noise for 5–30 years may show increased blood pressure and an increased risk for hypertension. Cardiovascular effects have also been demonstrated after long-term exposure to air- and road-traffic with LAeq,24h values of 65–70 dB(A). Although the associations are weak, the effect is somewhat stronger for ischaemic heart disease than for hypertension. Still, these small risk increments are important because a large number of people are exposed.

Mental Illness. Environmental noise is not believed to cause mental illness directly, but it is assumed that it can accelerate and intensify the development of latent mental disorders. Exposure to high levels of occupational noise has been associated with development of neurosis, but the findings on environmental noise and mental-health effects are inconclusive. Nevertheless, studies on the use of drugs such as tranquillizers and sleeping pills, on psychiatric symptoms and on mental hospital admission rates, suggest that community noise may have adverse effects on mental health.

Performance. It has been shown, mainly in workers and children, that noise can adversely affect performance of cognitive tasks. Although noise-induced arousal may produce better performance in simple tasks in the short term, cognitive performance substantially deteriorates for more complex tasks. Reading, attention, problem solving and memorization are among the cognitive effects most strongly affected by noise. Noise can also act as a distracting stimulus and impulsive noise events may produce disruptive effects as a result of startle responses.

Noise exposure may also produce after-effects that negatively affect performance. In schools around airports, children chronically exposed to aircraft noise under-perform in proof reading, in persistence on challenging puzzles, in tests of reading acquisition and in motivational capabilities. It is crucial to recognize that some of the adaptation strategies to aircraft noise, and the effort necessary to maintain task performance, come at a price. Children from noisier areas have heightened sympathetic arousal, as indicated by increased stress hormone levels, and elevated resting blood pressure. Noise may also produce impairments and increase in errors at work, and some accidents may be an indicator of performance deficits.

Social and Behavioural Effects of Noise; Annoyance. Noise can produce a number of social and behavioural effects as well as annoyance. These effects are often complex, subtle and indirect and many effects are assumed to result from the interaction of a number of non-auditory variables. The effect of community noise on annoyance can be evaluated by questionnaires or by assessing the disturbance of specific activities. However, it should be recognized that equal levels of different traffic and industrial noises cause different magnitudes of annoyance. This is because annoyance in populations varies not only with the characteristics of the noise, including the noise source, but also depends to a large degree on many non-acoustical factors of a social, psychological, or economic nature. The correlation between noise exposure and general annoyance is much higher at group level than at individual level. Noise above 80 dB(A) may also reduce helping behaviour and increase aggressive behaviour. There is particular concern that high-level continuous noise exposures may increase the susceptibility of schoolchildren to feelings of helplessness.

Stronger reactions have been observed when noise is accompanied by vibrations and contains low-frequency components, or when the noise contains impulses, such as with shooting noise. Temporary, stronger reactions occur when the noise exposure increases over time, compared to a constant noise exposure. In most cases, LAeq,24h and L_{dn} are acceptable approximations of noise exposure related to annoyance. However, there is growing concern that all the component parameters should be individually assessed in noise exposure investigations, at least in the complex cases. There is no consensus on a model for total annoyance due to a combination of environmental noise sources.

Combined Effects on Health of Noise from Mixed Sources. Many acoustical environments consist of sounds from more than one source, i.e. there are mixed sources, and some combinations of effects are common. For example, noise may interfere with speech in the day and create sleep disturbance at night.

These conditions certainly apply to residential areas heavily polluted with noise. Therefore, it is important that the total adverse health load of noise be considered over 24 hours, and that the precautionary principle for sustainable development be applied.

Vulnerable Subgroups. Vulnerable subgroups of the general population should be considered when recommending noise protection or noise regulations. The types of noise effects, specific environments and specific lifestyles are all factors that should be addressed for these subgroups. Examples of vulnerable subgroups are: people with particular diseases or medical problems (e.g. high blood pressure); people in hospitals or rehabilitating at home; people dealing with complex cognitive tasks; the blind; people with hearing impairment; fetuses, babies and young children; and the elderly in general. People with impaired hearing are the most adversely affected with respect to speech intelligibility. Even slight hearing impairments in the high-frequency sound range may cause problems with speech perception in a noisy environment. A majority of the population belongs to the subgroup that is vulnerable to speech interference.

4. Guideline values

In chapter 4, guideline values are given for specific health effects of noise and for specific environments.

Specific health effects.

Interference with Speech Perception. A majority of the population is susceptible to speech interference by noise and belongs to a vulnerable subgroup. Most sensitive are the elderly and persons with impaired hearing. Even slight hearing impairments in the high-frequency range may cause problems with speech perception in a noisy environment. From about 40 years of age, the ability of people to interpret difficult, spoken messages with low linguistic redundancy is impaired compared to people 20–30 years old. It has also been shown that high noise levels and long reverberation times have more adverse effects in children, who have not completed language acquisition, than in young adults.

When listening to complicated messages (at school, foreign languages, telephone conversation) the signal-to-noise ratio should be at least 15 dB with a voice level of 50 dB(A). This sound level corresponds on average to a casual voice level in both women and men at 1 m distance. Consequently, for clear speech perception the background noise level should not exceed 35 dB(A). In classrooms or conference rooms, where speech perception is of paramount importance, or for sensitive groups, background noise levels should be as low as possible. Reverberation times below 1 s are also necessary for good speech intelligibility in smaller rooms. For sensitive groups, such as the elderly, a reverberation time below 0.6 s is desirable for adequate speech intelligibility even in a quiet environment.

Hearing Impairment. Noise that gives rise to hearing impairment is by no means restricted to occupational situations. High noise levels can also occur in open air concerts, discotheques, motor sports, shooting ranges, in dwellings from loudspeakers, or from leisure activities. Other important sources of loud noise are headphones, as well as toys and fireworks which can emit impulse noise. The ISO standard 1999 gives a method for estimating noise-induced hearing impairment in populations exposed to all types of noise (continuous, intermittent, impulse) during working hours. However, the evidence strongly suggests that this method should also be used to calculate hearing impairment due to noise exposure from environmental and leisure time activities. The ISO standard 1999 implies that long-term exposure to LAeq,24h noise levels of up to 70 dB(A) will not result in hearing impairment. To avoid hearing loss from impulse noise exposure, peak sound pressures should never exceed 140 dB for adults, and 120 dB for children.

Sleep Disturbance. Measurable effects of noise on sleep begin at LAeq levels of about 30 dB. However, the more intense the background noise, the more disturbing is its effect on sleep. Sensitive groups mainly include the elderly, shift workers, people with physical or mental disorders and other individuals who have difficulty sleeping.

Sleep disturbance from intermittent noise events increases with the maximum noise level. Even if the total equivalent noise level is fairly low, a small number of noise events with a high maximum sound pressure level will affect sleep. Therefore, to avoid sleep disturbance, guidelines for community noise should be expressed in terms of the equivalent sound level of the noise, as well as in terms of maximum noise levels and the number of noise events. It should be noted that low-frequency noise, for example, from ventilation systems, can disturb rest and sleep even at low sound pressure levels.

When noise is continuous, the equivalent sound pressure level should not exceed 30 dB(A) indoors, if negative effects on sleep are to be avoided. For noise with a large proportion of low-frequency sound a still lower guideline value is recommended. When the background noise is low, noise exceeding 45 dB LAmax should be limited, if possible, and for sensitive persons an even lower limit is preferred. Noise mitigation targeted to the first part of the night is believed to be an effective means for helping people fall asleep. It should be noted that the adverse effect of noise partly depends on the nature of the source. A special situation is for newborns in incubators, for which the noise can cause sleep disturbance and other health effects.

Reading Acquisition. Chronic exposure to noise during early childhood appears to impair reading acquisition and reduces motivational capabilities. Evidence indicates that the longer the exposure, the greater the damage. Of recent concern are the concomitant psychophysiological changes (blood pressure and stress hormone levels). There is insufficient information on these effects to set specific guideline values. It is clear, however, that daycare centres and schools should not be located near major noise sources, such as highways, airports, and industrial sites.

Annoyance. The capacity of a noise to induce annoyance depends upon its physical characteristics, including the sound pressure level, spectral characteristics and variations of these properties with time. During daytime, few people are highly annoyed at LAeq levels below 55 dB(A), and few are moderately annoyed at LAeq levels below 50 dB(A). Sound levels during the evening and night should be 5–10 dB lower than during the day. Noise with low-frequency components require lower guideline values. For intermittent noise, it is emphasized that it is necessary to take into account both the maximum sound pressure level and the number of noise events. Guidelines or noise abatement measures should also take into account residential outdoor activities.

Social Behaviour. The effects of environmental noise may be evaluated by assessing its interference with social behavior and other activities. For many community noises, interference with rest/recreation/watching television seem to be the most important effects. There is fairly consistent evidence that noise above 80 dB(A) causes reduced helping behavior, and that loud noise also increases aggressive behavior in individuals predisposed to aggressiveness. In schoolchildren, there is also concern that high levels of chronic noise contribute to feelings of helplessness. Guidelines on this issue, together with cardiovascular and mental effects, must await further research.

Specific environments.

A noise measure based only on energy summation and expressed as the conventional equivalent measure, LAeq, is not enough to characterize most noise environments. It is equally important to measure the maximum values of noise fluctuations, preferably combined with a measure of the number of noise events. If the noise includes a large proportion of low-frequency components, still lower values than the guideline values below will be needed. When prominent low-frequency components are present, noise measures based on A-weighting are inappropriate. The difference between dB(C) and dB(A) will give crude information about the presence of low-frequency components in noise, but if the difference is more than 10 dB, it is recommended that a frequency analysis of the noise be performed. It should be noted that a large proportion of low-frequency components in noise may increase considerably the adverse effects on health.

In Dwellings. The effects of noise in dwellings, typically, are sleep disturbance, annoyance and speech interference. For bedrooms the critical effect is sleep disturbance. Indoor guideline values for bedrooms are 30 dB LAeq for continuous noise and 45 dB LAmax for single sound events. Lower noise levels may be disturbing depending on the nature of the noise source. At night-time, outside sound levels about 1 metre from facades of living spaces should not exceed 45 dB LAeq, so that people may sleep with bedroom windows open. This value was obtained by assuming that the noise reduction from outside to inside with the window open is 15 dB. To enable casual conversation indoors during daytime, the sound level of interfering noise should not exceed 35 dB LAeq. The maximum sound pressure level should be measured with the sound pressure meter set at “Fast”.

To protect the majority of people from being seriously annoyed during the daytime, the outdoor sound level from steady, continuous noise should not exceed 55 dB LAeq on balconies, terraces and in outdoor living areas. To protect the majority of people from being moderately annoyed during the daytime, the outdoor sound level should not exceed 50 dB LAeq. Where it is practical and feasible, the lower outdoor sound level should be considered the maximum desirable sound level for new development.

In Schools and Preschools. For schools, the critical effects of noise are speech interference, disturbance of information extraction (e.g. comprehension and reading acquisition), message communication and annoyance. To be able to hear and understand spoken messages in class rooms, the background sound level should not exceed 35 dB LAeq during teaching sessions. For hearing impaired children, a still lower sound level may be needed. The reverberation time in the classroom should be about 0.6 s, and preferably lower for hearing impaired children. For assembly halls and cafeterias in school buildings, the reverberation time should be less than 1 s. For outdoor playgrounds the sound level of the noise from external sources should not exceed 55 dB LAeq, the same value given for outdoor residential areas in daytime.

For preschools, the same critical effects and guideline values apply as for schools. In bedrooms in preschools during sleeping hours, the guideline values for bedrooms in dwellings should be used.

In Hospitals. For most spaces in hospitals, the critical effects are sleep disturbance, annoyance, and communication interference, including warning signals. The LAmax of sound events during the night should not exceed 40 dB(A) indoors. For ward rooms in hospitals, the guideline values indoors are 30dB LAeq, together with 40 dB LAmax during night. During the day and evening the guideline value indoors is 30 dB LAeq. The maximum level should be measured with the sound pressure instrument set at “Fast”.

Since patients have less ability to cope with stress, the LAeq level should not exceed 35 dB in most rooms in which patients are being treated or observed. Attention should be given to the sound levels in intensive care units and operating theaters. Sound inside incubators may result in health problems for neonates, including sleep disturbance, and may also lead to hearing impairment. Guideline values for sound levels in incubators must await future research.

Ceremonies, Festivals and Entertainment Events. In many countries, there are regular ceremonies, festivals and entertainment events to celebrate life periods. Such events typically produce loud sounds, including music and impulsive sounds. There is widespread concern about the effect of loud music and impulsive sounds on young people who frequently attend concerts, discotheques, video arcades, cinemas, amusement parks and spectator events. At these events, the sound level typically exceeds 100 dB LAeq. Such noise exposure could lead to significant hearing impairment after frequent attendances.

Noise exposure for employees of these venues should be controlled by established occupational standards; and at the very least, the same standards should apply to the patrons of these premises. Patrons should not be exposed to sound levels greater than 100 dB LAeq during a four-hour period more than four times per year. To avoid acute hearing impairment the LAmax should always be below 110 dB.

Headphones. To avoid hearing impairment from music played back in headphones, in both adults and children, the equivalent sound level over 24 hours should not exceed 70 dB(A). This implies that for a daily one hour exposure the LAeq level should not exceed 85 dB(A). To avoid acute hearing impairment LAmax should always be below 110 dB(A). The exposures are expressed in free-field equivalent sound level.

Toys, Fireworks and Firearms. To avoid acute mechanical damage to the inner ear from impulsive sounds from toys, fireworks and firearms, adults should never be exposed to more than 140 dB(lin) peak sound pressure level. To account for the vulnerability in children when playing, the peak sound pressure produced by toys should not exceed 120 dB(lin), measured close to the ears (100 mm). To avoid acute hearing impairment LAmax should always be below 110 dB(A).

Parkland and Conservation Areas. Existing large quiet outdoor areas should be preserved and the signal-to-noise ratio kept low.

Table 1 presents the WHO guideline values arranged according to specific environments and critical health effects. The guideline values consider all identified adverse health effects for the specific environment. An adverse effect of noise refers to any temporary or long-term impairment of physical, psychological or social functioning that is associated with noise exposure. Specific noise limits have been set for each health effect, using the lowest noise level that produces an adverse health effect (i.e. the critical health effect). Although the guideline values refer to sound levels impacting the most exposed receiver at the listed environments, they are applicable to the general population. The time base for LAeq for “daytime” and “night-time” is 12–16 hours and 8 hours, respectively. No time base is given for evenings, but typically the guideline value should be 5–10 dB lower than in the daytime. Other time bases are recommended for schools, preschools and playgrounds, depending on activity.

It is not enough to characterize the noise environment in terms of noise measures or indices based only on energy summation (e.g., LAeq), because different critical health effects require different descriptions. It is equally important to display the maximum values of the noise fluctuations, preferably combined with a measure of the number of noise events. A separate characterization of night-time noise exposures is also necessary. For indoor environments, reverberation time is also an important factor for things such as speech intelligibility. If the noise includes a large proportion of low-frequency components, still lower guideline values should be applied. Supplementary to the guideline values given in Table 1, precautions should be taken for vulnerable groups and for noise of certain character (e.g. low-frequency components, low background noise).

Table 1: Guideline values for community noise in specific environments.

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

#1: As low as possible.

#2: Peak sound pressure (not LAF, max) measured 100 mm from the ear.
#3: Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low.
#4: Under headphones, adapted to free-field values.

5. Noise Management

Chapter 5 is devoted to noise management with discussions on: strategies and priorities in managing indoor noise levels; noise policies and legislation; the impact of environmental noise; and on the enforcement of regulatory standards.

The fundamental goals of noise management are to develop criteria for deriving safe noise exposure levels and to promote noise assessment and control as part of environmental health programmes. These basic goals should guide both international and national policies for noise management. The United Nation's Agenda 21 supports a number of environmental management principles on which government policies, including noise management policies, can be based: the principle of precaution; the "polluter pays" principle; and noise prevention. In all cases, noise should be reduced to the lowest level achievable in the particular situation. When there is a reasonable possibility that the public health will be endangered, even though scientific proof may be lacking, action should be taken to protect the public health, without awaiting the full scientific proof. The full costs associated with noise pollution (including monitoring, management, lowering levels and supervision) should be met by those responsible for the source of noise. Action should be taken where possible to reduce noise at the source.

A legal framework is needed to provide a context for noise management. National noise standards can usually be based on a consideration of international guidelines, such as these *Guidelines for Community Noise*, as well as national criteria documents, which consider dose-response relationships for the effects of noise on human health. National standards take into account the technological, social, economic and political factors within the country. A staged program of noise abatement should also be implemented to achieve the optimum health protection levels over the long term.

Other components of a noise management plan include: noise level monitoring; noise exposure mapping; exposure modeling; noise control approaches (such as mitigation and precautionary measures); and evaluation of control options. Many of the problems associated with high noise levels can be prevented at low cost, if governments develop and implement an integrated strategy for the indoor environment, in concert with all social and economic partners. Governments should establish a "National Plan for a Sustainable Noise Indoor Environment" that applies both to new construction as well as to existing buildings.

The actual priorities in rational noise management will differ for each country. Priority setting in noise management refers to prioritizing the health risks to be avoided and concentrating on the most important sources of noise. Different countries have adopted a range of approaches to noise control, using different policies and regulations. A number of these are outlined in chapter 5 and Appendix 2, as examples. It is evident that noise emission standards have proven insufficient and that the trends in noise pollution are unsustainable.

The concept of environmental an environmental noise impact analysis is central to the philosophy of managing environmental noise. Such an analysis should be required before implementing any project that would significantly increase the level of environmental noise in a community (typically, greater than a 5 dB increase). The analysis should include: a baseline description of the existing noise environment; the expected level of noise from the new source; an assessment of the adverse health effects; an estimation of the population at risk; the calculation of exposure-response relationships; an assessment of risks and their acceptability; and a cost-benefit analysis.

Noise management should:

1. Start monitoring human exposures to noise.
2. Have health control require mitigation of noise immissions, and not just of noise source emissions. The following should be taken into consideration:
   - specific environments such as schools, playgrounds, homes, hospitals.
   - environments with multiple noise sources, or which may amplify the effects of noise.
   - sensitive time periods such as evenings, nights and holidays.
   - groups at high risk, such as children and the hearing impaired.
3. Consider the noise consequences when planning transport systems and land use.
4. Introduce surveillance systems for noise-related adverse health effects.
5. Assess the effectiveness of noise policies in reducing adverse health effects and exposure, and in improving supportive "soundscapes".
6. Adopt these *Guidelines for Community Noise* as intermediary targets for improving human health.
7. Adopt precautionary actions for a sustainable development of the acoustical environments.

Conclusions and recommendations

In chapter 6 are discussed: the implementation of the guidelines; further WHO work on noise; and research needs are recommended.

Implementation. For implementation of the guidelines it is recommended that:

- Governments should protection the population from community noise and consider it an integral part of their policy of environmental protection.
- Governments should consider implementing action plans with short-term, medium-term and long-term objectives for reducing noise levels.
- Governments should adopt the *Health Guidelines for Community Noise* values as targets to be achieved in the long-term.
- Governments should include noise as an important public health issue in environmental impact assessments.
- Legislation should be put in place to allow for the reduction of sound levels.
- Existing legislation should be enforced.
- Municipalities should develop low noise implementation plans.
- Cost-effectiveness and cost-benefit analyses should be considered potential instruments for meaningful management decisions.
- Governments should support more policy-relevant research.

Future Work. The Expert Task Force worked out several suggestions for future work for the WHO in the field of community noise. WHO should:

- Provide leadership and technical direction in defining future noise research priorities.
- Organize workshops on how to apply the guidelines.

- Provide leadership and coordinate international efforts to develop techniques for designing supportive sound environments (e.g. "soundscapes").
- Provide leadership for programs to assess the effectiveness of health-related noise policies and regulations.
- Provide leadership and technical direction for the development of sound methodologies for environmental and health impact plans.
- Encourage further investigation into using noise exposure as an indicator of environmental deterioration (e.g. black spots in cities).
- Provide leadership and technical support, and advise developing countries to facilitate development of noise policies and noise management.

Research and Development. A major step forward in raising the awareness of both the public and of decision makers is the recommendation to concentrate more research and development on variables which have monetary consequences. This means that research should consider not only dose-response relationships between sound levels, but also politically relevant variables, such as noise-induced social handicap; reduced productivity; decreased performance in learning; workplace and school absenteeism; increased drug use; and accidents.

In Appendices 1–6 are given: bibliographic references; examples of regional noise situations (African Region, American Region, Eastern Mediterranean Region, South East Asian Region, Western Pacific Region); a glossary; a list of acronyms; and a list of participants.

Introduction

Community noise (also called environmental noise, residential noise or domestic noise) is defined as noise emitted from all sources, except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic, industries, construction and public work, and the neighbourhood. Typical neighbourhood noise comes from premises and installations related to the catering trade (restaurant, cafeterias, discotheques, etc.); from live or recorded music; from sporting events including motor sports; from playgrounds and car parks; and from domestic animals such as barking dogs. The main indoor sources are ventilation systems, office machines, home appliances and neighbours. Although many countries have regulations on community noise from road, rail and air traffic, and from construction and industrial plants, few have regulations on neighbourhood noise. This is probably due to the lack of methods to define and measure it, and to the difficulty of controlling it. In developed countries, too, monitoring of compliance with, and enforcement of, noise regulations are weak for lower levels of urban noise that correspond to occupationally controlled levels (>85 dB LAeq,8h; Frank 1998). Recommended guideline values based on the health effects of noise, other than occupationally-induced effects, are often not taken into account.

The extent of the community noise problem is large. In the European Union about 40% of the population is exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dBA daytime; and 20% is exposed to levels exceeding 65 dBA (Lambert & Vallet 19 1994). When all transportation noise is considered, about half of all European Union citizens live in zones that do not ensure acoustical comfort to residents. At night, it is estimated that more than 30% is exposed to equivalent sound pressure levels exceeding 55 dBA, which are disturbing to sleep. The noise pollution problem is also severe in the cities of developing countries and is caused mainly by traffic. Data collected alongside densely traveled roads were found to have equivalent sound pressure levels for 24 hours of 75–80 dBA (e.g. National Environment Board Thailand 19 1990; Mage & Walsh 19 1998).

(a) In contrast to many other environmental problems, noise pollution continues to grow, accompanied by an increasing number of complaints from affected individuals. Most people are typically exposed to several noise sources, with road traffic noise being a dominant source (OECD-ECMT 19 1995). Population growth, urbanization and to a large extent technological development are the main driving forces, and future enlargements of highway systems, international airports and railway systems will only increase the noise problem. Viewed globally, the growth in urban environmental noise pollution is unsustainable, because it involves not simply the direct and cumulative adverse effects on health. It also adversely affects future generations by degrading residential, social and learning environments, with corresponding economical losses (Berglund 1998). Thus, noise is not simply a local problem, but a global issue that affects everyone (Lang 1999; Sandberg 1999) and calls for precautionary action in any environmental planning situation.

The objective of the World Health Organization (WHO) is the attainment by all peoples of the highest possible level of health. As the first principle of the WHO Constitution the definition of ‘health’ is given as: “A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". This broad definition of health embraces the concept of well-being and, thereby, renders noise impacts such as population annoyance, interference with communication, and impaired task performance as 'health' issues. In 1992, a WHO Task Force also identified the following specific health effects for the general population that may result from community noise: interference with communication; annoyance responses; effects on sleep, and on the cardiovascular and psychophysiological systems; effects on performance, productivity, and social behavior; and noise-induced hearing impairment (WHO 1993; Berglund & Lindvall 1995; *cf*. WHO 1980). Hearing damage is expected to result from both occupational and environmental noise, especially in developing countries, where compliance with noise regulation is known to be weak (Smith 1998).

Noise is likely to continue as a major issue well into the next century, both in developed and in developing countries. Therefore, strategic action is urgently required, including continued noise control at the source and in local areas. Most importantly, joint efforts among countries are necessary at a system level, in regard to the access and use of land, airspace and seawaters, and in regard to the various modes of transportation. Certainly, mankind would benefit from societal reorganization towards healthy transport. To understand noise we must understand the different types of noise and how we measure it, where noise comes from and the effects of noise on human beings. Furthermore, noise mitigation, including noise management, has to be actively introduced and in each case the policy implications have to be evaluated for efficiency.

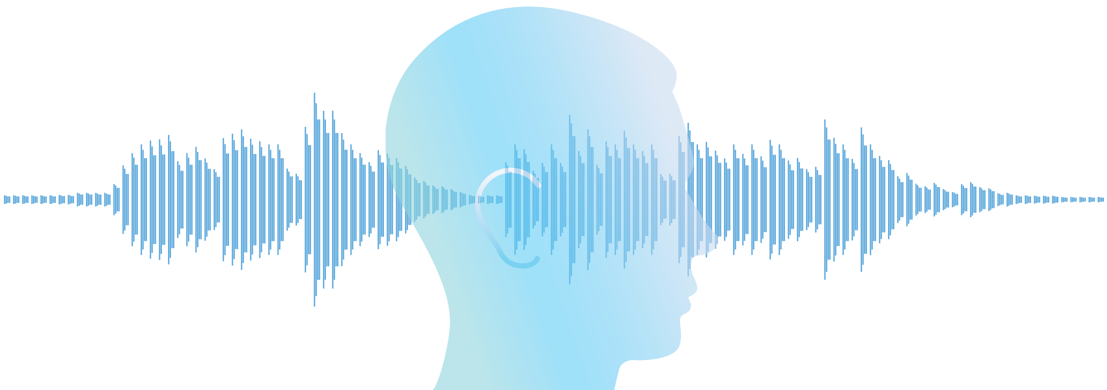
This document is organized as follows. In Chapter 2 noise sources and measurement are discussed, including the basic aspects of source characteristics, sound propagation and transmission. In Chapter 3 the adverse health effects of noise are characterized. These include noise-induced hearing impairment, interference with speech communication, sleep disturbance, cardiovascular and physiological effects, mental health effects, performance effects, and annoyance reactions. This chapter is rounded out by a consideration of combined noise sources and their effects, and a discussion of vulnerable groups. In Chapter 4 the Guideline values are presented. Chapter 5 is devoted to noise management. Included are discussions of: strategies and priorities in the management of indoor noise levels; noise policies and legislation; environmental noise impact; and enforcement of regulatory standards. In Chapter 6 implementation of the WHO Guidelines is discussed, as well as future WHO work on noise and its research needs. In Appendices 1–6 are given: bibliographic references; examples of regional noise situations (African Region, American Region, Eastern Mediterranean Region, South East Asian Region, Western Pacific Region); a glossary; a list of acronyms; and a list of participants.

World Health Organization
REGIONAL OFFICE FOR Europe

ENVIRONMENTAL NOISE GUIDELINES

for the European Region

EXECUTIVE SUMMARY



Abstract

Noise is an important public health issue. It has negative impacts on human health and well-being and is a growing concern. The WHO Regional Office for Europe has developed these guidelines, based on the growing understanding of these health impacts of exposure to environmental noise. The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. They provide robust public health advice underpinned by evidence, which is essential to drive policy action that will protect communities from the adverse effects of noise. The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience. The full publication of the guidelines can be downloaded here:
www.euro.who.int/en/env-noise-guidelines

Keyword

NOISE – ADVERSE EFFECTS, PREVENTION AND CONTROL

ENVIRONMENTAL EXPOSURE – ADVERSE EFFECTS, PREVENTION AND CONTROL

GUIDELINES

EUROPE

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Executive summary

Environmental noise is an important public health issue, featuring among the top environmental risks to health. It has negative impacts on human health and well-being and is a growing concern among both the general public and policy-makers in Europe.

At the Fifth Ministerial Conference on Environment and Health in Parma, Italy, in 2010, WHO was requested by the Member States in the European Region to produce noise guidelines that included not only transportation noise sources but also personal electronic devices, toys and wind turbines, which had not yet been considered in existing guidelines. Furthermore, European Union Directive 2002/49/EC relating to the assessment and management of environmental noise (END) and related technical guidance from the European Environment Agency both elaborated on the issue of environmental noise and the importance of up-to-date noise guidelines.

The WHO Regional Office for Europe has therefore developed environmental noise guidelines for the European Region, proposing an updated set of public health recommendations on exposure to environmental noise.

Objectives

The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. Leisure noise in this context refers to all noise sources that people are exposed to due to leisure activities, such as attending nightclubs, pubs, fitness classes, live sporting events, concerts or live music venues and listening to loud music through personal listening devices. The guidelines focus on the WHO European Region and provide policy guidance to Member States that is compatible with the noise indicators used in the European Union's END.

The following two key questions identify the issues addressed by the guidelines.

- In the general population exposed to environmental noise, what is the exposure–response relationship between exposure to environmental noise (reported as various indicators) and the proportion of people with a validated measure of health outcome, when adjusted for confounders?
- In the general population exposed to environmental noise, are interventions effective in reducing exposure to and/or health outcomes from environmental noise?

In light of these questions, the guidelines set out to define recommended exposure levels for environmental noise in order to protect population health.

Methods used to develop the guidelines

The process of developing the WHO guidelines followed a rigorous methodology involving several groups with separate roles and responsibilities. Throughout the process, the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach was followed. In particular, the different steps in the development of the guidelines included:

- formulation of the scope and key questions of the guidelines;
- review of the pertinent literature;
- selection of priority health outcome measures;
- a systematic review of the evidence;

- assessment of certainty of the bodies of evidence resulting from systematic reviews;
- identification of guideline exposure levels; and
- setting of the strength of recommendations.

Based on the defined scope and key questions, these guidelines reviewed the pertinent literature in order to incorporate significant research undertaken in the area of environmental noise and health since the community noise guidelines and night noise guidelines for Europe were issued (WHO, 1999; WHO Regional Office for Europe, 2009). In total, eight systematic reviews of evidence were conducted to assess the relationship between environmental noise and the following health outcomes: cardiovascular and metabolic effects; annoyance; effects on sleep; cognitive impairment; hearing impairment and tinnitus; adverse birth outcomes; and quality of life, mental health and well-being. A separate systematic review of evidence was conducted to assess the effectiveness of environmental noise interventions in reducing exposure and associated impacts on health.[1] Once identified and synthesized, the quality of the evidence of the systematic reviews was assessed by the Systematic Review Team. Subsequently, the Guideline Development Group (GDG) formulated recommendations, guided by the Systematic Review Team's assessment and informed by of a number of additional contextual parameters. To facilitate the formulation of recommendations, the GDG first defined priority health outcomes and then selected the most relevant health outcome measures for the outcomes. Consecutively, a process was developed to identify the guideline exposure levels with the help of the exposure–response functions provided by the systematic reviews. To reflect the nature of the research (observational studies) underpinning the relationship between environmental noise and health, the GRADE procedures were adapted to the requirements of environmental exposure studies where needed.

Noise indicators

From a scientific point of view, the best noise indicator is the one that performs best in predicting the effect of interest. There are, however, a number of additional criteria that may influence the choice of indicator. For example, various indicators might be suitable for different health end-points. Some considerations of a more political nature can be found in the European Commision's Position paper on EU noise indicators (EC, 2000).

The current guidelines are intended to be suitable for policy-making in the WHO European Region. They therefore focus on the most used noise indicators L_{den} and/or L_{night}. They can be constructed using their components (L_{day}, $L_{evening}$, L_{night} and the duration in hours of L_{night}), and are provided for exposure at the most exposed façade, outdoors. The L_{den} and L_{night} indicators are those generally reported by authorities and are widely used for exposure assessment in health effect studies.

[1] All systematic reviews are publicly available online in the *International Journal of Environmental Research and Public Health*. A detailed list of links to the individual reviews is provided in section 2.3.2 of these guidelines.

Recommendations

Specific recommendations have been formulated for road traffic noise, railway noise, aircraft noise, wind turbine noise and leisure noise. Recommendations are rated as either strong or conditional.

Strength of recommendation

- A strong recommendation can be adopted as policy in most situations. The guideline is based on the confidence that the desirable effects of adherence to the recommendation outweigh the undesirable consequences. The quality of evidence for a net benefit – combined with information about the values, preferences and resources – inform this recommendation, which should be implemented in most circumstances.
- A conditional recommendation requires a policy-making process with substantial debate and involvement of various stakeholders. There is less certainty of its efficacy owing to lower quality of evidence of a net benefit, opposing values and preferences of individuals and populations affected or the high resource implications of the recommendation, meaning there may be circumstances or settings in which it will not apply.

Alongside specific recommendations, several guiding principles were developed to provide generic advice and support for the incorporation of recommendations into a policy framework. They apply to the implementation of all of the specific recommendations.

Guiding principles: reduce, promote, coordinate and involve

- Reduce exposure to noise, while conserving quiet areas.
- Promote interventions to reduce exposure to noise and improve health.
- Coordinate approaches to control noise sources and other environmental health risks.
- Inform and involve communities potentially affected by a change in noise exposure.

The recommendations, source by source, are as follows.

Road traffic noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by road traffic below **53 decibels (dB)** L_{den}, as road traffic noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by road traffic during night time below **45 dB** L_{night}, as night-time road traffic noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from road traffic in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions, the GDG recommends reducing noise both at the source and on the route between the source and the affected population by changes in infrastructure.	Strong

Railway noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by railway traffic below **54 dB** L_{den}, as railway noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by railway traffic during night time below **44 dB** L_{night}, as night-time railway noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from railways in the population exposed to levels above the guideline values for average and night noise exposure. There is, however, insufficient evidence to recommend one type of intervention over another.	Strong

Aircraft noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft below **45 dB** L_{den}., as aircraft noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft during night time below **40 dB** L_{night}., as night-time aircraft noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions the GDG recommends implementing suitable changes in infrastructure.	Strong

Wind turbine noise

Recommendation	Strength
For average noise exposure, the GDG conditionally recommends reducing noise levels produced by wind turbines below **45 dB** L_{den}, as wind turbine noise above this level is associated with adverse health effects.	Conditional
No recommendation is made for average night noise exposure L_{night} of wind turbines. The quality of evidence of night-time exposure to wind turbine noise is too low to allow a recommendation.	
To reduce health effects, the GDG conditionally recommends that policy-makers implement suitable measures to reduce noise exposure from wind turbines in the population exposed to levels above the guideline values for average noise exposure. No evidence is available, however, to facilitate the recommendation of one particular type of intervention over another.	Conditional

Leisure noise

Recommendation	Strength
For average noise exposure, the GDG conditionally recommends reducing the yearly average from all leisure noise sources combined to **70 dB** $L_{Aeq,24h}$ as leisure noise above this level is associated with adverse health effects. The equal energy principle[2] can be used to derive exposure limits for other time averages, which might be more practical in regulatory processes.	Conditional
For single-event and impulse noise exposures, the GDG conditionally recommends following existing guidelines and legal regulations to limit the risk of increases in hearing impairment from leisure noise in both children and adults.	Conditional
Following a precautionary approach, to reduce possible health effects, the GDG strongly recommends that policy-makers take action to prevent exposure above the guideline values for average noise and single-event and impulse noise exposures. This is particularly relevant as a large number of people may be exposed to and at risk of hearing impairment through the use of personal listening devices. There is insufficient evidence, however, to recommend one type of intervention over another.	Strong

Target audience

The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience, as a large body of the evidence underpinning the recommendations was derived not only from European noise effect studies but also from research in other parts of the world – mainly in America, Asia and Australia.

[2] The equal energy principle states that the total effect of sound is proportional to the total amount of sound energy received by the ear, irrespective of the distribution of that energy in time (WHO, 1999).

The WHO Regional Office for Europe

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

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Noise is an important public health issue. It has negative impacts on human health and well-being and is a growing concern. The WHO Regional Office for Europe has developed these guidelines, based on the growing understanding of these health impacts of exposure to environmental noise. The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. They provide robust public health advice underpinned by evidence, which is essential to drive policy action that will protect communities from the adverse effects of noise. The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience.

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enHEALTH

The health effects of environmental noise

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SUMMARY

Overview

The potential health risks of environmental noise are gaining increasing attention.

With increasing urban populations and changes in urban development, a growing number of people in Australia are being exposed to environmental noise.

The research literature has grown substantially, providing new insights into how people are being exposed to noise and potential health risks.

This review intends to inform noise policy and regulation in Australia by evaluating the evidence of the health effects of environmental noise. It also highlights specific areas for further research.

The review concludes that although the evidence is still emerging, it is sufficient to show that noise adversely affects health. Actions to reduce environmental noise exposure should be considered where feasible.

Scope of this review

This review updates and revises a 2004 enHealth Australia report on the non–auditory effects of environmental noise. It evaluates more than 200 research papers, publications and policies from January 1994 to March 2014.

It includes a systematic review of international evidence on the influence of environmental noise on sleep, cardiovascular disease and cognitive outcomes.

For each outcome, the review considers evidence for the relationship between levels of environmental noise exposure and health outcomes, the influence of different noise sources, and impact on vulnerable populations.

It considers annoyance as a mediating factor between environmental noise exposure and health outcomes, rather than a separate factor. The auditory impacts of noise are excluded as most of these studies are in the context of occupational noise.

Chapter 1 in this document defines noise and common noise measurements, and introduces the effects of noise on health.

Chapter 2 identifies sources of environmental noise and reviews current Australian regulatory approaches to managing community exposures. It draws on the European Union's experience in implementing its environmental directive. This framework allows for reliable and strategic noise mapping and action planning and may prove useful in an Australian context.

Chapters 3, 4 and 5 systematically review studies on the effect of noise on sleep disturbance, cardiovascular disease and cognition.

Chapter 6 includes discussion on the highest quality studies examining these health effects. It aims to give further guidance to assist regulatory authorities and public health professionals by providing insight into causal probability, identifying threshold boundaries for health effects and the magnitude of these effects.

Chapter 7 details the review's recommendations for policy review and further research, and actions for state health, environment and planning authorities.

The objectives and methodology for this review are further defined in appendix A.

Summary of findings

There is sufficient evidence of a causal relationship between environmental noise and both sleep disturbance and cardiovascular disease to warrant health based limits for residential land uses:

- During the night-time, an evidence based limit of 55 dB(A) at the facade using the $L_{eq,night,}$ or similar metric and eight-hour night-time period is suggested.
- During the day-time, an evidence based limit of 60 dB(A) outside measured using the $L_{eq,day,}$ or similar metric and a 16 hour day-time period is suggested.

There is some evidence that environmental noise is associated with poorer cognitive performance. However findings were mixed and this relationship requires further investigation.

It is plausible that aircraft, rail and road traffic noise have differential effects on sleep quality and cardiovascular health, but the evidence is not conclusive.

It is possible that health impacts may be greater among certain vulnerable groups, but further investigation is needed before making conclusions.

Research on the health impacts of environmental noise in the Australian context should be a priority. There is a particular lack of research on environmental noise exposure and health impacts in rural areas. Intervention studies examining the effects of change in noise exposure on changes in population health are also needed.

Key recommendations of this review

This review makes four overarching recommendations for measures to address the health impacts of environmental noise.

Recommendation 1: Recognise that environmental noise is a health risk

Policy

- consider this review when developing national environmental noise goals
- include noise as an important environmental health issue for strategic and local planning at a state and national level
- review the adequacy of existing health guidelines in state and territory legislation

Interventions

- promote awareness of the impacts of environmental noise on health

Information

- inform communities and stakeholders of national and international standards and guidelines

Recommendation 2: Promote measures to reduce environmental noise and associated health impacts

Policy

- review consistency of existing legislation across all levels of government

Interventions

- review noise arising from transportation, including noise criteria for areas adjacent to transport infrastructure
- promote noise mitigation measures such as acoustic barriers or noise insulation in residential buildings and licensing controls to limit noise impacts

Information

- develop a national environmental noise reduction education program, which could be supplemented with additional state-specific campaigns

Recommendation 3: Address environmental noise in planning and development activities

Policy

- include environmental noise in the health impact assessment of proposed developments, where warranted
- determine baseline environmental noise levels to inform planning actions (noise mapping)
- review noise control practices and how to further integrate noise control into planning processes, for all levels of government (with attention to future noise research findings)
- foster national consistency on guidelines to minimise or prevent environmental noise from developments, limiting noise from major sources, and methods to set noise limits

Interventions

- carry out baseline monitoring of environmental noise levels to ascertain existing ambient levels across a broad range of populations and land use areas
- apply appropriate controls where noise is known to have an effect
- develop national and state action plans for both the long and short term to integrate planning and research at all levels of government
- develop guidelines for noise sensitive developments for layout, design and construction for planning authorities

Information

- develop state information strategies to keep communities informed of advances in measures to improve noise

Recommendation 4: Foster research to support policymaking and action

Policy

- identify factors giving rise to sensitivity to noise and vulnerability to non-auditory health effects to inform environmental, planning and health policies

Interventions

- conduct a rigorous evaluation of national, state and city population exposures to each major noise source
- support noise mapping projects to determine community noise exposures to each major noise source that could be used to inform land use planning or burden of disease studies
- conduct evaluations of noise reduction schemes on community health
- promote further research on the effects of noise on learning performance in children, sleep disturbance, annoyance and cardiovascular health and mental wellbeing to establish threshold levels

Information

- translate research findings into useful information for community and relevant stakeholders

Oversight of this review

An expert advisory group oversaw this review and endorsed the final document. The group comprised experts in acoustics, environmental health, epidemiology, sleep medicine, urban studies and noise exposure, public health medicine and environmental noise regulation.

The group provided technical advice on the review's scope, content, conclusions and recommendations. The group also oversaw the process for commissioning evidence reviews including the scope, search strategy and criteria for high quality research and the revision of high quality papers and grading of evidence.

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This document updates the original enHealth document, *the Health Effects of Environmental Noise – Other Than Hearing Loss*, published in 2004.

1 SOUND, NOISE, HEARING AND HEALTH

1.1 Noise, environmental noise and health

Noise can be defined as unwanted sound. Environmental noise, or community noise, is defined by the World Health Organisation (WHO) as ‘noise emitted from all sources except noise at the industrial workplace’ (Berglund et al., 1999).

The main sources of community noise include: transport (road, rail and air traffic), industries, construction, public works, and the neighbourhood.

The potential health risks of environmental noise are gaining increasing attention. WHO defines health as ‘a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity’ (WHO, 1946). This broad definition enables us to consider not only the direct impacts environmental noise has on health, but also its impacts on sleep disturbance, cognitive effects and annoyance. In 2011, WHO quantified the burden of disease due to environmental noise exposure. Health end points included cardiovascular disease, cognitive impairment, sleep disturbance, tinnitus and annoyance. In one example of this, WHO estimates that at least 1 million healthy life years are lost every year from traffic-related noise in western Europe (WHO, 2011).

Table 1-1: Definitions and acronyms

Term	Definition
A-weighting i.e. dB(A)	A frequency weighting devised to attempt to take into account the fact that human response to sound is not equally sensitive to all frequencies
Amplitude	A measurement of the energy carried by a wave – the greater the amplitude of the wave, the higher the level of energy carried; for a sound wave, the greater the amplitude, the louder the sound
Audibility threshold	Also known as the absolute threshold of hearing, it is the minimum sound level across the frequency spectrum that an average ear with normal hearing can register with no other sound present
Broadband sound	When a sound is produced by a broad range of frequencies, it is generally called broadband (such as sound from a waterfall)
Decibel (dB)	A unit of measure used to express the level of sound, calculated as the logarithmic ratio of sound pressure level against a reference pressure
Environmental noise	A term to describe unwanted outdoor noise generated by human activity
Frequency (hertz, Hz)	The number of sound waves or cycles passing a given point per second; 1 cycle per second = 1 hertz (Hz)
Noise	Unwanted sound or an unwanted combination of sounds.
Presbycusis	Age-related hearing loss. The cumulative effect of ageing on hearing
Sound	An energy form that travels from a source in the form of waves or pressure fluctuations, transmitted through a medium and received by a receiver (e.g. human ear)
Sound frequency ranges	Infrasound <20 Hz Low-frequency sound 20 – 200 Hz Mid-frequency sound 200 – 2000 Hz High-frequency sound 2000 – 20,000 Hz
Sound intensity (I)	A measure of the sound power per unit area of a sound wave; alternatively, the product of the sound pressure and the particle velocity

Term	Definition
Sound power (watt, W)	A measure of the sonic energy per unit of time of a sound wave; alternatively called acoustic power; calculated by the sound intensity times the unit area of the wave; the total acoustic power emitted in all directions by the source
Sound pressure	A measure of the sound power at a given observer location; can be measured at the specific point by a single microphone or receiver
Sound pressure level (SPL)	A logarithmic measure of the sound pressure of a sound relative to a reference value, measured in decibels (dB) above a standard reference level using the formula SPL = $10\log_{10}[p^2/p_{ref}^2]$ where p_{ref} is the reference pressure or 'zero' reference for airborne sound (20×10^{-6} Pascals)
Syscusis	Lowering of the threshold of aural discomfort and pain
Unspecified noise	Noise for which study authors have not specified a frequency range or decibel level
Vibration	Vibration refers to the oscillating movement of any object and can be used to describe what a person feels
Tinnitus	The conscious perception of sound in the absence of an external sound
Tonal sound	Sound containing audible discrete frequencies

1.2 Basics of noise measurement

In scientific terms, sound is energy that travels from a source in the form of waves or pressure fluctuations. It is transmitted through a medium and picked up by the human ear or another receiver.

Sound has several important properties:

- level or amplitude (loudness) of sound – the sound pressure level (SPL) relative to a reference sound pressure level, which is measured in decibels (dB) using a logarithmic scale
- duration or time period – how sound is distributed over time (continuous, intermittent or impulsive)
- frequency (pitch) – the number of sound waves or cycles passing a given point per second; measured in cycles per second (1 cycle per second = 1 hertz (Hz)).

Humans can hear a wide range of sound frequencies, from 20 to 20 000 Hz and over a wide range of amplitudes, from a whisper to the point of pain.

Noise definitions vary slightly in different countries. In general, noise is classified in three broad frequency ranges:

- low frequency range: 20 – 200 Hz
- medium frequency range: 200 – 2,000 Hz
- high frequency range: 2,000 – 20,000 Hz.

Frequencies below 20 Hz are infrasonic. As the frequency below 200 Hz falls to about 16 Hz and less, the hearing sensation changes to a feeling of pressure.

Low frequency noise is part of urban background noise. Examples include noise from road vehicle and aircraft emissions, industrial and construction activities, ventilation and air-conditioning units, and compressors. Low frequency noise also occurs in nature. Examples include noise from wind or waves at a beach.

Very high frequencies (above 20,000 Hz) are ultrasonic and cannot be heard by the human ear.

Figure 1-1 gives examples of familiar sounds at their noise level dB(A). It shows that the risk of hearing loss depends on the noise level and length of exposure.

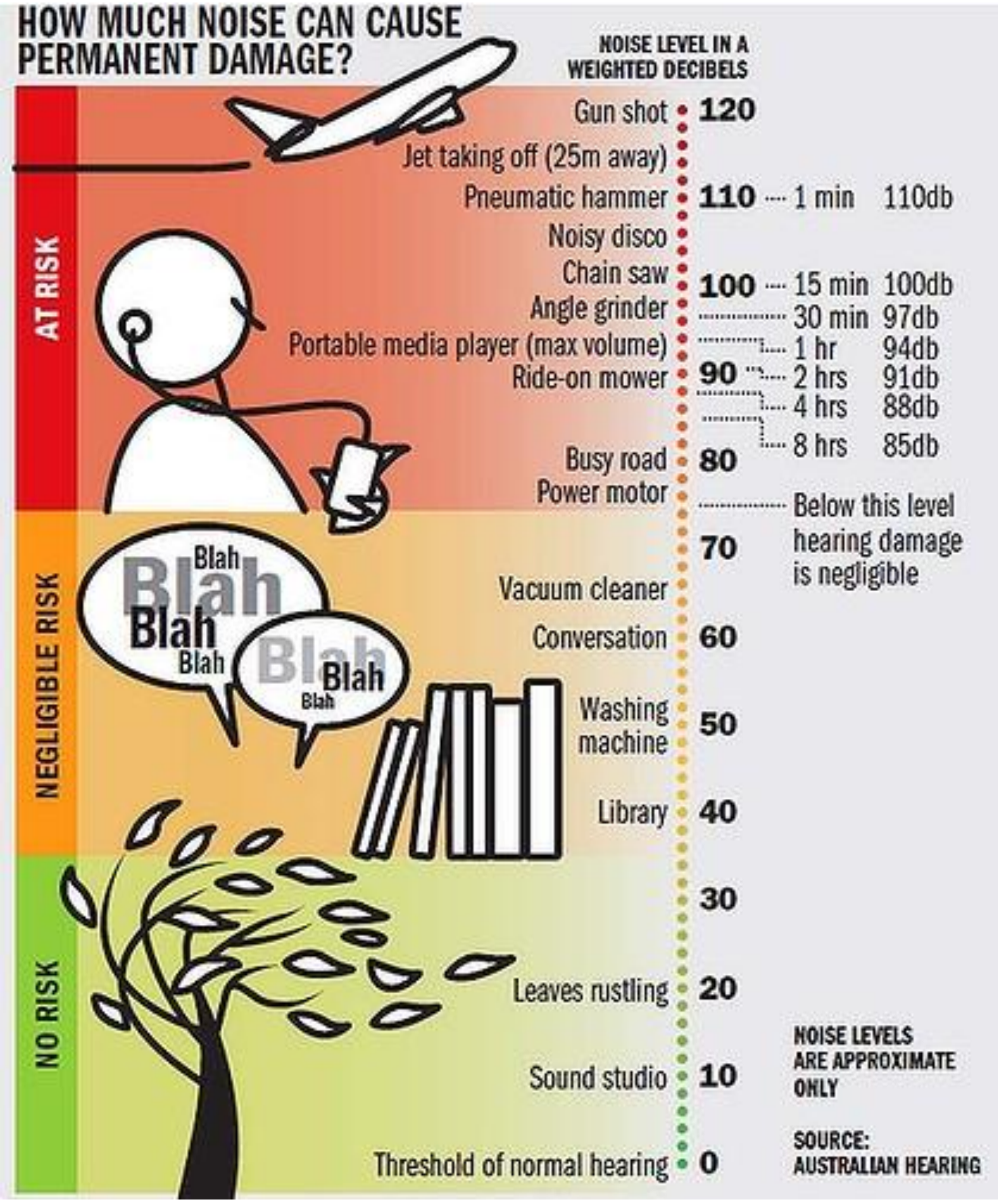

Figure 1-1: Noise levels of familiar sounds and the risk of hearing loss (Australian Hearing, 2014; image adapted by *The Sydney Morning Herald*, 2011).

Humans hear some frequencies more acutely than others and sound measurements are often filtered to reflect this sensitivity. The most common example is the ‘A-weighting’. This focuses on the mid and high-range frequencies we hear and has less emphasis on low frequencies to which our hearing is less sensitive. However, it should be noted that although humans are less sensitive to low frequencies, that does not mean we should give less emphasis to low frequencies. Many complaints arise from low-frequency noise.

As sound is emitted from a source, it spreads in the air and its level decreases as it travels further. According to the WHO (1990) this attenuation is due to several factors:

- the distribution of acoustic energy over a geometrically expanding area with increasing distance
- sound absorption by the air
- interference with the ground surface
- physical barriers between noise sources and receivers
- meteorological factors such as wind, temperature gradients and humidity.

When interpreting acoustical data, different metrics are often used for different classifications or types of noise.

A knowledge of sound, noise and human response leads to a selection of noise descriptors, frequency and time weightings to describe and replicate human responses to sound and its impact. Table 1-2 lists common descriptors used to quantify the noise environment.

Table 1-2: Common noise descriptors

Descriptor	Definition
$L_{Aeq,T}$	The equivalent continuous A-weighted sound pressure level measured over a period T – that level of constant noise equivalent to the varying noise levels occurring over a measurement period T, often termed the energy-average noise level. It is often used to measure road and rail noise, industrial noise, noise from heating, ventilation and air conditioning and occupational noise exposure. Time periods can include $L_{Aeq,night}$ and $L_{Aeq,day}$. Similarly, periods can vary from 1 minute to 24 hours and are recorded as $L_{Aeq,1\ min}$ and $L_{Aeq,24\ hr}$*
L_{peak} (linear)	Used in setting hearing conservation limits for impulsive noise
$L_{Ar,T}$	The time average A-weighted sound pressure level of a sound source during a specified time interval, plus specified adjustments for tonal and impulsive character of the sound (time weighting may be 'F' or 'S' †)
L_{dn}	Day-night sound level is the equivalent A-weighted sound level during a 24-hour period with a 10 dB weighting applied to L_{Aeq} during the hours of 10pm to 7am to reflect greater annoyance experienced during night time
L_{den}	The day-evening-night level is the equivalent A-weighted sound level during a 24-hour period with a 5 dB weighting for evening and a 10 dB weighting for night. Day is 12 hours, the evening 4 hours and the night 8 hours and is determined over a year
L_{night}	The night-time noise indicator is the A-weighted long-term average sound level determined over all the nights of a year and in which the night is 8 hours. The definition of L_{night} does not include an addition of 10 dB
L_{ax}, L_{AE} or SEL	Sound exposure level of a discrete noise event is the instantaneous A-weighted sound pressure level integrated over the duration of the noise event and referenced to a duration of one second. SEL is used for measuring noise from individual pass-bys of transportation. A cumulative L_{Aeq} over a reference period can be determined from this. SEL is also sometimes used for sleep disturbance criteria
L_{Amax}	The maximum instantaneous sound pressure level measured on 'F' time weighting or 'S' time weighting

* Local regulatory requirements may define varying periods for $L_{Aeq,T}$.

† F and S are defined in relevant Australian Standards.

Descriptor	Definition
$L_{An,T}$	The A-weighted sound pressure level obtained by using 'F' or 'S' time weighting that is equalled or exceeded for a percentage of the time interval considered. Common examples are: • $L_{A10,T}$: the A-weighted sound pressure level which is exceeded 10% of the time; T, often used to represent the average of the maximum noise levels during a measurement period • $L_{A90,T}$: the A-weighted sound pressure level which is exceeded 90% of the time; T, often used to represent the average of minimum noise levels during a measurement period or the background noise level in the absence of the noise under investigation
N70	Other noise descriptors are used in some circumstances. This includes N70 (number of aircraft events >70 dB(A) over any specified period), which is used to describe over-flight noise exposures. The 70 dB(A) sound level is chosen because an aircraft noise event of this, or louder, magnitude is likely to disturb conversation or interfere with listening to the radio or television inside a house with an open window

1.3 Tranquillity, quiet areas and potential positive health effects of sound environments

The absence of unwanted sound (noise) is not necessarily quietness. In fact, natural background sounds in certain contexts can be seen as enjoyable or wanted. For example: wind rustling in trees, waves crashing on a beach, waterfalls and birds singing. Some human sounds may also be comforting, such as the burble of voices or the sound of children playing.

Tranquillity is a term used globally. It is defined as: 'the quality or state of being tranquil; calmness, serenity, a disposition free from stress or emotion and a state of peace and quiet'. It can also be defined as: 'a sense of calm or quietude'. It is often understood in terms of engagement with the natural environment (Jones, 2012).

Related concepts include soundscapes and quiet areas. Soundscape is a complementary concept to environmental noise management, where sound is seen as a resource to be managed. Soundscapes focus on sounds of preference rather than sounds that cause discomfort. The metric is listener-centred rather than an objective-based energy metric.

Quiet areas are referred to in the European Union's Environmental Noise Directive. These are defined for an urban agglomeration as 'an area which is not exposed to a value of $L_{den,}$ or of another separate indicator greater than a certain value set by the member state, from any noise source' (European Union, 2002). This definition of quiet, put more simply, is 'not noisy'. The directive legislates for the identification and protection of quiet areas throughout the European Union.

The benefits of quiet or tranquil places are not usually considered in terms of health but rather in ideas of amenity, attractiveness, pleasantness, calmness, restfulness and restoration. While there are plausible grounds for considering some acoustic environments as conducive to health benefits, there is a lack of substantive evidence on the issue. This is an emerging field. Aiming to achieve tranquillity may encourage broader interest in managing the acoustic environment.

1.4 Theoretical models to account for how noise affects human response

Several theoretical models explain the complex relationship between noise and the human response to it. Some of these models are outlined below. However, a detailed discussion is outside the scope of this document.

1.4.1 The noise/stress concept and general stress model

The noise/stress concept (Babisch, 2002) considers noise in terms of its physiological response: a psychosocial stressor that stimulates the sympathetic and endocrine systems. Noise activates the hypothalamo-pituitary-adrenal axis and the sympathetic-adrenal-medullary axis producing catecholamines and steroid hormones that affect metabolism. Changes in adrenalin, noradrenalin and cortisol levels are frequently observed in acute and chronic noise experiments.

According to the general stress model, neuroendocrine arousal suppresses the immune system, influences the metabolic state of the organism, and acts as a mediator along the pathway from the perceived sound to the stress-related disease. Some established risk factors may be affected. For example, risk factors for ischemic heart disease, including blood lipids, glucose level, haemodynamic and haemostatic factors, can be elevated by neuroendocrine arousal (Babisch, 2002).

1.4.2 Theory of the four primary interferences

In this theory, Miedema (2007) proposes four primary interferences caused by environmental noise, which may be accompanied by acute stress responses. These primary effects can lead to long-term effects, and chronic stress is proposed to play an important role.

Sound masking route (communication disturbance)

Sound masking reduces speech comprehension, which may limit speech and human interaction in noisier environments.

Attention route (concentration disturbance)

Attention involves selection of elements such as visual impressions, acoustical impressions or mental representations and selecting, ending or redirecting attention to each. Attention can be focused, or it may be divided over more elements. Noise can negatively affect processes requiring attention.

Arousal route (sleep disturbance)

Higher levels of arousal lower the probability of falling asleep or continuing sleep. Because of its arousal potential, sound can prevent a person falling asleep, affect sleep quality and cause awakening.

Affective–emotional route (fear and anger)

Many sounds are neutral. However, some types of noise can cause affective–emotional responses. Examples include fear and anger.

1.4.3 Effect modifiers

Other factors considered include social and psychological effect modifiers. There is a growing body of literature on the psychological and psychosocial modifiers of annoyance and dissatisfaction due to noise (Guski, 1999; Hatfield et al., 2001; Kroesen et al., 2010; Nitschke et al., 2014; Schreckenberg et al., 2010).

Annoyance

Annoyance is defined as ‘a feeling of displeasure associated with any agent or condition, known or believed by any individual or group to adversely affect them’ (Berglund et al. 1999). Noise annoyance is a feeling of resentment, displeasure, discomfort, dissatisfaction or offence caused by noise interference. It is a well-established construct in the study of environmental noise and is considered an important end point for measuring the impact of noise in exposed populations.

However, its relationship with health remains uncertain. In Australia annoyance is often considered an issue of amenity. But it forms an important part of the regulatory framework for noise.

It is not yet possible to predict noise annoyance on an individual level, given the many exogenous and endogenous factors that affect it. However, relationships between noise exposure and annoyance can be understood together with several effect-modifying factors. To assess noise-induced annoyance at the population level, a standardised questionnaire can be used. The percentage of respondents who report being highly annoyed can then be used as a prevalence indicator for annoyance in the population (WHO, 2011).

Several theoretical models, including those described above (Babisch, 2002; Miedema, 2007) consider annoyance on a causal pathway to health effects such as stress, cardiovascular effects and sleep disturbance.

1.5 Effects of environmental noise on health and related outcomes

Early research on the health effects of noise is from research into occupational health, and subsequently environmental health, in the 1960s and 1970s in Scandinavia, Europe and the US, as well as Australia. Environmental noise has become an increasingly important issue and many more studies on the health effects of noise have been done over the past few decades. The focus of these studies has shifted from the effect of noise on hearing and cardiovascular health to its broader effect on wellbeing, quality of life and amenity.

While environmental noise is generally recognised as a problem, the extent to which noise adversely affects health, particularly where subjective measures are used, is the subject of continued discussion. This section provides a brief overview of the effects of noise on health.

1.5.1 Effects on hearing

A person who is not able to hear as well as someone with normal hearing (hearing thresholds of greater than 25 dB in both ears) is said to have hearing loss. Around 2.1 million Australians are affected by complete or partial hearing loss (ABS, 2012).

Prevalence of hearing loss is age related: less than 1 per cent of people under the age of 15 are affected by hearing loss, while three in every four people over the age of 70 are affected. In about one-third of people with hearing loss, exposure to excessive noise was reported to be at least partially responsible.

The most common sources of noise injury are workplace noise and recreational noise (Wilson, 1998). Further consideration of exposure to occupational or recreational noise-induced hearing loss is outside the scope of this document.

1.5.2 Effects on health and human response other than hearing loss

Sleep

Sleep is essential for human function. A good night’s sleep is also considered essential for quality of life. Sleep disturbance is a common complaint of noise-exposed populations and has the potential to affect health and quality of life.

Sleep parameters can be measured in terms of immediate effects, after-effects and long-term effects. Immediate effects include arousal, sleep stage changes, awakenings, body movements, total wake time and autonomic responses. After-effects include sleepiness, daytime performance and cognitive deterioration. Long-term effects include self-reported chronic sleep disturbance. Chapter 3 addresses noise and sleep disturbance.

Cardiovascular disease

Cardiovascular disease includes ischaemic heart disease, myocardial infarction, hypertension (high blood pressure) and stroke. The number of epidemiological studies on the association between exposure to road traffic and aircraft noise and hypertension and ischaemic heart disease has increased in recent years. Very few studies have investigated the cardiovascular effects of exposure to rail noise (WHO, 2011). Chapter 4 addresses noise and cardiovascular disease.

Cognitive performance

Most observational studies examining cognitive performance are done in children, with experimental studies often involving young adults. Few studies investigate the effects of environmental noise on older adults.

Outcomes investigated include attention, memory, reading comprehension and mathematical tasks.

Chapter 5 addresses noise and cognition.

1.5.3 Other reported health effects and outcomes

Mental health

Environmental noise is not believed to be a direct cause of mental illness, but it is thought to accelerate and intensify the development of latent mental disorders (Berglund et al., 1999).

The effect of noise is complicated. Research suggests that poor psychological health is associated with greater annoyance responses. Studies in adults have found that noise exposure relates to an increase in reported psychological symptoms such as anxiety and depression, rather than to clinically diagnosable psychiatric disorders.

Overall, evidence suggests that in adults and children, noise exposure is unlikely to be associated with serious psychological illness. However, there may be effects on wellbeing and quality of life (Clark and Stansfield, 2007).

Birth outcomes

Ristovska et al. (2014) conducted a systematic review looking at the association between exposure to noise and birth outcomes. The evidence suggests an adverse effect on birth weight. Only a small number of studies have looked at other reproductive outcomes, and no clear links have yet been established.

Vulnerable groups

Particular sub-groups of the population are more vulnerable to experiencing annoyance or adverse health effects from noise.

Vulnerable groups include people with particular diseases or medical problems; people in hospital or rehabilitating at home; people dealing with complex cognitive tasks; those who have a visual or hearing impairment; babies and children; and the elderly.

These groups should be considered when recommending noise regulation or protection, including types of noise effects and specific environment and lifestyle factors (Berglund et al., 1999).

2 Noise exposure and regulatory approaches in Australia

This chapter examines the noise environment in Australia. While most of Europe has been able to build a picture of the types and extent of noise exposure across the continent, a lack of systematic data for the Australian context makes understanding and quantifying our noise environment difficult.

In the absence of information that reliably and systematically maps noise exposure and affected populations, researchers use modelled or measured information from significant sources such as aircraft and road traffic.

Complaints information and social surveys may provide some insight into the impact noise has on communities and individuals. These may or may not be typical of how the general population responds.

Both types of information are useful. Modelled and measured data provides an objective measure of noise levels. Complaints and social surveys provide further insight into people's subjective or physical responses to noise. However, complaints data does not always correspond to areas with the highest recorded noise levels. This underscores the subjective nature of noise and suggests other factors such as habituation are important.

The availability of different types of noise data varies, and information is available for some jurisdictions but not others. For example, Airservices Australia provides online summaries of noise monitoring data from major airports that are updated quarterly. Information on road and rail traffic may be available for major developments but obtaining this data is logistically difficult. This information and other data are needed if we are to build a picture of noise exposure across Australia (Airservices Australia, 2015a, b).

This chapter describes some of the common environmental noise sources and provides examples of the types of data available. It summarises the regulatory response to major sources and examines noise mapping in the European context under *European Noise Directive (END) 2002/49/EC relating to the assessment and management of environmental noise* (European Union, 2002).

A significant portion of this chapter focuses on road, aircraft and rail noise, which are characterised by lower, intermittent and higher frequencies respectively. Most research is done on road, aircraft and rail noise because their characteristics are similar to other noises.

2.1 Sources of noise exposure

2.1.1 Road traffic noise

Road traffic noise is mainly generated from the engine and from frictional contact between the wheels, the ground and the air. Road contact noise exceeds engine noise at speeds higher than 35km/hour. However, the physical principle responsible for generating noise from contact between the tyre and the road is less well understood (Berglund et al., 1999). It is estimated that more than 70 per cent of environmental noise (unwanted sound) in urban Australia is due to road traffic (Marquez et al., 2005).

Noise levels from traffic can be predicted from the traffic flow rate, the speed of the vehicle, the proportion of heavy vehicles, and the nature of the road surface. Vehicle noise is related to traffic speed. As speed-changing traffic is noisier than steady traffic, congestion may add to noise.

Congestion typically reduces traffic noise due to lower vehicle speeds. An indirect consequence of congestion is an increase in night-time freight as freight operators, encouraged by government agencies, try to avoid daytime congestion. Noise from heavy truck exhaust and gear changes as well as engine noise and braking, is a particular problem. Rising traffic levels and growing freight movements lead to increasing violations of transport noise level guidelines (Marquez et al., 2005).

In highly urbanised Australia, the population exposed to noise is mostly concentrated in metropolitan areas (Brown and Bullen, 2003). Most noise impacts of traffic occur when people are in their homes. Estimating community exposure requires estimating the levels of road traffic noise at the facades of dwellings in Australian cities.

A survey of road traffic noise in five capital cities by Brown and Bullen (2003) shows the proportion of dwellings affected by road traffic noise. The study was done in 1997–98. At the time, it provided the best available estimate of road traffic noise exposure in urban Australia. The study drew a random sample of dwellings from the urban centres in each capital and estimated road traffic noise exposure at each dwelling.

The results show that 8 to 20 per cent of dwellings are exposed to $L_{A10,18h}$ levels above 63 dB and 5 to 11 per cent above $L_{A10,18h}$ 68 dB. L_{A10} is the noise level exceeded for 10 per cent of the measurement period. $L_{A10,18h}$ is the average of L_{A10} noise levels from 6am to midnight.

Sydney was significantly different to the other cities with a higher proportion of dwellings subject to external noise between $L_{A10,18h}$, 60 and 70 dB. The study suggested this might be due to a different pattern of road use and Sydney's physical location.

Figure 2-1 shows an estimate of the proportion of dwellings in the urban centres of Sydney, Melbourne, Brisbane, Perth and Adelaide where calculated traffic noise exceeds values on the $L_{A10,18h}$ scale.

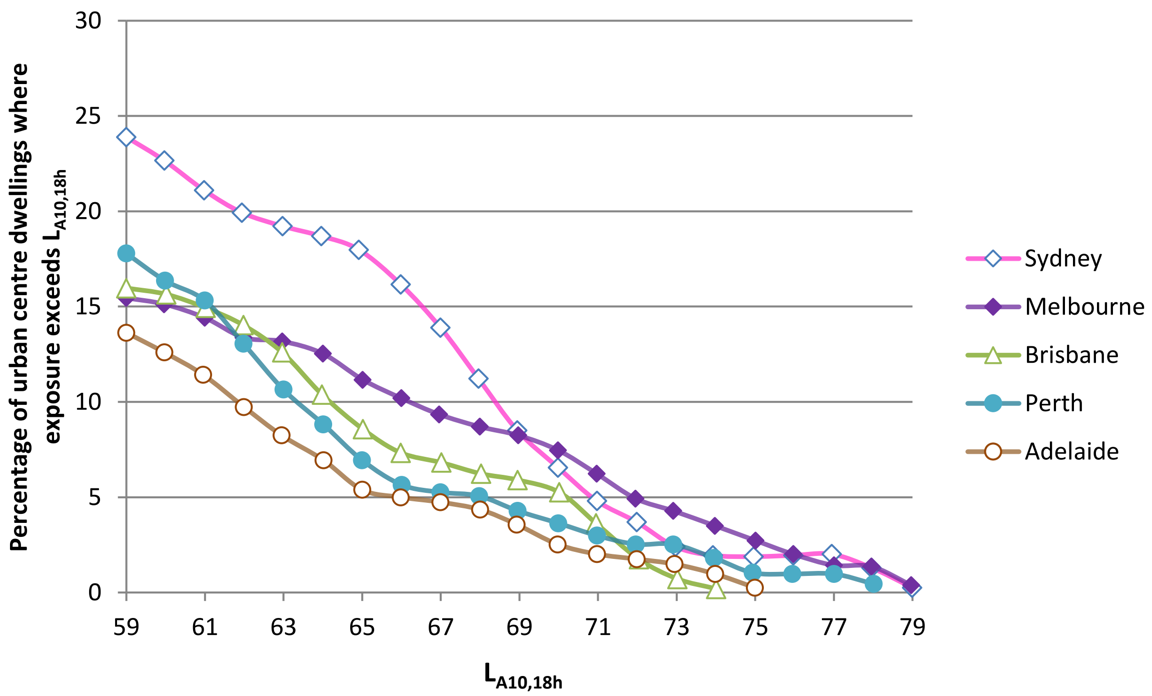

Figure 2-1: Cumulative noise exposure of dwellings in Australian capital cities, $L_{A10,18h}$ (Adapted from Brown and Bullen 2003)

Since that survey, vehicle fleet mix has changed. The ABS Motor Vehicle Census (2014) shows a slight decrease in the proportion of passenger vehicles in Australia with these accounting for about 75.4 per cent of all registered vehicles in 2014 as opposed to about 80 per cent in 1999. This has been offset by a rise in the proportion of light commercial vehicles, heavy rigid trucks, buses and motorcycles in each jurisdiction. The total number of vehicles increased from about 12.3 million in 1999 to about 17.6 million in 2014. The passenger vehicle fleet rose from about 9.7 million to about 13.3 million in the same period.

These changes will have an impact on the noise environment and the characteristics of the noise experienced. A noise measurement survey by Victoria's Environment Protection Authority (EPA) compared noise measurements in 2007 with data collected in 1978 (EPA Victoria, 2007). It measured noise levels at 50 sites across the inner, middle and outer suburbs of Melbourne and showed that despite the growth in traffic volumes, noise levels across Melbourne were similar to those in 1978 (Figure 2-2). This graph depicts noise levels in terms of the $L_{Aeq,1hour}$.

These results suggest that while traffic volumes have grown and the mix has changed, quieter vehicles and other factors may be offsetting any rise in noise. Examples include improvements in road surface and better policies for new and upgraded roads. However, increasing residential densities along major urban roads means a greater percentage of the population is likely to be exposed to higher traffic noise.

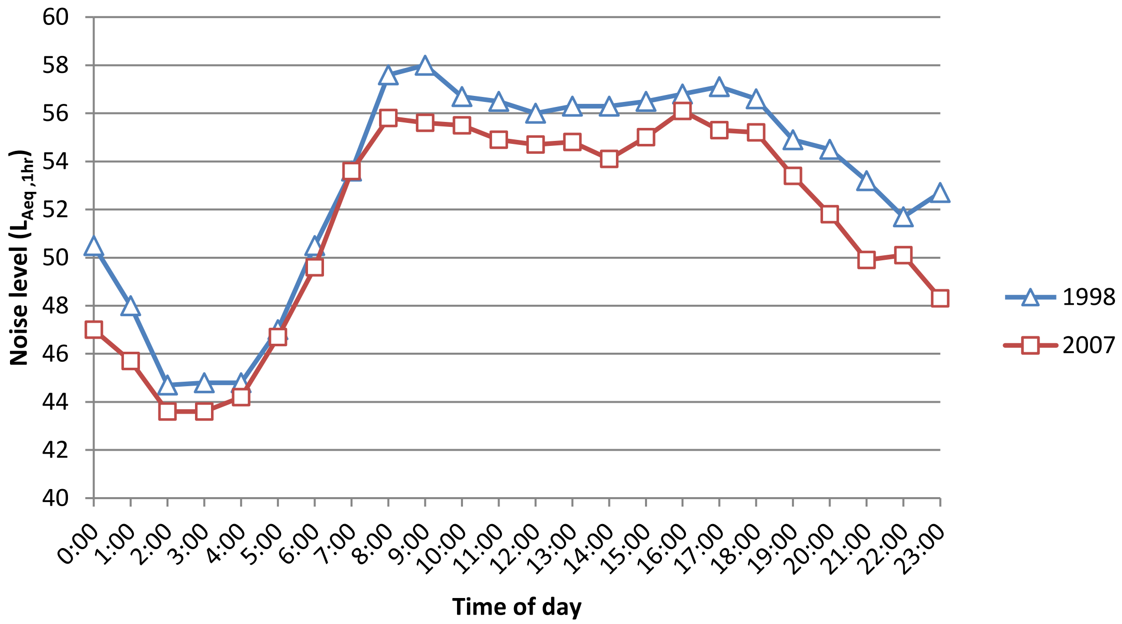

Figure 2-2: Average noise levels for each hour on weekdays for 1978 and 2007 in Melbourne (Adapted from EPA Victoria, 2007)

Following EPA Victoria's noise measurements in 2007, WSP Acoustics did environmental noise modelling for the authority on the greater Melbourne area in 2013. It provided estimates of the population exposed to a range of noise levels. Using Sound PLAN, it constructed a three dimensional representation of the environment of greater Melbourne. This provided noise maps to visualise noise exposure. These maps can inform EPA Victoria's input into activities such as land use planning, transport planning and design standards that change the community's exposure to noise. Modelling for each scenario considered ground contours, road and traffic data, locations of sensitive receptors, noise barriers and other inputs affecting the road traffic noise environment (WSP, 2014).

Mitigation of road traffic noise

Noise mitigation of road traffic tends to focus on controlling noise at the source, between the source and the receiver (noise pathway), and at the receiver location. Effective noise management may use a combination of mitigation techniques to reduce noise. Effectiveness is the degree of reduction achieved and perceptions of change in the noise environment. It also includes practical considerations such as feasibility of construction and if these measures are reasonable.

Noise mitigation techniques include vehicle noise control (Department of Infrastructure and Regional Development, Australian Design Rules) and controlling traffic (reducing volumes, controlling speed or decreasing flow).

Construction techniques include road alignments (vertical and horizontal), low noise road surfaces and noise barriers (NSW Environment Protection Authority Road Noise Policy, 2011).

Urban planning controls and acoustic insulation for new buildings next to busy roads are also used to reduce noise (Australian Building Codes Board and some state planning departments).

The results of these different options vary.

Controlling vehicle noise and traffic can reduce noise by 1 to 5 dB(A).

Noise barriers can cut up to a 10 dB(A) although effectiveness depends on barrier height, length, material density and distance from noise source. However, barriers can only be fitted along no-access roadways and many urban roadways have road frontages from properties. Extra height in barriers can reduce noise further, although these are restricted by structural elements and aesthetics. Retrofitting noise walls to existing roads is expensive (Austroads, 2005).

2.1.2 Aircraft noise

Aircraft operations generate substantial noise, exposure to which is concentrated around airports. Take-off produces intense noise, including vibration and rattle, while landings generate noise in long low-altitude flight corridors. For the most part, larger and heavier aircraft are responsible for more noise than lighter aircraft (Berglund et al., 1999).

In older, turbojet-powered aircraft, the main mechanism of noise generation was turbulence created by the jet exhaust mixing with surrounding air. In more modern aircraft this noise source is significantly reduced by using high by-pass ratio turbo-fan engines that surround the high velocity jet exhaust with lower velocity airflow generated by the fan. Noise can also be generated by the fan itself, particularly during landing and taxiing. Multi-bladed turbo prop engines can produce relatively high levels of tonal noise (Berglund et al., 1999).

The overall sound pressure levels from airports can be determined from the number and types of aircraft, their flight paths, the proportions of take-offs and landings, and the atmospheric conditions. Airports hosting helicopters or smaller aircraft used for private business, flight training and leisure purposes may also contribute to significant noise associated with flight paths.

Over the past three decades, Australia has seen a substantial increase in aircraft numbers and movements. Kingsford Smith airport in Sydney has experienced the greatest growth in flight movements (BITRE, 2014). This increase, seen in Figure 2-3, has resulted in continued exposure to aircraft noise, particularly on communities close to airports and underneath flight paths. This is despite reduced noise emissions from newer types of aircraft.

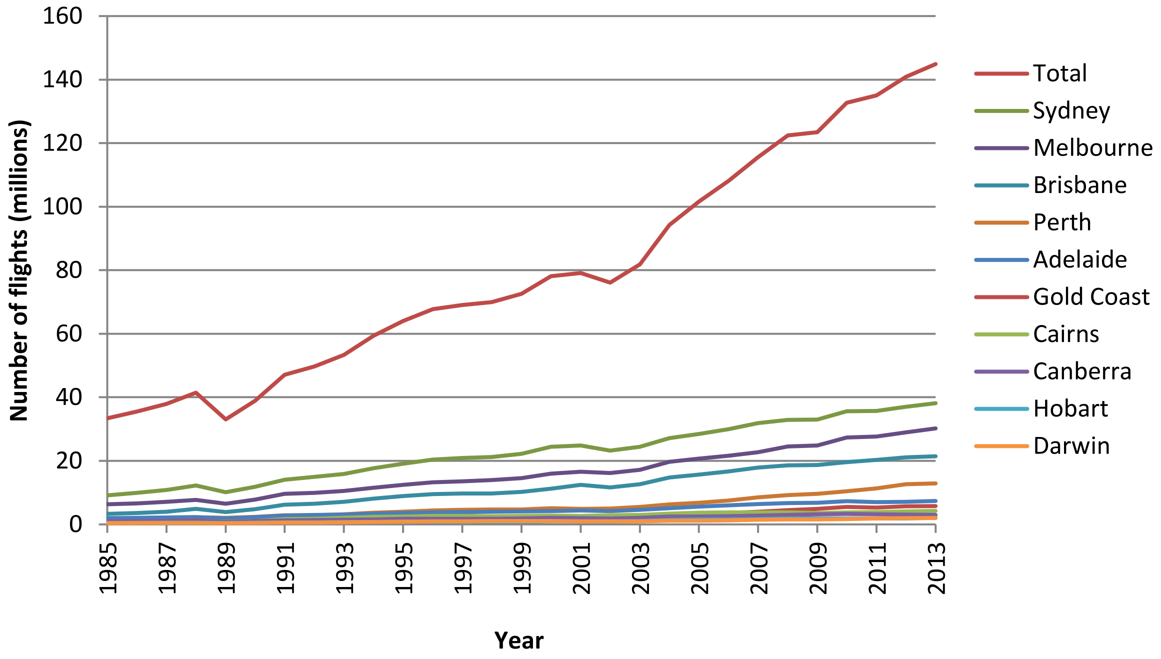

Figure 2-3: Aircraft movements at Australian airports 1985-2013 (Data sourced from Bureau of Infrastructure, Transport and Regional Economics (BITRE) 2014a)

Australian Noise Exposure Forecast

Information about aircraft noise in Australia is provided through the Australian Noise Exposure Forecast (ANEF). This forecast system is based on findings from a major socio-acoustic survey done near several Australian airports (Hede et al., 1982).

The study shows that a weighting period from 7pm to 7am gives the best correlation between noise dose and community reaction. The contours relate to the total noise energy received by locations on the ground near an airport on an annual average day. They show predicted future aircraft noise levels.

While ANEF is an effective land use planning tool, it does not convey information about the actual aircraft noise levels experienced at a given location. This means other noise descriptors are often used as supplements to ANEF contours.

ANEF is the officially endorsed chart for an aerodrome.

N contours

N contours are designed to supplement ANEF and better describe aircraft noise levels to the public. They were developed by the Commonwealth Department of Infrastructure and Transport in consultation with industry and the community. N contours measure the number of noise events per day exceeding 60, 65 or 70 dB (see Table 2-1) and show the expected noise levels in a particular area (Department of Transport and Regional Services, 2000).

Table 2-1: Description of N contours

N contour	Definition
N60	Number of events exceeding 60 decibels per day
N65	Number of events exceeding 65 decibels per day
N70	Number of events exceeding 70 decibels per day
Night contours	For example: 6 or more events exceeding 60 decibels per day

Australian Noise Exposure Index

The Australian Noise Exposure Index (ANEI) is similar to ANEF but based on historical data, where flight paths and aircraft movements are known rather than forecast. It uses an integrated noise model comprising data for the flight path, aircraft type, runway used and time of day (weighted for 7pm to 7am).

ANEI contours are plotted on a map using geographic information systems (GIS) software. The contours are consistent with flight tracks and aircraft operations for the period.

Figure 2-4 shows ANEI contours for Sydney airport. The population beneath the ANEI contours is estimated using the latest census data and suburb boundary information.

The Australian Noise Exposure Concept (ANEC) is an illustration of aircraft noise exposure at a site, using data that may bear no relationship to actual or future situations.

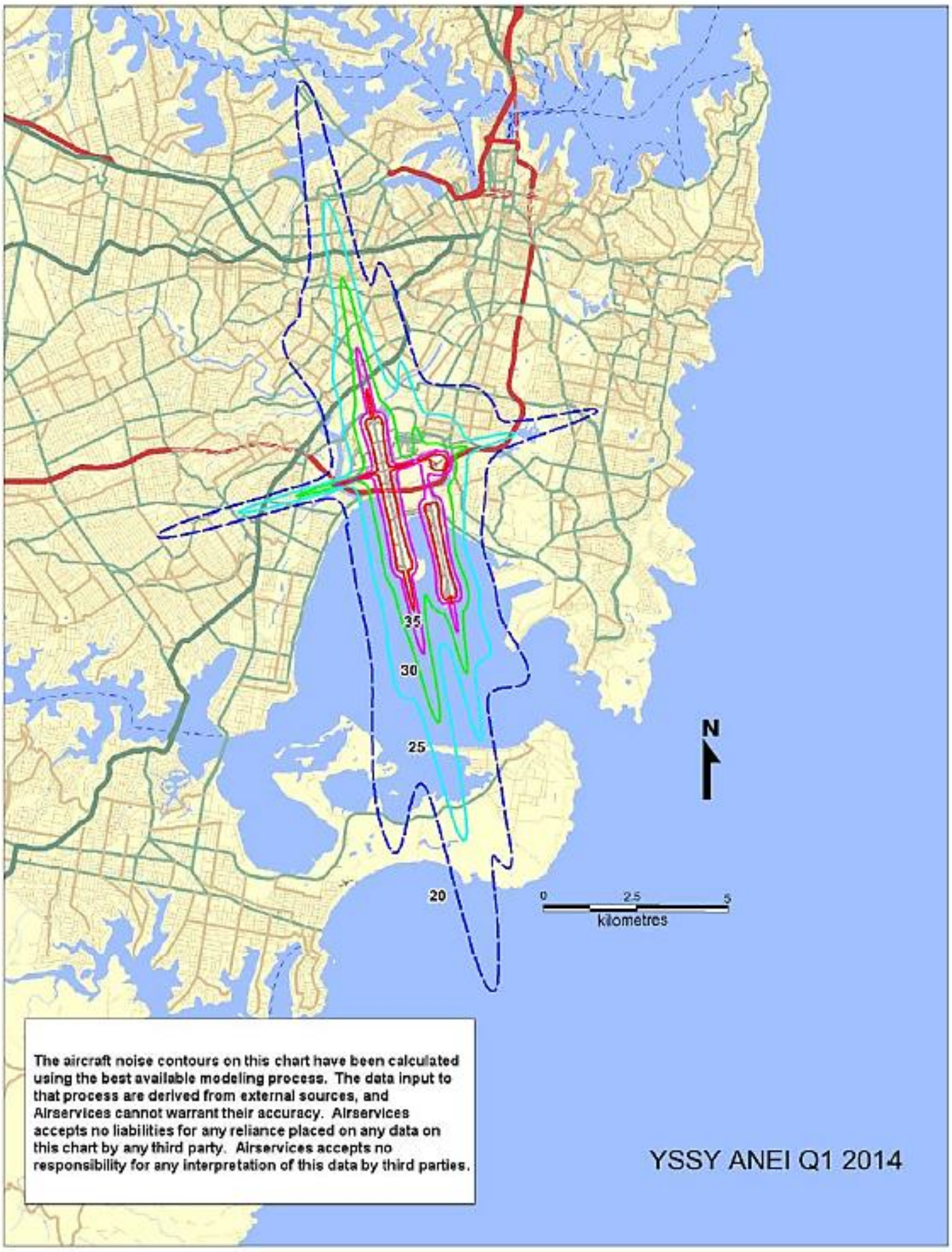

Figure 2-4: ANEI contours for Sydney Airport, January to March 2014 (Airservices Australia 2015)

Aircraft noise monitoring

Noise monitoring is done at major airports including Adelaide, Brisbane, Cairns, Canberra, Gold Coast, Melbourne, Perth and Sydney. Information includes the identity, flight path and altitude of each aircraft operating to and from the airport, and the noise levels produced by individual aircraft. The information is collected for each 24-hour period per week by fixed noise monitors or environmental monitoring units along the flight path.

This data can be used in several ways to show average noise during a period, background noise levels or the number of noise events over a certain threshold.

Airservices Australia provides online summaries of noise monitoring data from major airports that are updated quarterly (Airservices Australia, 2018a). It also displays historical and near real-time noise data from each monitoring unit in WebTrak (Airservices Australia, 2018b).

Mitigation of aircraft noise

Aircraft operating in Australia are required to adhere to noise standards set out by the International Civil Aviation Organisation in *Annex 16 — Environmental Protection*, *Volume I — Aircraft Noise* to the Convention on International Civil Aviation (ICAO, 2008).

Some airlines seek to reduce noise by buying quieter aircraft or organising their fleet so quieter aircraft fly at sensitive times. Airlines can also take a continuous descent approach, using technology to glide into the airport in one smooth descent.

Airports and airlines work together to minimise noise exposure during night hours. This includes procedures such as preferred runways and flight paths and reducing engine thrust when safe to do so (Airservices Australia and Australian Airports Association).

Curfews attempt to balance airport commercial operations and safety requirements with the need to reduce night-time aircraft noise. They do not stop all aircraft movements, but they limit take-offs and landings by restricting the type of aircraft that can operate, the runways they can use and the number of flights. Curfews usually operate from 11pm to 6am, with most commercial aircraft prohibited from flying during that time. The exceptions to this are shoulder movements, which occur from 5am to 6am and 11pm to midnight. These are permitted on a quota basis to account for differences during the northern hemisphere’s summer, which affects flying schedules (Airservices Australia and Australian Airports Association). Curfews are in place at Sydney, Adelaide, Coolangatta and Essendon airports (Department of Infrastructure and Regional Development, 2016).

2.1.3 Rail noise

Rail noise depends on many factors, including the speed at which the train is travelling. Noise characteristics vary depending on the type of engine, wagons, the rails and their foundations, as well as the roughness of the wheels and the rail. Small radius curves in the track can lead to very high frequency sound, often called ‘wheel squeal’. Noise is also generated by running engines, whistles and loudspeakers, and shunting operations in marshalling yards.

High-speed trains have been associated with sudden, but not impulsive, rises in noise. At speeds greater than 250 km/hour, the proportion of high frequency sound energy increases with the sound similar to an overflying jet aircraft (Berglund et al., 1999).

The Cooperative Research Centre (CRC) for Rail Innovation (CRC for Rail Innovation, 2011) classifies rail noise as:

1. Rolling noise: the vertical excitation of the rail and wheel generated by variations or roughness of the wheel or the rail surfaces
2. Impact noise: the result of discontinuities in the running surfaces of the rail and wheel
3. Traction noise: generated by power units of any kind including diesel or electrical power sources. It covers possible mechanisms associated with the function of converting the supply energy to mechanical work
4. Friction braking noise: generated by the interaction between the friction material and the rotating element. In some cases this is seen as a subset of traction noise
5. Curving noise: caused by friction induced self-excitation of the wheel and rail in the lateral direction on low radius curves, including flanging noise and curve squeal noise

6. Aerodynamic noise: caused by disturbance of air flow over the train, becoming significant at high speeds (greater than 200km/hour)
7. Other noise sources: including wagon ‘bunching’, coupler noise, warning signals, communication systems noise, stabling and yard noise, maintenance noise, and internal noise such as air conditioning and gangway noise.

Growth in rail sector

The use of rail freight (rolling stock or fleet) is expected to grow 1.9 times the 2010 level by 2030 (BITRE, 2014b) .

Rail is competitive for long distance non-bulk freight, such as from Sydney to Perth. This expanded use of rail for freight may increase noise in metropolitan areas and in rural areas that have not been previously affected.

Figure 2-5 shows the increase in sending freight by road and rail to 2013, with rail freight set to increase significantly (BITRE, 2014c).

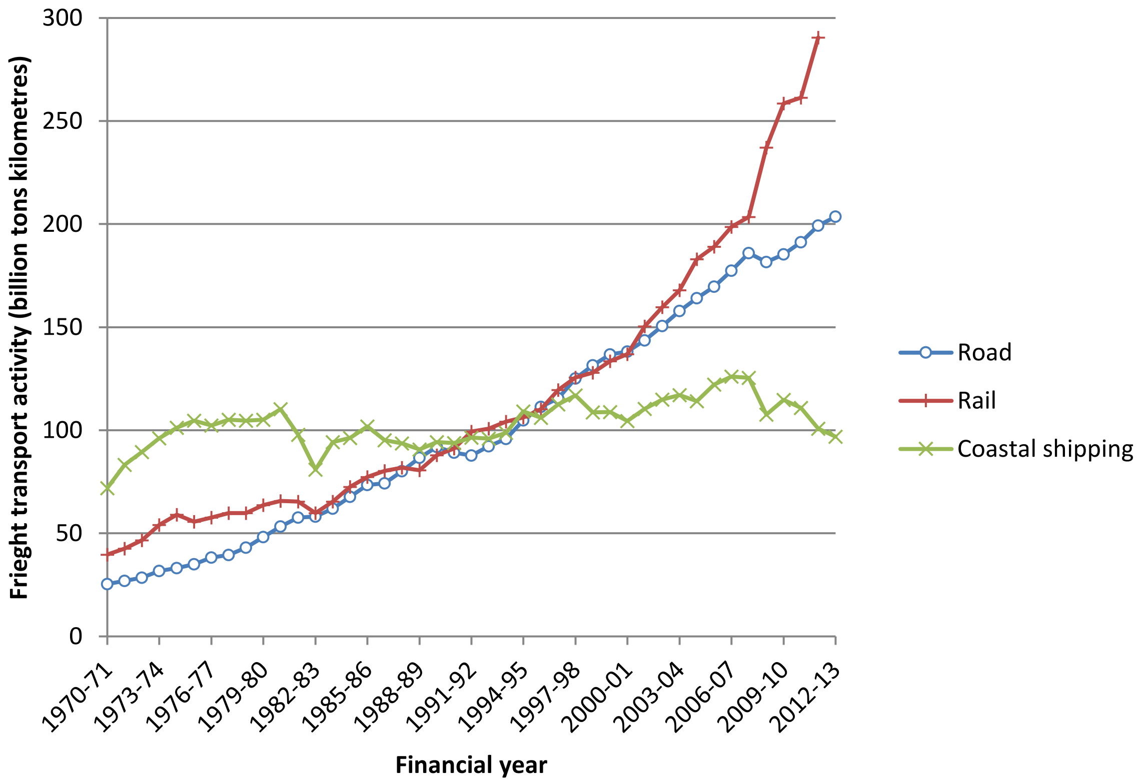

Figure 2-5: Domestic freight transport activity by mode (Adapted from BITRE 2014c)

Growth of passenger rail

Rail passenger transport is not expected to increase as much as freight, due to the dominance of private cars. Very high speed trains have been proposed to connect Brisbane, Sydney and Melbourne, with the first link between Sydney and Canberra operational by 2035 (Department of Infrastructure and Regional Development, 2013). If high-speed rail is a genuine possibility in Australia, its health impact should be considered now.

Proportion of the population exposed to rail noise

Estimates from Europe indicate the noise contribution from railways is around 10 per cent of the total noise burden from both roads and railways (EPA, 2014). There are no estimates for Australia, but an example of rail noise exposure is shown below.

In 2002 the former NSW Rail Infrastructure Corporation undertook modelling work on five priority lines in the Sydney metropolitan rail network. The percentage of receivers (people) exposed to different noise levels are shown for two of these train lines in Figure 2-6. With increasing urban density and the development of new passenger and freight lines, the number of people exposed will have steadily increased.

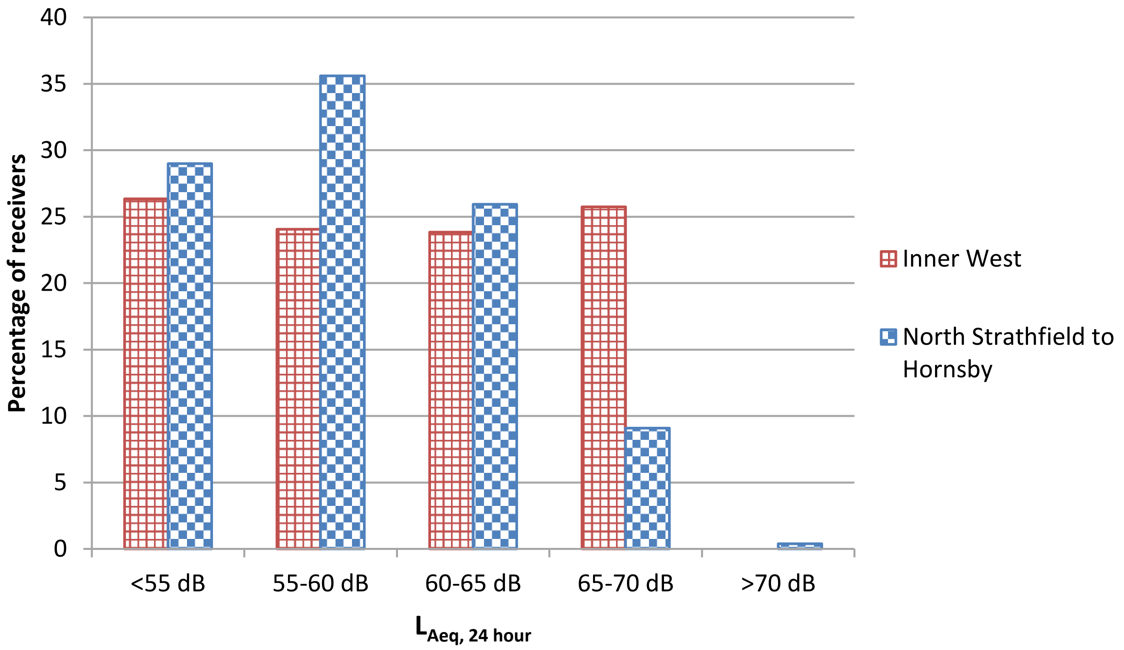

Figure 2-6: Percentage of receivers exposed to various noise categories along two major railway lines in Sydney

Mitigation of rail noise

Several European studies confirm that measures to reduce noise at the source are more cost effective than constructing noise barriers. Mitigation strategies tend to follow those outlined for road traffic noise. This may be problematic for rail upgrades, as source control measures usually provide only a small decrease in noise levels and may take significant time to be installed.

Examples of types of mitigation include: minimisation of wheel and rail roughness (for example regular wheel and rail grinding); reduction of wheel and rail acoustical radiation; track lubrication to reduce squeal on curves; and lessening of sound propagation using rail screens, barriers and vehicle skirts.

Appropriate combinations of measures applied to wheel and track design can reduce noise by more than 10 dB(A) L_{Aeq}. However, this requires a coordinated approach between rolling stock operators and infrastructure owners. This can prove challenging in many contexts, particularly where responsibility for vehicles and track are segregated (CRC for Rail Innovation, 2011).

2.1.4 Industrial noise and other fixed noise sources

Noise from mechanised industry creates problems both for indoor and outdoor settings. The noise is generally due to machinery and often increases with the power of the machines. The noise generated by machinery may contain mainly low or high frequencies, tonal components, be impulsive or have unpleasant and disruptive temporal sound patterns. Rotating and reciprocating machines produce sound that includes tonal components.

Air-moving equipment tends to create noise with a wide frequency range. Components or gas flows that move at high speed result in high sound pressure levels (Berglund et al., 1999). Examples include fans and steam pressure relief valves, as well as operations involving mechanical impacts, such as stamping, riveting and road breaking.

Fixed sources of industrial and other noise include: extractive industries – oil, gas and mining, manufacturing, construction, agriculture, military and power generation.

The National Health and Medical Research Council (NHMRC) has investigated the evidence on wind farms and human health and concluded there is no consistent evidence that wind farms cause adverse health effects in humans. Given the poor quality of current direct evidence and the concern expressed by some community members, high quality research into possible health effects of wind farms, particularly within 1500 metres, is warranted (NHMRC, 2015).

2.2 Social surveys of noise annoyance

South Australia noise perception and quality of life survey (2014)

In South Australia, a representative state-based survey interviewed 3015 people using a standardised noise annoyance survey tool (Nitschke et al., 2014). Noise from road transport was reported as a source of annoyance (little to extreme) by the highest proportion of respondents (27.7 per cent), followed by noise from neighbours (22 per cent), construction noise (10.0 per cent), air conditioner noise (5.8 per cent), rail transport noise (4.7 per cent) and industrial noise (3.9 per cent).

The survey indicated that 25.1 per cent of people surveyed lived less than 50 metres from a major road in South Australia. When the results were extrapolated to the state population, 6.9 per cent of people were estimated as being highly annoyed by noise from at least one source.

Perth community noise survey (2011)

The West Australian Department of Environment and Conservation (DEC) undertook a survey in 2011 to evaluate community attitudes to and experience of local noise. A stratified random sample of 410 respondents from the greater Perth area was surveyed. Of the respondents, 30.2 per cent considered noise a problem in their area, with 12.7 per cent considering noise a significant problem, and 5.6 per cent considering it to be a major problem (DEC, 2011).

Victoria noise survey (2007)

A social survey of 1213 respondents by Environment Protection Authority Victoria was done in 2006 to understand the impact of noise on the community. It found that almost half of all Victorians (49 per cent) had been disturbed or annoyed by environmental noise at some stage in the preceding 12 months (EPA Victoria, 2007).

2.3 Relevance of urban and built form, climate and behaviour to noise exposure

The urban population of Australia accounts for about 70 per cent of the total population (ABS, 2014). Concerns about the growth of larger cities have placed more focus on urban design and planning in the past five years, with most state governments producing strategic plans for their capital cities. These include policies to minimise outer suburban sprawl and encourage higher density residential development around major activity centres and routes served by public transport. Policies to abate the problem of increases in external noise have also been put forward by public and private sector agencies.

The main responses to reduce noise are through building design, public engineering works and land use planning. Examples of good architectural design of buildings to reduce noise include orientation of buildings and habitable rooms away from the noise source. Examples of public engineering works include barriers and landscaping close to roads and railways as well as quieter roads and railways. Examples of land use planning approaches include separating noisy transport routes from noise sensitive areas, managing traffic and reducing speed, and restricting the slope of roads and curves in railway tracks to decrease noise.

In NSW the State Environment Planning Policy (Infrastructure) 2007 sets out specific planning provisions and controls for developments in rail corridors and near busy roads.

Legislated planning mechanisms are important at the earliest stage of the development, such as at the zoning, subdivision or initial development design stages. This helps manage the potential for land use conflict around noise before construction starts.

For residential dwellings near noise sources, the effectiveness of exposed façades in attenuating noise is another important factor. The simplest types of facades reduce sound by about 15 dB(A) from outside to inside when the windows are closed. Double brick walls generally provide adequate noise reduction. Weatherboard walls can be upgraded with in-cavity insulation, although the effectiveness is relatively small. Insulation of roofs is also important, particularly in areas where aircraft noise is an issue.

Due to their lightweight construction, windows are generally the weakest point in the sound propagation path. Single and double window glazing can reduce noise by up to 30 and 35 dB(A) when closed. However, when windows are slightly open, outside sound levels are reduced only by 10 to 15 dB(A). This is particularly important as many Australians prefer their windows slightly open at night for ventilation. In Western Australia state planning policies recommend fans or air conditioning in conjunction with upgraded glazing to ensure adequate ventilation when windows are closed to exclude noise.

2.4 Regulatory approaches and mechanisms to limit exposure

2.4.1 Road traffic noise

The Australian Design Rules for motor vehicles are national standards for safety, anti-theft and emissions. They are generally performance based and cover issues such as occupant protection, structures, lighting, noise, engine exhaust emissions, braking and other items. Under the *Motor Vehicle Standards Act 1989*, four rules apply to noise from vehicles. These define the limits on external noise generated from cars, trucks, buses, motor cycles and mopeds (Department of Infrastructure and Regional Development, Australian Design Rules). Similarly, state-based road rules prohibit driving in a way that makes unnecessary noise. An example includes Victorian Road Safety Rule 291 that states: "a person must not start a vehicle, or drive a vehicle, in a way that makes unnecessary noise or smoke".

Noise from engine brakes is the greatest source of community complaint against the heavy vehicle industry. In November 2007, Australian transport ministers unanimously approved a regulatory proposal and model law for an in-service engine brake noise standard and testing procedure for heavy vehicles. The standard would provide an objective enforcement approach that defines a limit on the noise emitted from an engine brake. However, this has not yet been implemented across the states and territories due to technical and operational issues (National Transport Commission, 2013). State-based vehicle standards put limits on noise from in-service noise but these are often less stringent than Australian Design Rules.

Traffic restrictions and traffic calming measures have generally reduced traffic noise due to changes in: traffic volume and composition, road layout and surface, vehicle speed and driving style. The use of traffic calming and restrictions may need more attention to address urban noise in residential areas. Transportation and town planners may need to explore freight traffic patterns, particularly in areas with increasing urban density, and consider approaches such as special routing, freight traffic centres and ways to encourage more environmentally friendly freight traffic.

Efforts to reduce noise exposures through home insulation and construction of noise barriers in communities exposed to road traffic noise have also been made. Australian Standard 3671:1989, Acoustics – Road traffic noise intrusion – Building siting and construction, provides guidance on acoustic requirements for residential dwellings near roads. There are also statutory approval processes for new and redeveloped roads.

Examples of policies used in these approval processes in NSW include the Road Noise Policy (NSW EPA, 2011), which assigns acoustic design requirements. The NSW State Environment Planning Policy (Infrastructure) requires homes built alongside busy road and rail corridors to incorporate measures to achieve required internal noise levels. NSW Roads and Maritime Services has a specialised noise abatement program to address road traffic noise through a range of approaches.

2.4.2 Aircraft noise

Air Navigation (Aircraft Noise) Regulations (1984) require all aircraft operating in Australian airspace to comply with noise standards and recommended practices under the Chicago Convention (Convention on International Civil Aviation). These are set out in the International Civil Aviation Organisation (ICAO) document Annex 16, Environmental Protection – Volume I (ICAO, 2008). Aircraft found to be compliant are issued with a noise certificate. Aircraft without a noise certificate are not permitted to operate in Australia.

Flight activities and aircraft curfews are the responsibility of Airservices Australia, individual airport authorities and the Commonwealth government. The *Airports Act (1996)* was passed to cover environmental protection regulations. It governs noise and other environmental issues, but only 21 airports are covered by this act.

The Australia Standard AS 2021:2015 Acoustics – Aircraft noise intrusion – Building siting and construction (Standards Australia, 2015) provides guidance on the siting and construction of buildings near airports to minimise aircraft noise. The assessment of potential aircraft noise exposure at a given site is based on the Australian Noise Exposure Forecast (ANEF) system. The standard also provides guidelines for the type of building construction necessary to reduce noise to a given level. It is widely referred to in guiding strategic land use planning near airports. The AS 2021:2015 specifies that it is acceptable to build noise-sensitive developments in areas where ANEF is less than 20. Noise-sensitive developments are conditionally acceptable between ANEF 20 and 25 provided required internal sound levels are achieved through building design. However, some airport noise complaints come from areas beyond ANEF 20 contours.

Noise insulation programs were established around Sydney Airport in 1995 and Adelaide Airport in 2000. Residential properties with greater than ANEF 30 contour exposure and public buildings (schools, churches, day care centres and hospitals) with greater than ANEF 25 contour exposure were eligible for assistance in obtaining insulation. The programs aimed to achieve a 35 dB(A) lowering of noise levels for bedrooms, and 30 dB(A) for living rooms (Department of Infrastructure and Regional Development, 2014). Sydney airport also has a long-term operating plan to manage aircraft noise by directing flights over water and non-residential land and by spreading the noise across different communities (Airservices Australia, 2015a,b).

2.4.3 Rail noise

There has been a great deal of discussion at the national government level about rail infrastructure and ways to improve rail operations. Funds for improving track and rolling stock might be invested in equipment with reduced noise generation. Limited information is available on national efforts to reduce rail traffic noise in concert with rail improvements. However, a national initiative to develop rolling stock standards is being led by the Rail Industry Safety and Standards Board.

Individual states have developed rail noise initiatives, including standards, guidelines and noise abatement programs. These programs include methods for assessing and prioritising requests for mitigation from people particularly affected. Environmental planning guidelines for residential developments near rail corridors set acceptable internal noise levels and provide advice to developers on how to achieve them.

2.4.4 Industrial noise and other fixed noise sources

Control of industry noise affecting communities is the responsibility of planning and environment authorities in the states and territories. Local ordinances or operation restrictions may be needed if construction activities take place in an area with sensitive uses, such as schools or hospital zones, or outside standard construction hours. Reductions in industrial noise can be achieved by encouraging quieter equipment or by zoning controls to separate acoustically incompatible land uses, such as the contrast between residential and industrial zones. Noise emissions, like other environmental emissions, may also be licensed or regulated under relevant environmental legislation.

2.4.5 Other noise sources

Domestic equipment may have times-of-use restrictions, such as grass cutting machines, leaf blowers, chainsaws, domestic air conditioners, mobile air compressors, pavement breakers, and mobile garbage compacters. This includes the use of power tools on residential properties either under state and territory legislation or local government regulation. The former Standing Council on Environment and Water discussed a national policy on noise labelling for portable equipment but this has yet to come to fruition. Noise labelling is required in some states, for example NSW, under the revised *Protection of the Environment (Noise Control) Regulation* 2008.

Other noise sources of concern include that from fireworks and explosives during celebrations, and from children's toys. Australian Standard AS/NZS 8124.1:2002, Safety of toys, includes noise regulations.

2.4.6 Building requirements to protect against noise

The internal acoustic requirements for dwellings are determined by the National Construction Code (NCC, 2016) as well as local councils. The Australian Building Codes Board administers and maintains the code to encourage national consistency based on minimum safety and health requirements. The code is given legal effect by relevant legislation in each state and territory.

Australian Standard 2107:2016, Acoustics—Recommended design sound levels and reverberation times for building interiors, is the standard most commonly referred to in building acoustics. The standard, while not mandatory, sets out recommendations for design sound levels for building interiors. The Australian Association of Acoustical Consultants has also produced a *Guideline for Apartment and Townhouse Acoustic Rating* (AAAC, 2010), a performance-based guideline for insulation. The guideline contains a star rating corresponding to the intrusion of external noise into bedrooms and habitable rooms as shown in Table 2-2. This has been adopted by many in the industry.

Table 2-2: Guideline for acoustic rating of apartments (Adapted from Australian Association of Acoustical Consultants, 2010)

Apartment rooms	External noise intrusion	2 star	3 star	4 star	5 star	6 star
Bedrooms	Continuous noises	36 dB(A)	35 dB(A)	32 dB(A)	30 dB(A)	27 dB(A)
	Intermittent noises	50 dB(A)	50 dB(A)	45 dB(A)	40 dB(A)	35 dB(A)
Other habitable rooms including open kitchens	Continuous noises	41 dB(A)	40 dB(A)	37 dB(A)	35 dB(A)	32 dB(A)
	Intermittent noises	55 dB(A)	55 dB(A)	50 dB(A)	45 dB(A)	40 dB(A)

2.5 Best practice noise exposure information – noise mapping

Broadly defined, noise mapping is a means of presenting calculated and/or measured noise levels in a representative manner over a particular geographic area. The European experience may provide a basis for an Australian approach. The European Union Environmental Noise Directive (END) (2002) applies to noise to which humans are exposed. It focuses on built-up areas, public parks or other quiet areas in an agglomeration, quiet areas in open country, near schools, hospitals and other noise-sensitive buildings and areas (Article 2.1). The END is one of the main instruments to identify noise pollution levels and to trigger the necessary action at member state and European Union level.

In the context of the END, the European Commission has common noise assessment methods (CNOSSOS–EU) for road, railway, aircraft and industrial noise to improve the reliability and comparability of results across the European Union. This framework allows for coherent and reliable strategic noise mapping and action planning. Assessment of noise exposure is done using strategic noise maps with harmonised noise indicators L_{den} and L_{night} for major roads, railways, airports and agglomerations.

In the first phase (June 2007) strategic noise maps were compiled for EU member states. These covered agglomerations with more than 250,000 inhabitants, major roads with more than 6 million vehicle passages a year, railways with more 60,000 train passages a year and major airports with more than 50,000 movements a year.

The second phase (June 2012) produced strategic noise maps for agglomerations with a population of more than 100,000.

The END also determines levels of exposure to environmental noise using the above indicators. Estimates of the number of people living in dwellings exposed to values of L_{den} and L_{night} at the most exposed building façade are done separately for road, rail, air traffic and industrial noise. Where possible and available, information about people living in dwellings with special insulation against noise or with quiet façades is also reported.

Noise maps are only as accurate as the input data and techniques used to calculate sound levels. They may not always accurately depict sound level variations that occur locally. They can also be expensive to produce.

Despite these limitations, noise maps have significant uses for public health in providing estimates of exposure that can help quantify the burden of environmental noise. The European experience provides a useful insight into how similar work might be done in Australia.

3 NOISE AND SLEEP DISTURBANCE

3.1 Introduction and background

Sleep serves an important restorative purpose in promoting functioning and a sense of wellbeing. Obtaining sufficient duration and quality of sleep is important for overall health and wellbeing. Sleep problems are common in many countries, including Australia (Deloitte Access Economics, 2011).

Poor sleep has been linked to numerous adverse consequences, including health conditions such as cardiovascular disease, depression and obesity (Riemann et al., 2011), as well as accidents and disability due to fatigue (Horne and Reyner, 1999), and lost workplace productivity (Iverson et al., 2010; Rosekind et al., 2010). These translate into considerable social and economic costs, with three sleep disorders alone – obstructive sleep apnoea, primary insomnia and restless leg syndrome – estimated to cost the Australian economy $36 billion a year (Deloitte Access Economics, 2011). The economic costs of sleep problems more broadly (such as daytime sleepiness or short sleep) are estimated to be considerably higher (Deloitte Access Economics, 2011).

Many genetic, lifestyle, health and environmental factors have the potential to influence the quality and amount of sleep. Poor sleep can reflect lifestyle factors such as screen time, physical activity, alcohol consumption and caffeine consumption. Psychological characteristics such as stress, sensitivity and personality characteristics have also been linked to sleep quality.

Environmental noise has long been identified as a potential cause of poor sleep. Reviews conducted to help inform guidelines show a strong basis for believing that environmental noise during the night is a contributor to poor sleep (WHO, 2009). Many recent studies have suggested that exposure to road, rail and aircraft noise is linked to a range of sleep disturbances, including increased arousals (Tassi et al., 2010), insomnia symptoms (Halonen et al., 2012), and poorer self-reported sleep quality (Kim et al., 2014).

3.2 Systematic review of the literature: environmental noise and sleep disturbance

A systematic review of the literature was done for studies from January 1994 to March 2014 on the relationship between environmental noise and sleep. Appendix A details the review's objectives and methodology.

3.2.1 Search results

The results of the search process are summarised in the following PRISMA flow chart.

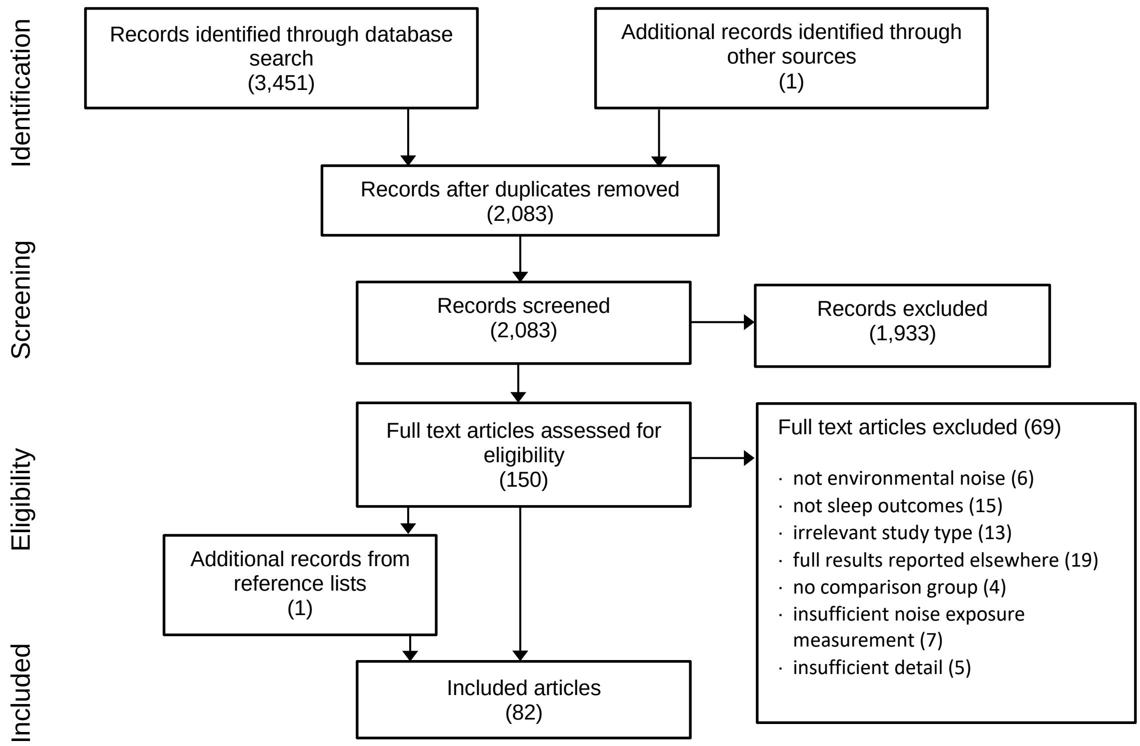

Figure 3-1: PRISMA flow chart – number of articles identified and reviewed during the systematic review (Moher et al. 2009)

3.2.2 Overview of included studies

Although outside the scope of this review, it is obvious that loud noises disrupt sleep. Loud noises are used throughout the world to disturb sleep as a method of studying its underlying functions.

Of the 82 articles identified, 79 were from distinct studies as some articles reported on the same data. Of these 79 studies, 43 were observational and 36 experimental. Most were observational studies (31 were cross-sectional studies (NHMRC level IV) and there was one prospective cohort study (NHMRC level II). There were eight field studies, where individuals had their sleep patterns and noise exposure monitored in their homes for several days. These were categorised as NHMRC level III-2 studies. Three studies included both a cross-sectional and field study component.

According to the NHMRC hierarchy of evidence (Table A-7), the experimental studies were either non-randomised experimental studies (31 studies, NHMRC level III-2) or pseudo-randomised studies (5 studies, NHMRC level III-1). Although many were non-randomised in design, several used counterbalancing to allocate participants to conditions and were thus rated as having a lower risk of bias (Table A-5). Most of these studies were done in temperature and sound-controlled sleep laboratory settings (32 studies). Some were done in the participant's home (7 studies) for some or all of the experimental period. Simulated noise was delivered via loudspeaker or personal music player with earphones.

3.2.3 Noise exposure and how it was measured

Observational studies explored: road traffic noise (29 studies), aircraft noise (8), railway noise (7), road work noise (1) and blast noise from a military base (1). Experimental studies simulated noise from: road traffic (21 studies), aircraft (9), railways (16) and road work (1).

For observational studies, noise exposure was measured by direct measurement with sound level meters in various locations (28 studies) or estimated using models or noise contour maps (17). In experimental studies, noise was delivered in such a way as to control the noise levels participants were exposed to.

The most common noise indicators used in the included studies were A-weighted equivalent sound levels (L_{Aeq}) for various periods. Maximum sound pressure levels (L_{Amax}) were also commonly used.

3.2.4 Types of outcomes reported

The included studies assessed a wide range of sleep outcomes. The most common were self-reported sleep disturbance outcomes (36 observational and 28 experimental studies). These included subjective assessments of problems falling and staying asleep, sleep duration, sleep quality/ disturbance ratings and feelings of tiredness/feeling well rested the next day.

Objective measures of sleep disturbance include activity trackers which can be referred to as actigraphy, actimetry or accelerometer (7 observational and 5 experimental studies) and polysomnography (4 observational and 22 experimental studies). These measure sleep parameters including arousals, gross bodily movement (motility) and sleep structure.

Other outcomes reported in these studies were the use of sleep medications (two observational studies) and prevalence or incidence of insomnia using International Statistical Classification of Diseases definitions (one observational study). One experimental study used an infrared pupillographic sleepiness test.

3.2.5 Quality ratings

Quality ratings according to GRADE criteria are shown in Table 3-1 to Table 3-3. These indicate that on aggregate, the quality of the evidence was rated as low.

All included studies are listed in section 8.3.

Table 3-1: GRADE evidence profile for environmental noise and sleep - Self-reported sleep disturbance (problems falling and staying asleep, sleep duration, quality/disturbance ratings, feelings of tiredness/or being well rested, and symptoms of insomnia)

No of studies (design)	Reasons for rating quality down	Reasons for rating quality up	Summary of key findings	Quality score
Thirty-two (cross-sectional)	Serious risk of bias	None	Exposure to road, rail and aircraft noise was associated with increased risk of sleep disturbance.	⊕⊕○○ Low
One (prospective cohort)	Serious risk of bias One small study	None	Self-reported sleep quality affected by road traffic noise, and significantly improved through noise abatement. Number of awakenings not affected by noise or noise abatement.	⊕⊕○○ Low

No of studies (design)	Reasons for rating quality down	Reasons for rating quality up	Summary of key findings	Quality score
Six (field studies)	Serious risk of bias Some inconsistency	None	Significant decreases in sleep quality and increased awakenings in participants exposed to high levels of night-time road traffic noise. Little to no effect of aircraft and rail.	⊕⊕○○ Low
Ten (experimental)	Some risk of bias Some inconsistency	None	Disruptions to sleep and poorer sleep quality are greater with increasing noise levels. Evidence was strongest for two aircraft noise studies.	⊕⊕⊕○ Moderate

Table 3-2: GRADE evidence profile - Objective sleep disturbance (actigraphy, polysomnography, accelerometer, Infrared pupillographic sleepiness test)

No of studies (design)	Reasons for rating quality down	Reasons for rating quality up	Summary of key findings	Quality score
Eleven (field studies)	Serious risk of bias Serious inconsistency	None	Increasing sleep stage changes and motility with maximum levels of aircraft and rail noise. Mixed results for road noise.	⊕⊕○○ Low
Twenty-six (experimental)	Some risk of bias Some inconsistency	None	Noise significantly changed sleep structure with less slow wave sleep, greater latency to slow wave sleep, more arousals and sleep stage changes.	⊕⊕⊕○ Moderate

Table 3-3: GRADE evidence profile for environmental noise and sleep - Use of sleep medication (self-report)

No of studies (design)	Reasons for rating quality down	Reasons for rating quality up	Summary of key findings	Quality score
Two (cross-sectional)	None	None	Increasing aircraft and railway noise levels associated with increased risk of sleep medication use.	⊕⊕○○ Low

3.3 Summary of findings from the systematic review

3.3.1 What is the evidence of a causal effect of environmental noise on sleep disturbance?

This systematic review identified 79 studies published between 1994 and 2014 examining the relationship between environmental noise exposure and sleep disturbance. A total of 43 of these studies were observational and 36 experimental.

A particular issue in sleep studies is the problem of blinding participants or outcomes assessors to the condition being tested. This is coupled with the problem of defining what constitutes disturbed sleep.

Subjective measures may provide a better indication of when sleep has been notably disturbed but suffers from bias because of the blinding issue.

Objective measures tend to derive from highly sensitive physiological measures such as collected by polysomnography and it remains unclear what sized effect, if any, perturbations in many of these measures means for people's health, or annoyance levels.

Many of the measurements of sleep may be too sensitive for a person to even notice and may be below their level of a just-noticeable difference.

Another issue is the heavy reliance on laboratory based experiments in sleep and noise research. These can be designed with better scientific rigour but this always comes at a cost to the external validity of the study as the participants are often heavily screened and do not represent the population as a whole. The participants are also not sleeping in their own environments, which may influence their response to noise either positively or negatively.

3.3.2 Observational studies

Several studies below examined more than one noise source.

Aircraft noise

Eight studies examined the associations between aircraft noise exposure and sleep disturbances. All indicated that aircraft noise was associated with poorer sleep.

Road traffic noise

A total of 28 studies examined the associations between exposure to road traffic noise and sleep disturbances. Most of these (21 of 28) indicated that higher noise levels were linked with poorer sleep. The rest found non-significant results.

Rail noise

Seven studies examined the relationship between railway noise and sleep disturbance. Six reported a significant relationship between rail noise and sleep disturbance, with one reporting non-significant results. Most assessed both freight and passenger rail noise in the study.

Other noise sources

Three studies examined other relevant environmental noise sources such as general community noise and noise from military areas. All found that higher levels of noise were linked with poorer sleep.

Study limitations

Despite the consistency of these findings, the quality of the evidence provided by these studies was determined to be low. This low quality rating reflects issues relating to study design (such as predominantly cross-sectional studies), and high risk of bias (primarily due to measurement of sleep and control of confounders). These issues are detailed below and limit our ability to draw definitive conclusions about the effects of environmental noise on sleep.

For the study design, most of the observational studies (34 out of 43) were cross-sectional (NHMRC level of evidence: IV). Although most of these reported significant relationships between environmental noise and sleep, they are not able to provide insight into the causal effect of noise on sleep. Further, 18 of the 34 cross-sectional studies had a high risk of bias and 13 had moderate risk of bias. Only two studies were rated as having a low risk of bias (Halonen et al., 2012; Kim et al., 2014). The large number of studies with moderate or high risk of bias was primarily due to self-reported measures of sleep (27 out of 34 studies) and inadequate control of relevant confounding variables (22 out of 34 cross-sectional studies). The Lundby tunnel study (Öhrström, 2004; Öhrström and Skanberg, 2004) was the only prospective cohort study in this review. It was rated as having a high risk of bias due to self-reporting measures of sleep and lack of control for potential confounders.

The eight field studies (NMHRC level of evidence: III-2) give better insight into the causal nature of the relationship between noise exposure and sleep disturbance. This is because these studies provide an indication of the concurrent relationships between noise exposure and sleep in the usual sleep environment. The immediate effects of noise exposure on sleep outcomes can therefore be assessed in these studies. However, only two of the eight studies had a low risk of bias. Of the remaining studies, three had a moderate risk of bias and three had a high risk of bias. The main issues underlying the moderate and high risk of bias were self-reported measures of sleep and inadequate control.

Some further issues in methodology require discussion. It was difficult to draw clear conclusions from these studies due to the large variation in the sleep outcomes assessed. For example, the types of sleep outcomes assessed included sleep disturbance, sleep quality, insomnia symptoms, night-time awakenings, daytime dysfunction, and use of sleep medication, sleep stages and sleep efficiency. This was further compounded because most sleep outcomes were based on self-reporting measures only, with a large number of studies using single-item measures of sleep quality. These measures lack validity compared with objective measures and have the potential to lead to imprecise estimates on the relationship between noise and sleep. These issues suggest that caution is needed when interpreting the results of the observational evidence base.

The noise exposure indicator is relatively consistent across studies (usually L_{Aeq} or L_{Amax}). However, studies varied considerably in how the noise exposed was estimated (such as direct measurement or contour maps) and the site at which it was measured (such as at building façade or the participant's ear). This complicates the synthesis of the evidence.

Similarly, within the studies it is important to distinguish between façade noise levels, often used in Australia and France, and the free field noise levels often used in other countries. Free field noise levels account only for noise coming from a source. Façade levels account for both noise coming from a source and noise reflected back from a façade. A façade level is typically 2.5 to 3.0 dB higher than the corresponding free field.

Studies with a low risk of bias

Only two cross-sectional (Halonen et al., 2012; Kim et al., 2014) and two longitudinal studies (Basner et al., 2006; Frei et al., 2014) had a low risk of bias. The results of these are briefly outlined below.

Halonen et al. (2012) conducted a cross-sectional study of 7019 adults and found that symptoms of insomnia were significantly higher when road traffic noise measured at a residential façade exceeded L_{night} 55 dB (odds ratio (OR) = 1.32 [1.05 – 1.65]). Kim et al. (2014) examined the relationship between exposure to aircraft noise (from a military airport) and sleep quality in a sample of 1982 adults. The results indicated that noise levels (Weighted Equivalent Continuous Perceived Noise Level measured externally) between 60 and 80 dB (OR = 2.61 [1.58 – 4.32]) and > 80 (OR = 3.52 [2.03 – 6.10]) were linked with disturbed sleep.

Basner et al. (2006) conducted an experimental field study of 64 adults. They found that aircraft noise events that were above 33 dB (measured at the ear) were associated with increased awakenings. Frei et al. (2014) conducted a study of 1122 adults comparing sleep disturbance using a standardised sleep disturbance score with modelled road traffic noise. This study found that road traffic noise levels > 55 dB L_{Aeq} (measured at the residential façade) were associated with a greater prevalence of sleep disturbance.

3.3.3 Experimental studies

There were 36 experimental studies examining the relationships between environmental noise exposure and sleep outcomes. Several studies examined multiple noise sources, such as road, rail and air.

Most studies indicated that exposure to environmental noise was significantly associated with sleep disturbances.

Aircraft noise

Nine studies examined the effects of aircraft noise exposure and sleep disturbances. All indicated that aircraft noise led to poorer sleep.

Road traffic noise

Twenty one studies examined the effect on sleep of exposure to road traffic noise. Most (15 out of 21) indicated that higher noise levels were linked with poorer sleep. The rest reported non-significant results.

Rail noise

Sixteen studies examined the effects of rail noise on sleep disturbance. Most (15 out of 16) reported significant deleterious effects of noise on sleep. Most assessed both freight and passenger rail noise within the study.

Other noise sources

Only one study investigated the effects of construction noise. It found that higher noise levels were associated with poorer sleep.

Study limitations

The experimental studies have higher level of evidence ratings (NHMRC), and thus provide an important insight into the effects of noise on sleep. In general, these studies had lower risk of bias compared with the observational studies. For example, nine studies had a low risk of bias and 14 had a moderate risk of bias. About one third of the experimental studies (13 studies) had a high risk of bias.

The main factors underlying moderate and high risk of bias reflect the lack of randomisation to conditions or the lack of counterbalancing. Several studies did not blind participants and outcome assessors to the condition allocation, which could also increase the risk of bias, noting that it is difficult to blind participants to noise conditions. Although many studies used objective measures of sleep, several relied on self-reported measures. In combination with the issues raised above, the often small sample sizes (such as those less than 10) contributed to an elevated risk of bias.

The wide variety of sleep outcomes examined also makes it difficult to draw clear conclusions about the effects of noise on sleep. The lack of prospective study registration in this field makes it impossible to gauge the extent of selective reporting of outcomes. Although most experimental studies used polysomnography, the specific sleep parameters varied. These parameters included sleep duration, sleep efficiency, sleep stages, sleep-stage transitions, sleep latency, time in rapid eye movement (REM) sleep and sleep spindles.

The implications of many of these outcomes (such as sleep spindles and sleep stage transitions) are yet to be determined. This means the implications of some findings for sleep disturbance are not clear.

Although the experimental studies generally had a lower risk of bias compared with the observational studies, many of them may lack external validity. This is particularly the case for those studies that assessed sleep in laboratory settings. The results of these studies may not provide a valid indication of the effects of noise on sleep in a real world setting.

3.3.4 Studies with a low risk of bias

All of the nine studies with a low risk of bias indicated that exposure to various sources of noise was linked with disturbed sleep. For example, Schapkin et al. (2006a) examined the effects of rail noise on sleep assessed via polysomnography and self-reporting in a sample of 22 adults. The results showed that increasing rail noise (from quiet to L_{Aeq} 50 dB(A)) measured at the ear was linearly associated with poorer subjective sleep.

Schapkin et al. (2006b) examined the effects of nocturnal aircraft noise measured at the ear on self-reported sleep. The results indicated that subjective sleep quality linearly worsened with increasing aircraft noise levels (from quiet to L_{Aeq} 50 dB(A)).

Basner and Samel (2005) examined sleep in 128 subjects (16 controls) across 13 consecutive nights. Their results indicated that exposure to aircraft noise measured at the ear was significantly associated with some indicators of disturbed sleep. This included increased awakenings and alterations to sleep architecture resulting in less slow wave sleep and more stage 1 light sleep.

Subsequent analysis suggested these associations became apparent only at maximum sound pressure level (SPL) at or above 50 dB(A) (awakenings), at or above 55 dB(A) (increased stage 1 light sleep), and at or above 65 dB(A) (decreased slow wave sleep). The analysis also suggested these associations were significant only when the number of aircraft noise events was greater than or equal to eight (increased awakenings), 16 (reduction in slow wave sleep), and 64 (increased stage 1 light sleep).

3.3.5 Summary of the evidence

The observational and experimental studies together indicate a significant relationship between exposures to higher levels of environmental noise and sleep disturbances. However, the issues in method noted above and variations in study design makes it difficult to draw definitive conclusions from the evidence base.

The quality of the evidence was rated as low for the observational studies given the large number of cross-sectional studies and the high risk of bias. The experimental studies generally provided better quality evidence.

Both observational and experimental studies assessed a wide range of sleep parameters using various measures.

Many studies used both objective and subjective measures of sleep disturbance. Noise was found to exert a larger effect on self-reported sleep compared with objectively assessed sleep. One mediating factor may be that annoyance caused by noise may cause sleep disturbance and extended awakening. Some individuals may therefore over-report the effects of noise on the quality of their sleep. Some studies using a combination of objective and subjective measures found effects for self-reported sleep but no or very weak effects for polysomnography-assessed sleep. Examples include the study by Schapkin et al., 2006a. This suggests that the effects of environmental noise are overestimated in those studies using self-reported sleep measures.

3.3.6 Is there a dose–response relationship between environmental noise and sleep disturbance?

Many observational studies demonstrated that sleep disturbances become more pronounced as noise level increases (e.g. Banerjee, 2013; Bluhm et al., 2004; Boes et al., 2013; de Kluizenaar et al., 2009; Franssen et al., 2004; Frei et al., 2014; Kim et al., 2014).

The precise measures of sleep varied considerably between studies, as did the quantification of noise exposure. For example, Boes et al. (2013) examined the effects of a 1 dB(A) increase in noise, de Kluizenaar et al. (2009) broke noise exposure into 10 dB(A) categories, and Frei et al. (2014) assessed four noise exposure groups (< 30 dB(A), 30 – 40 dB(A), > 40 – 55 dB(A), and > 55 dB(A)). This lack of consistency means it is possible to conclude that observational studies show a dose–response relationship, but the precise nature of the relationship cannot be determined easily.

Several experimental studies also indicated a dose–response relationship between noise exposure and sleep disturbance (e.g. Basner and Samel, 2005; Kawada and Suzuki, 1995; Schapkin et al., 2006a). Again, major methodological differences between studies make it difficult to combine studies. Studies were also difficult to compare due to the varying noise metrics used.

As an example, L_{den} is a noise metric that describes a hybrid of noise over the day, evening and night. It could be argued that the day and evening parts are irrelevant to sleep (unless the subjects sleep during the day). A night-time level would be more helpful. Also, L_{Aeq} is a noise metric that effectively describes noise as an average over an extended period. Particularly in the case of aircraft and train noise, it depends on the number of noise events and their specific noise levels.

Reported thresholds are outlined below for each of the three main noise sources.

Road traffic noise

Seven observational studies examined the effects of road traffic noise and found significant impairments in sleep quality associated with noise levels measured at the exterior façade above 55 dB L_{night} (Banerjee, 2013; Halonen et al., 2012; Ristovska et al., 2009) and 55 dB L_{Aeq} (Frei et al., 2014; Kristiansen et al., 2011; Lercher and Kofler, 1996; Yoshida et al., 1997)

Several experimental studies also reported significant effects of peak or equivalent noise levels at or above 45 dB(A) (Kawada and Suzuki, 1999; Kuwano et al., 2002).

Rail noise

Two observational studies examining rail noise found significant relationships with sleep disturbances at noise levels measured at the exterior façade of ≥ 60 dB L_{Aeq} (Aasvang et al., 2008) and ≥ 60 dB L_{den} (Lercher et al., 2010).

Experimental studies indicated that the effects of rail noise on sleep were observed at lower levels, with several studies finding effects above 50 dB(A) (Kaku et al., 2004; Saremi et al., 2008; Bonnefond et al., 2008) and 54 dB(A) (Griefahn and Robens, 2010).

Aircraft noise

Two observational studies indicated that threshold effects for aircraft noise were comparatively low at 32 dB $L_{Aeq,night}$ (Passchier-Vermeer et al., 2002) and 33 dB L_{ASmax} (Basner et al., 2006).

Experimental studies indicated some effects of aircraft noise at 39 dB(A) (Schapkin et al., 2006b) and 45 dB(A) (Basner et al., 2008), but effects were reported to be most evident at higher levels (for example, > 50 dB(A) or ≥ 65 dB(A)).

3.3.7 Is there any evidence that certain populations are vulnerable to the effects of environmental noise on sleep disturbance?

Only a small number of studies formally investigated whether the relationships between environmental noise and sleep disturbance were more pronounced in certain populations.

Halonen et al. (2012) found the effects of road traffic noise on insomnia symptoms were more pronounced in individuals with higher levels of self-reported anxiety traits. Bjork et al. (2006) found the effects of road traffic noise on self-reported sleep disturbances were greater in individuals with higher levels of annoyance and in individuals born overseas.

This raises the possibility that some effects may be greater in certain populations, but there is not sufficient evidence to draw strong conclusions on this.

3.3.8 Does the association between environmental noise and sleep disturbance vary by noise source?

Few studies compared whether the influence of noise on sleep disturbance varied depending on the source. Studies tended to examine one source, such as aircraft or road traffic noise. With little consistency in methods, such as sample characteristics, noise levels and experimental conditions, it is not possible to meaningfully compare results.

However, a small number of studies did compare the effects of different sources of noise. Griefahn et al. (2006b) compared the effects of aircraft, rail and road noise. Their results indicated similar effects from the sources of noise, although the effects appeared greatest for rail noise. Aasvang et al. (2011) compared the effects of road traffic noise with railway noise. The results indicated that railway noise had a greater effect on rapid eye movement (REM) sleep compared with road traffic noise. This suggests that railway noise may have a larger effect on sleep outcomes.

Basner et al. (2011) provided further insight into the nature of these differences in an experimental study that compared the effects of rail, road and aircraft noise on sleep parameters. Interestingly, the nature of the differences between noise sources varied depending on whether sleep was assessed via polysomnography or self-reported.

When polysomnography was examined, road traffic noise had the largest effects on sleep structure and continuity. However, when self-reporting measures were used, aircraft and rail noise were found to have a larger effect on sleep compared with road traffic noise (Basner et al., 2011).

Basner et al. (2011) suggested that because road traffic noise events are relatively short they were perceived as having less effect on sleep. In other words, the events were not long enough for participants to consciously perceive their sleep was affected.

In contrast, rail and aircraft noise typically last longer and so may be more likely to be perceived as having affected sleep. Basner et al. (2011) attributed the greater effects of road traffic noise on polysomnography-assessed sleep parameters to the specific acoustic properties of road traffic noise, such as faster sound pressure level rise time and greater energy in the high-frequency octave bands compared with aircraft noise.

It is plausible that aircraft, rail and road traffic noise have differential effects on sleep quality. However, because available data is limited it is not possible to draw definitive conclusions on the nature and magnitude of these differences.

3.3.9 Is there any evidence that annoyance is a mediator linking environmental noise exposure to sleep disturbance?

Annoyance is discussed by a large number of studies as a likely mechanism linking environmental noise exposure with poor sleep, particularly self-reported sleep. Some studies examined both annoyance and sleep disturbance as an outcome, but there is no evidence that studies have formally examined whether annoyance is a mediator linking noise exposure with sleep disturbance.

Frei et al (2014) found that annoyance was strongly related to self-reported sleep measures; actigraphy and diaries were used to assess sleep in a nested sub-group of this study. It was reported that measured sleep efficiency was more strongly associated with modelled noise exposure than with self-reported annoyance. This suggests annoyance is a mediating factor for subjective sleep complaints but not an objective measure for noise. It is possible that annoyance is a mechanism linking noise exposure with poor sleep. But it is not clear if these effects are limited to self-reported or objective assessment of sleep. Because of the lack of formal investigation, it is not possible to draw any definitive conclusion on the role of annoyance in the environmental noise-sleep disturbance literature.

3.4 Conclusions

Some studies suggest a dose–response relationship between noise and physiological effects on sleep. The systematic review identified 79 studies and sub-studies published between 1994 and 2014 that examined the associations between exposure to different forms of environmental noise and sleep disturbances. In general, the results of these studies are consistent in indicating that exposure to sources of environmental noise (mainly road traffic, rail and aircraft noise) are associated with sleep disturbances.

Overall the quality of the studies in this review was low, reflecting study design, risk of bias, and inconsistency in outcome measures. As a result, an NHMRC rating statement of C is applied to the overall body of evidence (see rating criteria in appendix A). The body of evidence from this systematic review has limitations and care should be taken in interpreting the findings.

4 NOISE AND CARDIOVASCULAR DISEASE

4.1 Introduction and background

Cardiovascular disease encompasses all conditions and diseases affecting the heart and blood vessels (AIHW, 2014a). In Australia, coronary heart disease, stroke and heart failure are the most common forms (AIHW, 2014a).

Although the incidence of cardiovascular disease has declined in Australia over the past two decades (AIHW, 2014a), it is estimated that 22 per cent of the adult population has some form of the disease. It remains the major cause of death in Australia, accounting for 31 per cent of all deaths, and second only to cancer as the largest contributor to total burden of disease (AIHW, 2014b). There are many risk factors for cardiovascular disease, including age, sex and genetics, as well as modifiable risk factors such as overweight/obesity, sedentary lifestyles, unhealthy diet, smoking and alcohol consumption (AIHW, 2009).

There has also been considerable interest in the role of environmental factors such as air pollution and noise in increased risk of cardiovascular disease. The World Health Organisation estimates that around 1.5 million ischemic heart disease deaths occur globally each year (based on 2012 estimates) due to ambient air pollution (WHO, 2014). Although there are no global estimates of the impacts of environmental noise on ischemic heart disease, regional estimates for Western Europe indicate that the burden is large at 61,000 Disability Adjusted Life Years (DALYs) a year. This is around 1.8 per cent of all ischemic heart disease DALYs attributable to transport noise (WHO, 2011).

Research since the late 1960s suggests that exposure to different forms of environmental noise is linked with a greater risk of cardiovascular disease and changes in indicators of cardiovascular health, such as heart rate and blood pressure (Babisch et al., 1990; Knipschild, 1977). Many subsequent studies have further examined these relationships and some reviews of the evidence have been conducted (Babisch, 2006).

4.2 Systematic review of the literature

A systematic review of the literature was conducted for studies investigating the relationship between environmental noise and cardiovascular disease for the period January 1994 to March 2014. This is further detailed in appendix A.

4.2.1 Search results

Details of the results of the search process are summarised in the following PRISMA flow chart.

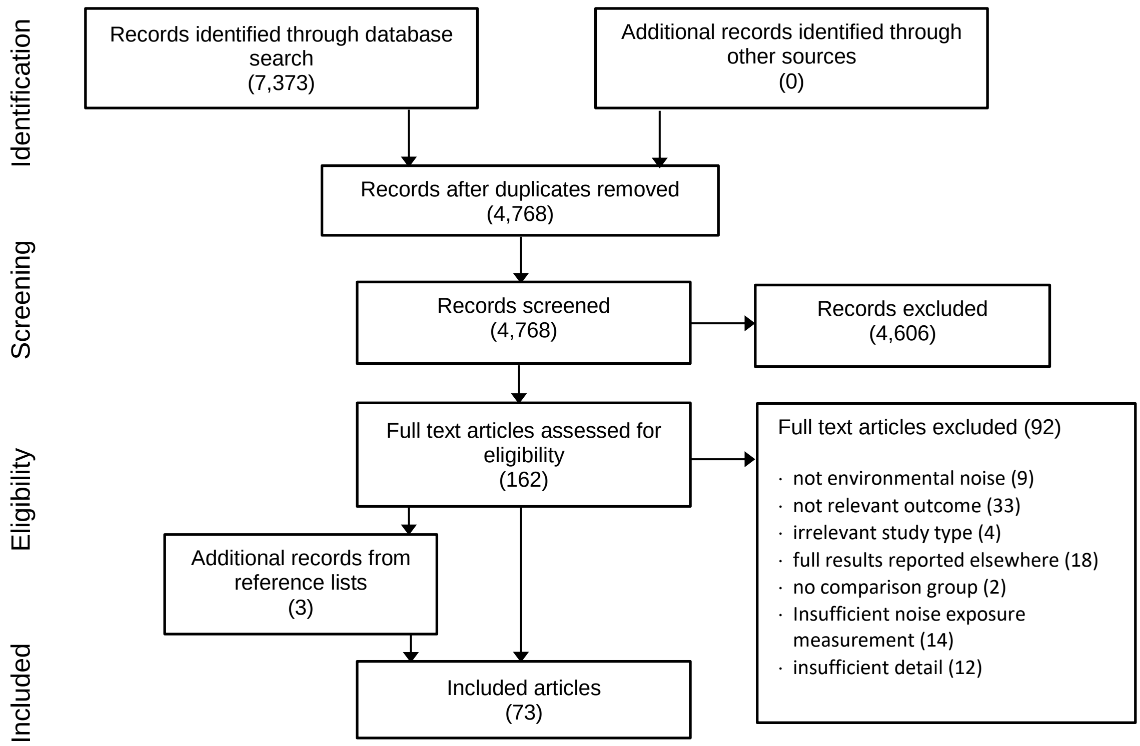

Figure 4-1: PRISMA flow chart. Number of articles identified and reviewed during the systematic review (Moher et al. 2009)

4.2.2 Overview of included studies

Of the 73 articles identified, 65 were from distinct studies (some reported on the same data); 62 were observational designs, while three were experimental. The majority of observational studies (40) were cross-sectional studies (NHMRC level IV). Some studies had multiple components with different methods, such as cross-sectional and prospective cohort components.

There was also a small number (10) of prospective cohort studies (NHMRC level II), ecological studies (five) (NHMRC level IV), case-control studies (four) (NHMRC level III-3) and field studies (three) (NHMRC level III-2).

All of the experimental studies were non-randomised experimental studies (three) (NHMRC level III-2). One was conducted in a sleep laboratory, one in a sound and temperature-controlled room and one in a park setting.

4.2.3 Noise exposure and how it was measured

Observational studies explored road traffic noise (42), aircraft noise (19), railway noise (seven), and general environmental noise (five). Experimental studies addressed the effects of road traffic (three), and aircraft noise (one) on cardiovascular disease. Several studies examined multiple sources of noise.

For observational studies, noise exposure was measured by direct measurement with sound level meters (17 studies) or estimated using models and contour maps (39 studies). Six studies used a combination of direct measurement and models/contour maps, while three did not clearly specify the measurement approach. Noise was measured using sound level meters in all three experimental studies.

The most common noise indicators used were A-weighted equivalent sound levels (L_{Aeq}) for various periods. Maximum sound pressure levels (L_{Amax}) were also commonly used.

4.2.4 Types of outcomes reported

A breakdown of the cardiovascular disease outcomes in these studies is:

- hypertension/blood pressure (45 studies)
- cardiovascular disease mortality (3 studies)
- ischemic heart disease and myocardial infarction (16 studies)
- stroke (6 studies)
- other relevant outcomes such as diabetes and aortic calcification (4 studies).

The measures used to assess these outcomes varied considerably. For example, a range of self-reported diagnoses and direct measurements of blood pressure were used across studies.

Note that several studies examined multiple cardiovascular disease outcomes.

4.2.5 Quality ratings

GRADE is a structured process for rating quality of evidence in systematic reviews. Quality ratings according to GRADE criteria are shown in Table 4-1. This indicates that on aggregate, the quality of the evidence was rated as low.

All included studies are listed section 8.4. GRADE criteria are detailed in appendix A.

Table 4-1: GRADE evidence profile for environmental noise and cardiovascular diseases (65 studies)

No of studies (design)	Reasons for rating quality down	Reasons for rating quality up	Key findings	Quality score
Cardiovascular disease mortality				
One (ecological)	None	None	Increased risk of death from myocardial infarction in people exposed to aircraft noise over 60 dB(A) especially those exposed >15 y	⊕⊕○○ Low
Three (prospective cohort)	None	None	High levels of transportation noise (≥ 65 dB(A)) associated with elevated risk of mortality.	⊕⊕⊕○ Moderate
Ischaemic heart disease and myocardial infarction (self-report)				
Four (cross-sectional)	Serious inconsistency	None	Road traffic noise may be associated with greater self-reported heart disease and stroke but confounding of air pollution may be an issue.	⊕○○○ Very low
Ischaemic heart disease and myocardial infarction (hospital record)				

No of studies (design)	Reasons for rating quality down	Reasons for rating quality up	Key findings	Quality score
Three (cross-sectional and ecological)	Serious risk of bias Serious inconsistency	None	Small association found between road traffic noise and hospitalisations for myocardial infarction. Aircraft noise may have small impact on hospitalisations for cerebrovascular disease, ischaemic heart disease and heart failure.	⊕⊕○○ Low
Three (prospective cohort)	Some inconsistency	None	Road traffic noise not significantly associated with ischaemic heart disease or cerebro-vascular disease. May have a small impact on myocardial infarction.	⊕⊕⊕○ Moderate
Four (case control)	Serious inconsistency	None	Mixed results for road traffic noise. May have small impact on hospitalisations for myocardial infarction, particularly in males at very high equivalent sound levels (>70 dB(A)).	⊕⊕⊕○ Moderate
Stroke (self-report)				
One (cross-sectional)	Serious risk of bias Serious inconsistency Stroke not analysed separately from other cardiovascular heart disease outcomes. One small study	None	No significant findings.	⊕○○○ Very low
Stroke (hospital records)				
One (ecological)	Some risk of bias Only one study	None	Aircraft noise at high equivalent sound levels may have a small effect on hospitalisations for stroke.	⊕○○○ Very low
One (prospective cohort)	Only one study	None	Road traffic noise (L_{den}) at very high levels may have small effect on hospitalisations for older people (≥ 64 y).	⊕⊕⊕○ Moderate
Hypertension (measured)				
Twelve (cross-sectional)	None	None	Road traffic noise not significantly associated with hypertension.	⊕⊕○○ Low
Two (prospective cohort)	Some risk of bias	None	Aircraft noise may be associated with increased hypertension in older males.	⊕⊕○○ Low
Hypertension (self-report)				
Sixteen (cross-sectional)	Serious risk of bias Serious inconsistency	None	Higher exposure to road traffic noise associated with increased self-reported hypertension.	⊕⊕○○ Low

No of studies (design)	Reasons for rating quality down	Reasons for rating quality up	Key findings	Quality score
Four (prospective cohort)	Serious risk of bias Serious inconsistency	None	Higher exposure to road traffic noise associated with increased self-reported hypertension.	⊕⊕○○ Low
Type 2 diabetes insulin levels (hospital records)				
One (prospective cohort)	Only one study	None	Road traffic noise may slightly increase risk of hospitalisation. No effect from rail noise.	⊕⊕⊕○ Moderate
One (experimental)	Serious risk of bias Only one small study	None	Insulin levels may be sensitive to road traffic noise.	⊕○○○ Very low
Blood pressure and heart rate				
Fifteen (cross-sectional)	Moderate risk of bias Some inconsistency	None	Road and aircraft noise significantly associated with increased systolic blood pressure, particularly in children.	⊕⊕○○ Low
Four (prospective cohort)	Serious risk of bias Serious inconsistency	None	Mixed results. Blood pressure is sensitive to changes in noise levels.	⊕⊕○○ Low
Two (field experimental)	None	None	During sleep aircraft noise events (L_{max}) had an effect on blood pressure and dipping in diastolic blood pressure. No effect on heart rate. Maximum noise level, not noise type (such as road or air) was most important.	⊕⊕○○ Low
One (experimental studies)	Serious risk of bias One small study	None	Walking through a noisy or quiet park made little difference to blood pressure and heart rate.	⊕⊕○○ Low
Cardiac arrhythmia				
One (experimental)	Serious risk of bias One small study	None	No effect of air and road traffic noise on cardiac arrhythmia.	⊕○○○ Very low
Coronary artery atherosclerosis and calcification				
Two (cross-sectional)	Serious risk of bias Serious inconsistency	None	Higher quality study suggests a small effect of road traffic noise on atherosclerosis.	⊕⊕○○ Low

4.3 Summary of findings from the systematic review

4.3.1 What is the evidence of a causal effect of environmental noise on cardiovascular health?

A total of 65 studies examining the relationship between environmental noise and cardiovascular outcomes were included in this review. Most of these studies were observational (62), with only three experimental studies identified. The findings for the observational and experimental studies are summarised below.

4.3.2 Observational studies

Aircraft noise

A total of 19 observational studies examined the associations between aircraft noise and various cardiovascular outcomes. Most studies (15) reported a significant relationship between exposure to aircraft noise and adverse cardiovascular outcomes in the total sample (14 studies) or in sub-groups (1 study). These studies indicated that exposure to aircraft noise was significantly associated with hypertension, increased blood pressure, hospitalisations for cardiovascular diseases, use of medications for hypertension and other cardiovascular disease and cardiovascular mortality. Only three studies reported no significant associations between aircraft noise exposure and cardiovascular health.

Road traffic noise

Forty-three observational studies examined the relationships between exposure to road traffic noise and cardiovascular outcomes. The evidence in these studies was mixed. A total of 21 studies reported that increased road traffic noise was significantly associated with adverse cardiovascular outcomes. One found a significant result in the opposite direction, with increased noise associated with lower systolic blood pressure in children (van Kempen et al., 2006). A further nine studies found no significant effect in the total sample, but evidence of associations in sub-groups such as certain age or gender groups. Twelve studies reported no significant associations between road traffic noise and cardiovascular outcomes.

Rail noise

The associations between rail noise and various cardiovascular outcomes were examined in seven studies. One of these studies indicated that greater railway noise was associated with hypertension (Dratva et al. 2012). One study indicated that railway noise was associated with hypertension but not stroke or diabetes (HYENA; Sørensen et al., 2011a, 2011b, 2013). One found that rail noise was associated with self-reported hypotension in females under the age of 42 (Lercher and Widmann, 2013). Another four reported no significant association between railway noise and cardiovascular outcomes.

General environmental noise

Five studies examined general environmental and community noise exposure. Except for one study (Lepore et al., 2010), all indicated that greater noise exposure was associated with poorer cardiovascular health.

Study limitations

There are some important limitations of the observational studies. A key limitation is that most of the observational studies were cross-sectional (NHMRC level of evidence: IV) and are unable to provide an indication of the direction of causation. Although there were several prospective, case-control, and field studies, the results were mixed. This limits conclusions on the temporal effect of environmental noise on cardiovascular health.

While the type of noise exposure indicator used was relatively consistent across the studies (usually L_{Aeq} or L_{Amax}), there was considerable variation in how the noise exposure was estimated, such as using direct measurement or contour maps. There was also variation in the location at which the measurements were taken, such as at the building façade or participant's ear, complicating the synthesis of evidence.

There were also considerable differences between studies in the types of cardiovascular outcomes examined and the measures used to assess them. Cardiovascular outcomes assessed included: incidence of hypertension, stroke, heart disease or diabetes; treatment of hypertension; hospital records; mortality data; and aortic calcification. This variation makes it difficult to draw clear conclusions about the effect of environmental noise on cardiovascular health. These issues are compounded because the observational studies differed in whether cardiovascular outcomes were assessed using self-reporting or objective measures. A large number of studies examined self-reported hypertension, which is less accurate than an objective measure of hypertension based on blood pressure measurements. Many middle and older-aged adults may have undiagnosed hypertension, which would not be reflected in these self-reported measures. Therefore, self-reporting measures can limit the validity of findings and contribute to risk of bias.

There is also considerable potential for residual confounding, given that many studies did not control for relevant covariates such as air pollution. This is important as some studies found that an association between noise exposure and cardiovascular outcomes became non-significant when air pollution was added as a covariate (for example, Babisch et al., 2014a). Failure to control for these covariates could lead to false positive associations between noise exposure and cardiovascular health.

Twenty studies were rated as having a low risk of bias, 22 a moderate risk, and 21 a high risk. The primary reasons for moderate and high risk related to the use of self-reported measures of cardiovascular health and lack of control for relevant confounding variables.

Studies with a low risk of bias

The 20 studies with low risk of bias generally indicated that environmental noise exposure was linked with poorer cardiovascular health, although some findings were mixed. For example, several of the studies with a low risk of bias found non-significant results. Babisch et al. (1994) conducted a prospective case-control study of 4035 male adults and found that day-time exposure to road traffic noise ($L_{Aeq,6\text{-}22hours,}$ exposure range 40 – 65 dB(A)) was not significantly associated with myocardial infarction incidence. In a prospective study of 18,213 adults, de Kluizenaar et al. (2013) found that road traffic noise (L_{den} at most exposed façade, per 10 dB increase) was not associated with cardiovascular disease hospitalisations. Foraster et al. (2011) found that road traffic noise (L_{night} and $L_{Aeq,24h}$ measured at the most exposed façade, per 10 or 5 dB increase) was not associated with hypertension in a cross-sectional study of 3480 adults. De Kluizenaar et al. (2007) found that road traffic noise (L_{den} at most exposed façade, per 10 dB increase) was not associated with use of antihypertensive medication. However, a significant effect was observed in adults aged 45 to 55 (odds ratio (OR) = 1.39 [1.08, 1.77]) at higher noise exposure (L_{den} > 55 dB). Clark et al. (2012) found that daytime road traffic and aircraft noise ($L_{Aeq,16\ h}$) were not associated with measured blood pressure in a sample of 351 children.

Other studies with a low risk of bias suggest a relationship between environmental noise and adverse cardiovascular outcomes. For example, Babisch et al. (2014a) conducted a cross-sectional study of 4166 adults and found that noise (L_{den} at exposed façade, per 10 dB increase) was not associated with hypertension but was associated with higher systolic blood pressure (OR per 10 dB(A) increase in noise = 1.43 [1.10, 1.86]). Selander et al. (2009) conducted a case control study of 3666 adults. Road traffic noise ($L_{Aeq,24h}$ ≥50 dB(A)) was not associated with myocardial infarction risk in the total sample but a significant effect was observed in participants without hearing loss and a history of exposure to other noise sources (OR = 1.38 [1.11, 1.71]). Gan et al. (2012) conducted a prospective study of 466,727 adults and found that combined rail, air and road noise (postcode level L_{den}, range) was associated with cardiovascular disease mortality (OR per 10 dB(A) = 1.09 [1.01, 1.18]). In the diet, cancer and health cohort study, a prospective study of 57,053 adults, road traffic noise (L_{den} at most exposed façade, range) was associated with stroke (OR = 1.14 [1.03, 1.25]) and diabetes (OR = 1.11 [1.05, 1.18]).

4.3.3 Experimental studies

The findings of three experimental studies were included in this systematic review. Carter et al. (1994) examined the effects of exposure to aircraft and road traffic noise under laboratory conditions. The results indicated noise was not significantly associated with cardiac arrhythmia. Tomei et al. (2000) examined the effects of exposure to road traffic noise on levels of insulin under laboratory conditions. The results indicated that higher noise levels were significantly associated with increases in insulin levels. Finally, Janssen et al. (2012) conducted a field-based study examining the effects of exposure to road traffic noise on heart rate and blood pressure and did not find any significant results. The risk of bias for these studies was high, which primarily reflected issues relating to lack of control groups.

This review identified a number of experimental studies examining cardiac-related outcomes that were not relevant to this review because they focused on cardiac responses to noise during sleep. Rather than indicating an adverse effect on cardiac health, these cardiac responses most likely reflect an arousal response during sleep, perhaps indicative of awakening. These outcomes were therefore not considered relevant to cardiovascular health. Several studies also examined the effects of noise exposure on levels of hormones related to cardiovascular health, such as cortisol. Although these hormones are important, they are not considered cardiovascular disease outcomes, but rather part of the causal pathways linking noise and cardiovascular health.

4.3.4 Summary of the evidence

As noted above, most studies examining the associations between environmental noise exposure and cardiovascular outcomes have been observational. These results suggest that exposure to environmental noise is associated with poorer cardiovascular outcomes. The most consistent findings were observed for aircraft noise, while several studies indicated an association between road traffic noise and cardiovascular health. Use of self-reporting measures of cardiovascular disease, along with lack of control for important confounders, contribute to the low quality ratings for the identified studies. The magnitude of the reported effects across studies is small.

4.3.5 Is there a dose–response relationship between environmental noise and cardiovascular health?

A small number of studies formally examined whether there was a dose–response relationship between noise exposure and cardiovascular outcomes. These studies suggested such a relationship. Many studies also reported that stronger relationships with cardiovascular outcomes were observed as noise levels increased (Babisch et al., 2012, 2014a, 2014b; Bluhm et al., 2007; Chang et al., 2012; Dratva et al., 2012; Eriksson et al., 2010a; Gan et al., 2012; Hansell et al., 2013; Jarup et al., 2008; Kälsch et al., 2014; Liu et al., 2013). These differed considerably in terms of how noise exposure was quantified. For example, some examined effects per 1 dB, 5 dB, or 10 dB increases, while others examined varying categories of noise exposure.

Very limited data was available regarding threshold effects. Given the variability in research designs and low study quality, summary threshold effects could not be determined from the studies in this review. Individual studies offer findings that indicate levels at which adverse outcomes are observed. These do not indicate clear thresholds but may inform future research that examines potential thresholds. These findings are outlined below for each of the three main noise sources.

Aircraft noise

Some studies indicate that average day-evening-night noise levels are associated with adverse cardiovascular outcomes: ≥ 50 dB L_{den} (Franssen et al., 2004), > 55 dB(A) L_{den} (Correia et al., 2013; Rosenlund et al., 2001), ≥ 55 dB(A) L_{Aeq} (Eriksson et al., 2007), ≥ 60 dB(A) L_{den} (Huss et al., 2010), or > 70 dB(A) L_{den} (Matsui et al., 2001). In terms of specific periods, daytime levels above 63 dB(A) have been linked with adverse cardiovascular outcomes (Hansell et al., 2013). Focusing specifically on the period from 3am to 5am, Greiser et al. (2007) found that noise levels ≥ 40 dB(A) were linked with adverse cardiovascular health. In addition to averaged noise events, Rosenlund et al. (2001) found that maximum noise levels > 72 dB(A) were linked with poor cardiovascular health.

Road traffic noise

Several studies found a significant relationship above 55 or 60 dB(A) $L_{Aeq.}$ (Bendokiene et al., 2011; Bluhm et al., 2007; Bodin et al., 2009; Regecova and Kellerova, 1995); Yoshida et al. (1997) found a significant effect at noise levels ≥ 65 dB(A) L_{Aeq}. Another study found a significant relationship at noise levels ≥ 60 dB(A) L_{den} (Banerjee et al., 2014). Two others indicate higher thresholds, with effects observed at > 70 dB(A) $L_{Aeq,6\text{-}22hours}$ (Babisch et al., 2005) and ≥ 80 dB(A) L_{Aeq} (Chang et al., 2011).

Rail noise

There was insufficient evidence to draw any conclusions on the relationship between rail noise and cardiovascular health.

4.3.6 Is there any evidence that certain populations are vulnerable to the effects of environmental noise on cardiovascular health?

Aircraft noise

Two studies indicated that the association between aircraft noise exposure and hypertension was stronger in older individuals (Eriksson et al., 2007; Rosenlund et al., 2001). Eriksson et al. (2010a) found that the association of aircraft noise with hypertension was evident in males (but not females). Babisch et al. (2013) and Eriksson et al. (2010a) found the effects of aircraft noise on cardiovascular outcomes were pronounced in individuals who reported high levels of noise annoyance.

Some studies also reported that the effects of noise exposure were most pronounced in individuals who had lived in noise-exposed areas for a longer period. For instance, Huss (2010) found that the association between aircraft noise and myocardial infarction mortality was greatest in individuals who had lived in the area for 15 years or more. This is consistent with the HYENA study (also see Floud et al., 2013) where an association between aircraft noise and self-reported cardiovascular disease was evident only in those who had lived in the area for more than 20 years.

Road traffic noise

The relationships with cardiovascular outcomes were found to vary by several factors. Several studies reported stronger associations between traffic noise exposure and outcomes such as hypertension (Bluhm et al., 2007; de Kluizenaar et al., 2007), coronary heart disease (Banerjee et al., 2014), myocardial infarction (Grazuleviciene et al., 2004) in middle-aged adults (aged 55–64 years). Sørensen et al. (2011a) found the association between road traffic noise and stroke was evident only in individuals aged over 65. Two studies indicated that the association of road traffic noise with cardiovascular outcomes was evident in individuals who had lived in an area for a longer period (Babisch et al., 2005; Barregard et al., 2009). Five studies reported significant differences by gender. The associations of road traffic noise with coronary heart disease (Banerjee et al., 2014) and hypertension (Bendokiene et al., 2011; Bjork, 2006; Lercher and Widmann, 2013) were stronger in females. In contrast, Belojevic (2008b) found that the relationship between road traffic noise and hypertension was stronger in males.

The effects of road traffic noise on cardiovascular outcomes were also stronger in individuals with higher noise sensitivity (Lercher and Widmann, 2013) and in those without hearing loss (Selander et al., 2009).

4.3.7 Does the association between environmental noise and cardiovascular health vary by noise source?

Most studies in this review examined the effects of one noise source (see de Kluizenaar et al., 2013). Although many other studies examined multiple noise sources, direct comparisons of effects were not made. Some studies investigating the effects of both road traffic and aircraft noise found significant associations for aircraft noise but not for road traffic noise. This may suggest that the effects of aircraft noise are stronger, but this is a very tentative conclusion. It is possible that aircraft, rail and road traffic noise have differential effects on cardiovascular health, but existing evidence is not conclusive.

4.3.8 Is there any evidence that annoyance is a mediator linking environmental noise exposure to cardiovascular health?

Many studies discussed annoyance as a potential pathway by which environmental noise exposure could influence cardiovascular health. However, only a few studies tried to examine whether annoyance was a mediator (see Fyhri and Klaeboe, 2009) and the evidence was inconclusive.

4.4 Conclusion

Variation in research design, study quality, adjustment for confounders, and outcome reporting make construction of dose–response relationships difficult for environmental noise and cardiovascular health.

The systematic review identified 65 studies published between 1994 and 2014 investigating the relationships between exposure to environmental noise and cardiovascular health. In general, the results were mixed, particularly for road traffic noise; the effects of rail noise on cardiovascular disease outcomes were not conclusive. Findings for the effects of aircraft noise were generally more consistent. However, it is important to note that for all noise sources, the magnitudes of the associations with cardiovascular disease were small. Small effect sizes are not surprising given that environmental noise could be one of a multitude of risk factors for cardiovascular disease. Other factors such as cigarette smoking and heredity probably play a much larger role in influencing an individual’s level of risk.

It is important to note that there are some important limitations of the evidence base. These limitations include a large number of studies using self-reported measures, variation in study designs, quantification of noise exposure, site at which noise exposure was measured, and differences in the scope of confounding variables controlled. These issues mean it is not possible to identify a clear threshold where the effects on cardiovascular health emerge or worsen. As a result, an NHMRC rating statement of C is applied to the overall body of evidence: the body of evidence has limitations and care should be taken in the interpretation of findings. See appendix A for details on ratings.

Further research is needed using designs that can demonstrate causality, using objective outcome measures. Controlling for a broad range of potential confounders is important to rule out the possibility of residual confounding. This is particularly the case for air pollution, which may be an important confounder but is not controlled in many studies. Based on existing research, vulnerable groups may include older adults. There is an absence of studies investigating annoyance as a mediator.

5 NOISE AND COGNITION

5.1 Introduction and background

Cognition is the process of learning that includes thinking, understanding and remembering. A large number of studies have examined the relationships between exposure to different sources of environmental noise – road traffic, aircraft and rail – and cognition. Associations have important implications since good cognitive performance is linked to higher quality of life, improved mental health and better academic and job performance. However, many aspects of the relationship between environmental noise and cognition remain unclear.

5.2 Systematic review of the literature

A systematic review of the literature was conducted for studies investigating the relationship between environmental noise and cognition for the period January 1994 to March 2014. This is further detailed in appendix A.

5.2.1 Search results

The flow chart below details the results of the search process.

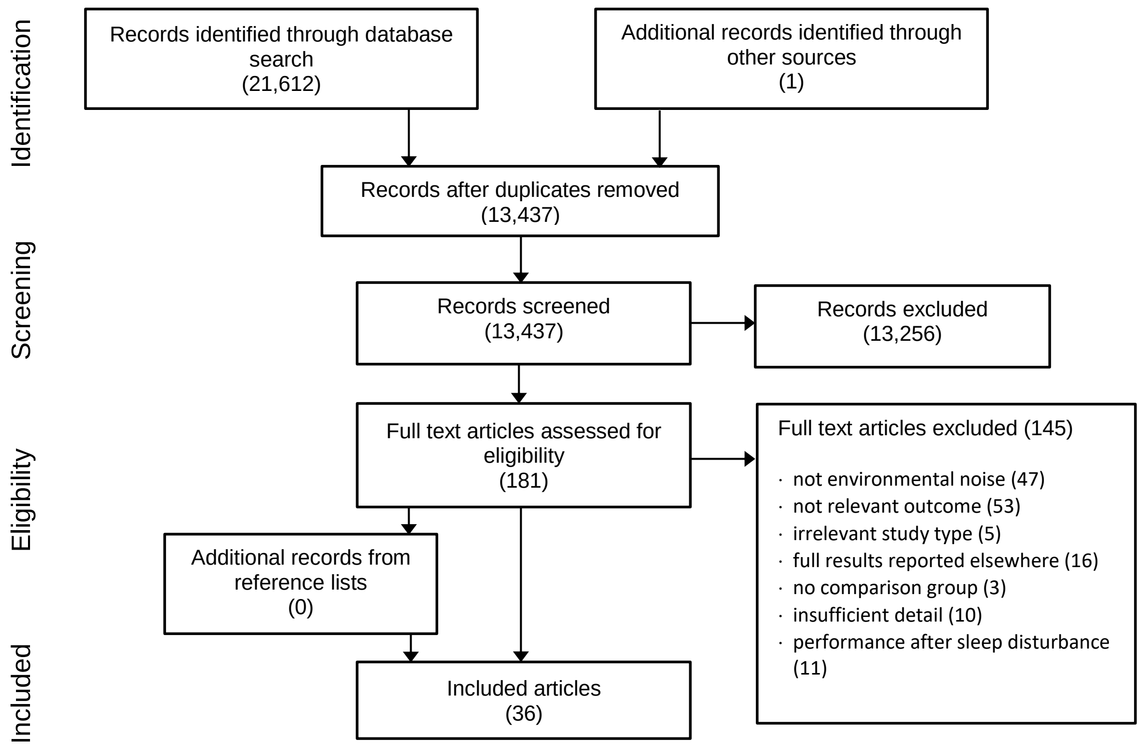

Figure 5-1: PRISMA flow chart. Number of articles identified and reviewed during the systematic review (Moher et al. 2009)

5.2.2 Overview of included studies

Study types and settings

Of the 36 articles identified, 29 were from distinct studies (some articles reported on the same data); a total of 14 observational and 15 experimental studies were included in the review. Most of the observational studies (11) were solely cross-sectional (NHMRC level IV), two included both cross-sectional and prospective cohort (NHMRC level II) components, and one was a controlled before and after study (NHMRC level III-3).

All of the experimental studies were either non-randomised experimental studies (8) (NHMRC level III-2) or pseudo-randomised studies (7) (NHMRC level III-1). Most were based in sound and temperature controlled laboratories (12), while three were conducted in classrooms.

5.2.3 Noise exposure and how it was measured

Most of the observational studies explored aircraft noise (8 studies), followed by road traffic noise (4) and general community noise (3). Most experimental studies simulated road traffic noise (12 studies), with a small number simulating aircraft noise (3), and rail noise (1).

For observational studies, noise exposure was measured by direct measurement with sound level meters in various locations (5 studies), or estimated using models (8). One study did not clearly specify the measurement method. Experimental studies delivered noise levels in a controlled way to participants.

The most common noise measures used were A-weighted equivalent sound levels (L_{Aeq}) for various periods. Maximum sound pressure levels (L_{Amax}) were also commonly used.

All of the observational studies involved children from seven to 16 years old. Experimental studies involved university students and young adults (7 studies), primary and secondary school students (5), and only one involved adults aged from 35 to 65 years.

5.2.4 Types of outcomes reported

Most studies explored multiple outcomes. The most common outcomes explored in observational studies were reading comprehension (8 studies), memory (7) and attention (6). The most common outcomes explored in experimental studies were memory (8 studies), attention (5) and mathematical tasks (4).

Most studies used standardised or well-known tests to assess outcomes.

5.2.5 Quality ratings

GRADE is a structured process for rating quality of evidence in systematic reviews. Quality ratings according to the GRADE criteria are shown in Table 5-1. This indicates that on aggregate, the quality of the evidence was rated as low.

All included studies are listed in section 8.5. GRADE criteria are detailed in appendix A.

Table 5-1: GRADE evidence profile for environmental noise and cognition (29 studies)

No of studies (design)	Reasons for rating quality down	Reasons for rating quality up	Key findings	Quality score
Reading (skills and comprehension)				
Six (cross-sectional)	Some risk of bias	None	Aircraft noise at school has a detrimental effect on children's reading comprehension	⊕⊕○○ Low
Three (prospective cohort)	Some inconsistency	None	Detrimental effects of aircraft noise on children's reading may not persist over time, especially if noise exposure is changed	⊕⊕⊕○ Moderate

No of studies (design)	Reasons for rating quality down	Reasons for rating quality up	Key findings	Quality score
Two (experimental)	Some risk of bias Some indirectness / applicability (see GRADE guidelines)	None	Road traffic noise may affect reading speed in children but no effect was found on reading comprehension in children	⊕⊕⊕○ Moderate
Memory (short and long term)				
Six (cross-sectional)	Serious risk of bias Some inconsistency	None	Aircraft noise may affect long term memory in children. No effect of road or aircraft noise on short term memory	⊕⊕○○ Low
One (prospective cohort)	Only one small study	None	Chronic exposure may have detrimental effect on long term memory in children which is not immediately resolved by removing noise	⊕⊕○○ Low
Six (experimental)	Serious risk of bias Some indirectness	None	No effect of acute road or aircraft noise on short term memory	⊕⊕⊕○ Moderate
Attention				
Four (cross-sectional)	Some risk of bias Some inconsistency	None	Mixed results	⊕⊕○○ Low
One (prospective cohort)	Only one small study	None	No significant findings	⊕⊕○○ Low
Four (experimental)	Some risk of bias Some inconsistency Some indirectness	None	No effect of noise	⊕⊕⊕○ Moderate
Academic achievement (student, school and borough level measures)				
Five (cross-sectional)	Serious risk of bias Serious inconsistency	None	Noise at school may affect achievement (one high quality study)	⊕⊕○○ Low
Mathematics tasks (arithmetic, mathematical reasoning)				
Four (experimental)	Serious risk of bias Some indirectness	None	No effect of road traffic noise	⊕⊕⊕○ Moderate

5.3 Summary of findings from the systematic review

5.3.1 What is the evidence of the effect of environmental noise on cognition?

This systematic review identified 29 primary studies published between 1994 and 2014 examining the relationship between environmental noise exposure and cognition. Fourteen studies were observational and 15 were experimental. The main findings were mixed and are summarised below.

These studies generally measured the noise exposure, or exposed the participants, within the learning environment.

5.3.2 Observational studies

The observational studies examined the relationships between environmental noise exposure and a range of cognitive outcomes. Eight studies examined aircraft noise and four road traffic noise. A further three assessed general community noise, which included a combination of noise sources but did not allow for the sources to be distinguished from one another. Most studies were conducted on samples of children. Evidence of a relationship between environmental noise exposure and cognition was mixed across these studies.

Aircraft noise

Six of the eight studies indicated a significant relationship between aircraft noise exposure and cognitive outcomes. For example, they reported that exposure to aircraft noise was cross-sectionally associated with poorer reading comprehension (Evans et al., 1995, Evans et al., 1997; Seabi et al., 2010; Seabi et al., 2012, RANCH study and Haines et al., 2001a, b). The RANCH study and Haines (2001a, b) study found that the relationship did not maintain significance when explored through a prospective cohort study. Mixed results were found for memory and attention with four studies finding a significant relationship (Evans et al., 1995; Haines et al., 2001; Seabie et al., 2010 and the RANCH Study). The remaining two indicated aircraft noise exposure was not associated with reading comprehension, memory, attention and academic achievement (Haines et al., 2001c, 2002).

Road traffic noise

Two of the four studies provided some support for an association between road traffic noise and cognition. Belojević et al. (2012) found that higher road traffic noise was associated with poorer executive functioning in boys but not girls. The RANCH study indicated that road traffic noise was associated with impaired recognition memory, but not reading comprehension (Clark et al., 2006; Clark et al., 2012; Stansfeld et al., 2005; Stansfeld et al., 2010). Two studies conducted by Xie et al. (2010, 2011) indicated that road traffic noise was not associated with measures of academic achievement.

Generic environmental noise

Two of the three studies indicated that generic environmental noise (total noise levels measured outside schools or homes) was associated with poorer cognitive outcomes. Lercher et al. (2003) found that increased environmental noise was associated with impaired memory, while Pujol et al. (2014) found increased environmental noise was associated with poorer academic achievement. Another study conducted by Shield et al. (2008) found mixed support for a relationship between environmental noise (excluding aircraft noise) and cognitive outcomes. They found that higher levels of noise were associated with poorer academic achievement in some, but not all, schools.

Study limitations

The quality of the observational studies was generally low, reflecting a combination of factors including study design and a high risk of bias. For example, most of the studies were cross-sectional, with only two studies examining the prospective associations between environmental noise and cognition. This is a major limitation because cross-sectional studies are not able to provide insight into the direction of causation between noise and cognition. The RANCH study and Haines et al. (2001a, b) also reported cross-sectional associations between noise exposure and poorer cognition. However, these associations were not supported in the prospective analysis. This raises further concerns on the validity of the cross-sectional findings.

Most of the studies (eight out of 13) had a high risk of bias, mainly reflecting the lack of control for relevant confounding variables. This is an important consideration because significant results reported by these studies could reflect residual confounding rather than a true relationship between noise and cognition. Three of the nine studies had a moderate risk of bias, reflecting the inclusion of some confounders but omission of some key confounders such as socioeconomic status. The adjustment of confounders differed substantially between studies, particularly for measures of socioeconomic status.

Two studies, the RANCH and the Pujol et al. (2014) studies, had a low risk of bias. Several articles reported on the RANCH study, which demonstrated significant relationships between exposure to aircraft noise and poorer cognition across measures of reading comprehension, memory and attention. The RANCH study also indicated that road traffic noise was associated with some impairments in memory. Pujol et al. (2014) examined a sample of 586 children and found that general environmental noise was associated with impairments in standardised measures of academic achievement.

The observational studies examined several measures of cognition. For example, articles using data from the RANCH study used several standardised measures to assess reading comprehension and different components of memory, such as episodic and prospective memory. Studies also used generic indicators of overall executive functioning (Belojević et al., 2012) or standardised school performance scores (Haines et al., 2002; Shield et al., 2008; Pujol et al., 2014; Xie et al., 2010, 2011). Many other studies assessed domains of cognitive performance including reading, memory, attention, speech perception and intelligence (Haines et al., 2001a, c).

The variations in outcome measures may partly explain the inconsistent findings and limits the conclusions that can be drawn. Further, because most studies examine only a select range of cognitive outcomes, they do not provide a comprehensive insight into the effects of environmental noise on cognition.

The type of noise exposure indicator used is relatively consistent across the studies (usually L_{Aeq} or L_{Amax}). However, how the noise exposed was estimated – such as direct measurement or contour maps – and the site at which it was measured – building façade or participant’s ear – varied considerably. This complicates a synthesis of the evidence.

5.3.3 Experimental evidence

Fifteen experimental studies examining the effects of environmental noise on cognitive outcomes were identified in this review. Twelve studies examined road traffic noise, three aircraft noise, and one rail noise, although some examined more than one noise source. The findings of these studies are summarised below.

Road traffic noise

Six of the 12 studies indicated that increased road traffic noise was associated with poorer cognitive performance. One study (Belojević et al., 2001) found that noise was not associated with cognitive performance in the total sample, although a significant effect was observed in introverts, but not extroverts. Three studies indicated that noise was not significantly associated with cognitive outcomes. Finally, two studies reported that increased noise led to improvements in cognitive performance. Alimohammadi et al. (2013) found that exposure to two hours of road traffic noise (71dB(A)) led to improved attention and concentration. However, these findings could feasibly be attributed to practice effects. White et al. (2012) reported that exposure to noise (road traffic and aircraft noise) led to faster reaction times, but this is not necessarily indicative of improved performance as accuracy was not affected by noise.

Aircraft noise

Two studies indicated that aircraft noise was not significantly associated with cognitive performance. As noted above, White et al. (2012) found that road traffic and aircraft noise were significantly associated with faster reaction times, but not differences in performance accuracy.

Rail noise

Klatte et al. (2007) found that rail noise did not lead to any differences in memory, listening comprehension, written language acquisition or visual recall.

Study limitations

The quality of the experimental evidence was moderate, with eight studies found to have a low risk of bias. But several other issues relating to the experimental evidence warranted consideration. One concerned the large variation of cognitive outcomes assessed between studies. The range of cognitive outcomes included attention, memory (short-term, long-term, prospective, cued recall), reading comprehension, speech perception, intelligence and academic performance. When similar outcomes were assessed, different approaches were used. For example, several studies examining the effects of environmental noise on reading comprehension used different measures such as the Suffolk Reading Scale (Haines et al., 2001a) and the Woodcock Reading Mastery Test (Evans et al., 1997). The variation in types of cognitive outcomes, and the measures used to assess them, limits comparisons between studies.

The nature of the experimental manipulation also differed considerably between studies. These related to the duration, mean levels and peak levels of noise exposure. There were also substantial variations in noise levels in the control or ‘quiet’ conditions used as a reference in these studies. These variations further limit comparisons that can be made between studies.

It is also important to note that these experimental studies assess the acute effects of noise on cognition and may lack external validity. That is, while the risk of bias was low in many studies, the results of these studies do not provide an indication of the effects of chronic noise exposure on longer term cognitive outcomes.

5.3.4 Is there a dose–response relationship between environmental noise and cognition?

None of the studies identified formally examined dose–response relationships between environmental noise and cognitive outcomes. However, some studies did report significant linear associations between noise exposure and cognition, suggesting that the effects on cognition are more pronounced at increased noise levels (Clark et al., 2006; Matheson et al., 2010).

The studies in this review did not provide a clear indication of dose–response relationships or threshold effects. An important consideration is that there may be distinct threshold effects for different cognitive outcomes, such as memory versus attention. Further, many of these studies examined the acute effects of noise on cognition and provide only a limited insight into the effects of chronic noise exposure. Chronic exposure could have a different relationship with cognitive outcomes.

5.3.5 Is there any evidence that certain populations are vulnerable to the effects of noise on cognition?

Most of the studies were conducted in children, with only a few on adults. For the studies examining children, there was very limited evidence as to whether certain populations were more vulnerable to the effects of environmental noise on cognition. Belojević et al. (2012) found a significant detrimental effect of road traffic noise exposure at home on teacher-rated executive functioning in boys but not girls. However, few other studies in children examined sub-group effects.

Similarly, there was insufficient evidence as to whether any adult sub-populations were more vulnerable to the effects of environmental noise on cognition.

5.3.6 Does the association between environmental noise and cognition vary by noise source?

There was limited evidence as to whether the associations between environmental noise and cognition varied by noise sources. This is primarily because very few studies examined the effects of multiple sources of noise. Because studies used different methods, it was not possible to directly compare results.

Clark et al. (2006) is an example of one study that compared the effects of different noise sources. They found that aircraft noise, but not road traffic noise, was significantly associated with impaired reading comprehension. Clark et al. (2006) suggested that this may occur because aircraft noise is more intense and less predictable than road traffic noise. The transient nature of aircraft flyovers, which have short-term high noise levels, may disrupt children’s concentration and distract them from learning tasks. The constant nature of road traffic noise may allow children to habituate and not be distracted.

5.3.7 Is there any evidence that annoyance is a mediator linking environmental noise exposure to cognition?

Clark et al. (2006) examined whether noise annoyance was a mediator linking noise with cognition. Their results indicated that annoyance was not a significant mediator. None of the other studies in this review formally examined the role of annoyance as a mediator of these relationships. However, many studies discussed annoyance as a potential mediator.

5.4 Conclusion

The systematic review identified 29 primary studies (14 observational and 15 experimental) from 35 papers published between January 1994 and March 2014 examining the associations between environmental noise and cognitive outcomes. There is some evidence that increased levels of environmental noise are associated with poorer cognitive performance as reflected by a range of measures assessing reading comprehension, memory and attention. However, many of the findings between studies were mixed, and the nature of the relationship between environmental noise and cognition requires further investigation.

In general, the quality of the observational evidence included in this review was low, and experimental studies were considered to have a lower risk of bias. Regardless of risk of bias, the results were generally inconclusive. From the systematic review, it is therefore not possible to draw any meaningful conclusions on threshold effects, sub-group differences, or differential effects between noise sources. There is also insufficient evidence to draw any conclusions on the role of annoyance as a mediator. As a result, an NHMRC rating statement of D is applied to the overall body of evidence: the body of evidence is weak and findings cannot be trusted**.**

It is plausible that a relationship exists between environmental noise and cognitive performance. For example, environmental noise could be a source of distraction and thus interfere with task performance. Environmental noise may also induce hyper-arousal and lead to deficits in performance. It is also plausible that environmental noise has an indirect effect on cognition through disturbed sleep. Although these mechanisms are often discussed, evidence of a strong association is still lacking.

6 DISCUSSION

With future urban population growth, a significant and increasing number of people in Australia are likely to be adversely affected by exposure to environmental noise. The number exposed to potentially harmful levels of environmental noise is yet to be comprehensively quantified.

Chapters 3, 4 and 5 systematically identify and appraise the evidence on the effect of exposure to environmental noise on sleep, cardiovascular and cognitive outcomes. The systematic reviews also considered the evidence for dose–response relationships, vulnerable groups and possible thresholds for risk.

The expert advisory group considered an analysis of the highest quality studies – studies with a risk of bias rating of one or two and an NHMRC higher quality study design – was important for further interpretative guidance.

This guidance can assist regulatory authorities, public health professionals and others by:

- providing insight into the likely causal probability
- identifying if there are broad threshold boundaries for health effects
- indicating the magnitude or importance of the effects described.

The following sections provide an additional synthesis of the available evidence from higher quality studies for sleep, cardiovascular and cognitive outcomes, along with limitations in the current literature.

6.1 Discussion on higher level studies with sleep related outcomes

Outcomes and their importance

Sleep disturbance can be quantified objectively by the number and duration of nocturnal awakenings, the number of sleep stage changes and modifications in their amounts. Subjectively, disturbance can also be measured through social surveys where individuals are asked to self-evaluate their sleep quality. Physiologically, sleep can be monitored using a sleep polygraph that measures total sleep time, sleep efficiency, total time in various sleep stages as well as arousals and awakenings. Motility (body movements) can be detected using accelerometers or actimetry and are also a useful indicator of sleep disturbance. A problem for interpretation in the systematic review was the proliferation of outcome measures. In general electroencephalogram awakenings are an acceptable proxy measure of sleep disturbance. However, small increases in awakenings have uncertain effects on sleep quality and uncertain long-term health consequences.

The systematic review examined a total of 79 studies, 43 of which were observational and 36 were experimental. The evidence base, while extensive, was not rated highly in terms of overall quality. An NHMRC rating statement of C was given. The low quality rating reflected issues around study design (most were cross-sectional) and a high risk of bias within studies (primarily due to measurement of sleep and control of confounders). These issues are detailed in chapter 3.

Higher quality studies

Higher quality studies included field studies with ratings of NHMRC III-2 and risk of bias one or two or NHMRC II and risk of bias one or two (Basner et al., 2006; Horne et al., 1994; Örhström et al., 2006; and Passchier-Vermeer, 2002). They also included experimental studies (all III-1 or III-2) with a risk of bias score one, (Basner and Samel, 2005; Basner et al., 2011; Griefahan et al., 2006a; Saremi et al., 2008). See appendix A, Table A-2 for the risk rating system. These are discussed below.

The field studies by Basner et al. (2006) and Passchier-Vermeer (2002) measured the noise a participant was exposed to indoors in their home and found a significant association between noise and an impact on a sleep parameter. Outcomes included reduced rapid eye movement (REM) sleep duration, increased sleep awakenings and increased motility as measured by actimetry.

Basner et al. (2006) examined awakenings and sleep stage transitions in response to aircraft noise events in a field study of 64 subjects. Sleep outcomes were measured using polysomnography, and sound pressure levels (SPL)($L_{As,max}$) were recorded inside the bedroom at the participant's ear as well as outside at the façade. Awakening probability increased with maximum SPL of an aircraft noise event. A threshold value of 33 dB(A) was found in the study, although it was noted that the effect was small, with only 0.2 per cent probability of awakening at an aircraft noise event maximum SPL of 34 dB(A) ear. The study showed a dose–response relationship with probability of awakenings increasing as maximum SPL increased. A 10 per cent rise in awakening probability corresponded to 73.2 dB(A) ear.

The study by Passchier-Vermeer (2002) measured aircraft noise both indoors and outdoors at the participant's residence and found indoor noise measurements – but not outdoor – were significantly associated with increased motility. Studies that more precisely measured the participants' noise exposure more clearly supported the influence of environmental noise on sleep.

Horne et al. (1994) and Örhström et al. (2006) did not use indoor noise monitoring, but for neighbourhood noise levels or modelled levels for the façade of the house they found less clear relationships. Horne et al. (1994) found that most aircraft noise events were not associated with an awakening, as measured by actimetry, and that other factors such as the presence of young children and concurrent illness, were more important. The study by Örhström et al. (2006) found mixed results, with some sleep parameters improved in high noise areas, although they were unable to adequately control for a government noise insulation program available in the highest noise area.

The higher quality experimental studies found similar outcomes (Basner and Samel, 2005; Basner, 2011; Griefahan et al., 2006a; Saremi et al., 2008). All experimental studies used polysomnography and, owing to their experimental design, tended towards better characterised or controlled noise exposure. The results were similarly small in magnitude of effect but all found statistically significant effects of noise on sleep. This included effects on sleep awakenings, sleep onset latency, sleep structure and micro-arousals.

The magnitude of these effects was low and the impact on sleep uncertain. There was insufficient evidence to determine a dose–response curve. There was also insufficient evidence across all studies to identify a specific threshold. However, there was consistency across higher quality studies when the threshold started at 55 dB L_{Amax} façade.

Other guidance recommendations

In recent years, WHO Europe has published two reports based on extensive reviews of the literature: the WHO Night Noise Guidelines for Europe (2009) and the Burden of Disease from Environmental Noise (2011). The night noise guidelines report identified threshold levels for a series of effects (biological, sleep quality, well-being and medical conditions), for which sufficient evidence was available. It identified children, elderly people, pregnant women and shift workers as at-risk groups. This report concluded with a proposed lowest observable adverse effect level (LOAEL) night noise guideline level of 40 dB $L_{night,outside}$ (WHO, 2009). This is not consistent with the threshold levels identified in the higher level studies described above.

The burden of disease report relied on several assumptions to arrive at estimates for exposure-response relationships. These were used to estimate the disease burden from environmental noise, measured in Disability Adjusted Life Years (DALYs). Such estimates of dose–response relationships and thresholds need to be interpreted with caution.

6.2 Discussion on higher level studies with cardiovascular outcomes

Outcomes and their importance

Cardiovascular outcomes reported in the studies in the systematic review are indisputably important health effects. Outcomes reported are hypertension (56 studies), cardiovascular disease usually comprising myocardial infarction or ischaemic heart disease (14 studies), heart failure and stroke. A variety of studies, equivalent to chamber studies in air pollution research, demonstrated acute effects of noise exposure on heart rate, blood pressure, insulin and catecholamine release.

A total of 65 studies was included in the systematic review. The overall body of evidence was given an NHMRC rating statement of C, where the body of evidence has limitations and care should be taken in interpreting findings. Higher quality non-experimental studies (Babisch et al., 1999; Beelen et al., 2009; Chang, 2009; de Kluizer et al., 2013; Eriksson, 2007 and 2010; Gan et al., 2012; Sørensen et al,. 2012a) included cardiovascular outcomes with a risk of bias rating of one or two and a prospective cohort design (NHMRC Level II evidence for aetiological questions).

Higher quality studies

Three higher quality studies addressed the outcome of hypertension (Eriksson, 2007 and 2010; Chang, 2009). Those by Eriksson used the Stockholm Diabetes Prevention Program Cohort to investigate the effects of modelled aircraft noise on self-reported diagnosis of hypertension. The earlier study found a significant association between increasing noise and escalated rates of self-reported hypertension. The second study by Eriksson (2010), which controlled for more confounders and had a longer follow-up period, found persistent effects only for men. Chang et al. (2009) investigated the effect of environmental noise (measured on a personal device that logged noise levels every five minutes) on blood pressure (measured every 30 to 60 minutes throughout the study period). This study found an association between increasing noise and short-term rises in blood pressure in young adults.

Five higher quality studies, all prospective cohort studies, examined cardiovascular outcomes more generally (including coronary heart disease and cerebrovascular events) as well as coronary heart disease specifically (Babisch et al., 1999; Beelen et al., 2009; de Kluizer et al., 2013; Gan et al., 2012; Sørensen, 2012). Effects seen were small and significant in only the three studies that examined cohorts of more than 50,000 people (Beelen et al., 2009; Gan, 2012; Sørensen, 2012). Sørensen et al. (2012) found a linear dose–response for traffic noise and myocardial infarction throughout the exposure range of the study (42-84 dB). As all these studies assessed exposure to road noise, consideration of air pollution as a potential confounder is important. Only two studies considered both cardiovascular risk factors and air pollution in their analysis, with the smaller cohort (Sørensen, 2012) finding a significant effect of noise, and the larger cohort (Beelen et al., 2009) finding a non-significant trend. A trend towards increased cardiovascular outcomes with noise was observed in all higher quality studies, be it statistically significant or not.

Most of the higher quality studies found an effect of noise on cardiovascular outcomes including hypertension, coronary heart disease and cerebrovascular disease. In general, effect sizes were low. Studies with fewer subjects often found non-significant trends towards an effect, while studies with more subjects found small but more often significant effects. Although the magnitude of effect was low and the impact of these effects uncertain, it is still possible to reach limited conclusions around adverse effects on cardiovascular health.

Higher level studies suggest a general threshold for cardiovascular disease outcomes, which may be observed as low as 52 dB(A) measured at the façade (or 42 dB(A) at the ear using an assumption of 10 dB loss across the façade) but which are definitely observed as having adverse health effects starting in the range 55–60 dB(A) façade. These outcomes are for chronic exposure to road traffic noise estimated using a standard composite noise metric (usually L_{den}).

Other guidance recommendations

WHO Europe's Burden of Disease from Environmental Noise report (2011) looked at the risk of cardiovascular disease (specifically ischemic heart disease and hypertension) from increased noise levels. It notes that no myocardial risk is detected at noise levels under 60 dB(A). This report relied on several assumptions to arrive at estimates for exposure-response relationships, which in turn were used to estimate the disease burden from environmental noise, measured in Disability Adjusted Life Years (DALYs). Such estimates of thresholds need to be interpreted with caution.

6.3 Discussion on higher level studies with cognitive outcomes

Outcomes and their importance

Cognitive outcomes are not commonly considered a health outcome unless they are persistent and affect the quality of social interaction, life opportunities or activities of daily living. Many of the cognitive outcomes considered by studies covered by the systematic review could be more properly considered educational or learning outcomes. Generally, experimental studies are able to report only short term cognitive deficits arising from noise interference with cognitive tasks. They provide insight into kinds of cognitive functions that noise can interfere with and possible thresholds for this interference. However, they cannot provide direct evidence for the level at which noise may cause persistent cognitive deficit.

The systematic review identified 14 observational and 15 experimental studies. The body of evidence was given an overall NHMRC rating statement of D, where the body of evidence is weak and findings cannot be trusted.

Higher quality studies included observational studies of NHMRC study type II (prospective cohort) and risk of bias rating one or two, or NHMRC study type IV (cross-sectional) and risk of bias rating one, and experimental studies with NHMRC study type (all III-1 or III-2) (Clark, 2006, 2013; Enmarker, 2004; Hygge, 2002; Hygge, 2003a; Klatte, 2007; Ljung, 2009; Pujol, 2014; Sandrock, 2010; Sörqvist, 2010; Stansfield, 2005; Sukowski, 2007; Trimmel, 2012). These are discussed below.

Higher quality studies

A number of these studies (mostly experimental in design) examined the relationship between noise and various aspects of memory. All studies that considered the effect of road or aircraft noise on an aspect of memory found a significant relationship with at least one aspect of memory (Enmarker, 2004; Hygge, 2003a; Sörqvist, 2010; Stansfield, 2005; Hygge, 2002). Klatte (2007), the only study that assessed rail noise, found a non-significant effect of rail noise on short term memory. Enmarker (2004) and Hygge (2002) considered attention in their studies but found noise did not have a significant effect.

The four experimental studies examined a range of noise exposures and outcomes. Three of these found an effect of noise on academic performance (Ljung, 2009; Sukowski, 2007; Trimmel, 2012). The study finding no effect of noise on academic performance (Sandrock, 2010) exposed participants to higher levels of noise in the control group compared to other studies, which might have been a factor in the non-significant result.

Observational studies that examined the effect of noise on academic performance all considered the influence of aircraft noise alone. The RANCH studies recruited students aged nine to 10 from 98 schools around airports in the Netherlands, Spain and the United Kingdom (Clark, 2006, 2012; Stansfeld, 2005). These considered outcomes related to academic performance such as school-based tests or other academic abilities, including mathematical reasoning, grammatical reasoning and reading comprehension. The RANCH studies found a significant effect on reading comprehension but not attention (Clark, 2006, 2012; Stansfeld, 2005). A study by Pujol (2014) found a significant effect of school noise on language and mathematical performance. A follow-up study by Clark (2013) of primary school children in the London arm of the RANCH study showed only non-significant decreases in reading comprehension persisting after six years.

In general, observational studies reported a large number of cognitive outcomes, did not report consistent direction of effect of cognitive outcomes, and did not report consistent effects across studies. Studies adjusted for a large range of potential confounders. However, we cannot discount a possible residual effect from socioeconomic status or other related confounders.

The high level studies suggest that noise may acutely interfere with some aspects of cognitive performance. Impairment may vary according to type of noise source, type of task and level of difficulty. There was insufficient evidence of what the long-term effects from environmental noise may be, or whether short-term effects persist over the longer term. These mixed findings may be attributable to the quality of the study designs or absence of high quality longitudinal studies but also reflect the inherently complex nature of cognitive processing.

Other guidance recommendations

In its report on the burden of disease from noise assessment, WHO (2011) proposed a hypothetical exposure–response relationship, where it is assumed that no children are affected at levels under 50 dB(A) L_{dn}, and that 100 per cent were affected at levels over 95 dB(A) L_{dn}. However, this report relied on several assumptions to estimate exposure-response relationships that were then used to estimate the disease burden from environmental noise, measured in Disability Adjusted Life Years (DALYs). Such estimates of dose–response relationships and thresholds need to be interpreted with caution.

6.4 Limitations

Limitations imposed by the quality of the body of evidence available for the systematic reviews have been discussed in chapters 3 to 5. Many studies did not consider the duration of exposure to noise, particularly for cardiovascular disease, which could have an impact on findings. Most studies were observational studies with a high risk of bias due to potential confounding, and there are issues with external validity of experimental studies (applicability of experimental findings to real world situations). These and the heterogeneity of measurement of both noise and outcomes restricted any attempt at meta-analysis of results in the systematic reviews.

Causality is difficult to demonstrate without randomised controlled trials or prospective cohort studies, and these studies are difficult or impossible to conduct in the area of environmental noise. Sections 10 and 11 in appendix A detail the overall quality assessment process using the GRADE guidelines (Guyatt et al., 2011), informed by relevant recommendations from the NHMRC (1999).

GRADE is an accepted method of providing a structured process for rating the quality of evidence in systematic reviews. However, it was developed primarily in the context of clinical trials, and there are ongoing debates about its application for public health. This includes environmental noise health effects, where randomised control trials are often not possible. The limitations in applying GRADE guidelines to public health evidence have been noted previously, including in a study by two members of the GRADE working group (Rehfuess and Akl, 2013). One issue identified was the low quality evidence grading for all observational studies – non-epidemiological evidence, such as experimental studies, is regarded as very low quality. Other issues included uncertainty about how to apply the GRADE criteria to narrative summaries, and potential for policymakers to misinterpret the GRADE terminology to describe the quality of evidence. The authors suggested the GRADE working group consider modifications to the criteria to better suit reviews of public health interventions.

The GRADE criteria used to rate evidence in the systematic reviews cited here have been modified to account for issues with experimental studies (see appendix A, section 7). While the formal GRADE requirement rates all observational studies as ‘low quality’, the studies we reviewed may have adopted close to the best feasible design for many of the measured noise outcomes.

7 SUMMARY AND RECOMMENDATIONS

This chapter summarises the findings, identifies the gaps in the literature and considers future priorities to protect and promote human health in relation to environmental noise.

7.1 Summary statement on environmental noise and sleep disturbance

There is consistency across higher quality studies to suggest a causal relationship between environmental noise and sleep disturbance above 55 dB(A) ($L_{night,outside}$) at the building façade.

Table 7-1 summarises the findings from the systematic review and areas of concern.

Table 7-1: Summary of current evidence on the effect of noise on sleep disturbance and dose–response, sources, thresholds and individual vulnerability

Concern	Summary of effects on sleep disturbance
Dose–response	It is likely there is a dose–response relationship between noise and physiological effects on sleep which some studies show begins above 32 dB(A) L_{Amax} measured at the ear (about equivalent to 42 dB(A) L_{Amax} at the façade). While physiological effects have been observed at these levels, this does not suggest this is the threshold for adverse health effects.
Variations by source	The systematic review concludes it is plausible that aircraft, rail and road traffic noise have differential effects on sleep quality. However, because available data are limited, it is not possible to draw definitive conclusions on the nature and magnitude of these differences.
Threshold	There is consistency across higher quality studies to suggest sleep disturbance above 55 dB(A) ($L_{night,outside}$) at the façade. Some studies show physiological effects below 55 dB(A) ($L_{night,outside}$) but because of the studies' limitations, the evidence was not sufficient to say when these outcomes constitute an adverse health effect.
Vulnerable populations	Evidence from the systematic review raises the possibility that some effects may be greater in certain populations, but it is not strong or complete enough to draw strong conclusions on vulnerable groups. WHO's night noise guidelines for Europe report identifies children, elderly people, pregnant women and shift workers as potential at-risk groups.
Gaps and research needs	Observational research should ideally be longitudinal in design. Use of standardised sleep measures and accurate noise exposure measures (not proxies), and appropriate control of covariates with potential to confound the findings, would help to compare and pool studies. Studies are needed that allow for further comparison of the effects of different noise sources, as well as formal examination of mechanisms that may link environmental noise and sleep (annoyance).

7.2 Summary statement on environmental noise and cardiovascular disease

The larger prospective cohort studies that more comprehensively controlled for confounders suggested a causal relationship between chronic exposure to environmental noise and cardiovascular outcomes above 60 dB $L_{Aeq,day,16h}$ at the façade. Note that the $L_{Aeq,day,16h}$ metric measures sound from 7 am to 11 pm and is an outdoor value.

Table 7-2 summarises the findings from the systematic review and areas of concern.

Table 7-2: Summary of current evidence on the effects of noise on cardiovascular disease and dose–response, sources, thresholds and individual vulnerability

Concern	Summary regarding effects on cardiovascular health
Dose–response	Variation in research design, study quality, adjustment for confounders, and outcome reporting make construction of dose–response relationships difficult. A small number of studies formally examined whether there was a dose–response relationship between noise exposure and cardiovascular outcomes. These studies were suggestive but not conclusive of a dose–response relationship. Many studies reported that stronger relationships with cardiovascular outcomes were observed as noise levels increased.
Variations by source	The systematic review concludes it is plausible that aircraft, rail and road traffic noise have differential effects on cardiovascular health, but existing evidence is not conclusive.
Threshold	The larger studies that more comprehensively controlled for confounders suggested adverse effect on the cardiovascular system occur above 60 dB $L_{Aeq,day,16h}$ at the façade. Note that the $L_{Aeq,day,16h}$ metric measures sound from 7 am to 11 pm and is an outdoor value. Given the variability in research designs and study quality, summary threshold effects could not be determined from the studies. Some studies offer findings that indicate levels at which adverse outcomes are observed, although these do not indicate clear thresholds.
Vulnerable populations	Evidence from the systematic review suggests the association between aircraft noise exposure and hypertension was stronger in older individuals, in those with high levels of annoyance and in individuals who had lived in noise exposed areas for a longer period. Road traffic noise was found in some studies to be associated with hypertension, coronary heart disease and myocardial infarction in middle aged adults and also in individuals who had lived in noise exposed areas for a longer time. There were significant but inconsistent gender differences in some studies.
Gaps and research needs	There is a need to better identify vulnerable groups and subgroups, and those who have lived in a high noise exposure area for a longer period (>10 years). Future studies should investigate whether factors such as annoyance mediate the association between noise exposure and cardiovascular health. Any further research should use study designs that show causality and use objective outcome measures to reduce bias. Many of the studies that considered cardiovascular outcomes did not comprehensively control for confounding, particularly air pollution.

7.3 Summary statement on environmental noise and cognition

There is some evidence that increased levels of environmental noise are associated with poorer cognitive performance. This is reflected in a range of measures assessing reading comprehension, memory and attention.

Many of the findings between studies were mixed, and the nature of the relationship between environmental noise and cognition requires further investigation.

There is insufficient evidence of a causal effect of environmental noise on persistent cognitive or learning deficits.

Table 7-3 below summarises the findings from the review and areas of concern.

Table 7-3: Summary of evidence on the effects of noise on cognition and dose–response, sources, thresholds and individual vulnerability

Concern	Summary regarding effects on cognition
Dose–response	The systematic review did not identify studies that formally examined dose–response relationships between environmental noise and cognitive outcomes. Some studies did report significant linear associations between noise exposure and cognition, suggesting that the effects on cognition are more pronounced at increased noise levels.
Variations by source	The systematic review noted there is limited evidence as to whether the associations between environmental noise and cognition varied by noise sources. This is primarily because very few studies examined the effects of multiple sources of noise. Because studies used different methods, it was not possible to directly compare results between studies. However, it is possible that aircraft noise is more disruptive to children's concentration.
Threshold	The systematic review did not provide a clear indication of a threshold but it suggested there may be distinct threshold effects for different cognitive outcomes.
Vulnerable populations	Evidence from the systematic review is not sufficient to identify vulnerable groups. Most studies were conducted on children, and it seems reasonable to suggest that children are a vulnerable population with regards to noise and cognition. Subgroup effects among different children groups, such as gender, are inconclusive.
Gaps and research needs	More research is needed to clarify the nature of the relationship between environmental noise and cognition, taking account of specific cognitive outcomes and chronic noise exposure. These should include well-designed prospective studies and experimental studies that involve randomisation and that compare the effects of different noise sources. Observational studies would also be useful to identify vulnerable populations, which could then be further examined in experimental studies. It would be valuable for studies to examine the role of annoyance as a mediator linking environmental noise to cognition.

7.4 Overall summary statement for the effect of environmental noise on health

There is sufficient evidence of a causal relationship between environmental noise and both sleep disturbance and cardiovascular disease, to warrant health based limits for residential uses.

During the night-time, an evidence based limit of 55 dB(A) at the facade using the $L_{eq,night,}$ or similar metric and an eight-hour night-time period is suggested.

During the day-time, an evidence based limit of 60 dB(A) at the facade measured using the $L_{eq,day,}$ or similar metric and a 16-hour day-time period is suggested.

7.5 Recommendations

It is likely that community and public health concern over environmental noise will grow. This is particularly due to increasing urban density along busy transport corridors, growth in urban transportation, significant shifts in inner city land use, growing residential use of rezoned industrial areas, and greater information and evidence.

This report confirms and expands on the findings of the enHealth report on the health effects of environmental noise published in 2004. The current evidence indicates that environmental noise is an ongoing public health problem, and one that deserves more attention than it receives.

Four main recommendations are presented as measures to address the health impacts of environmental noise. They are:

1. recognise that environmental noise is a health risk
2. promote measures to reduce environmental noise and health impacts
3. address environmental noise in planning and development activities
4. foster research to assist policymaking and action.

These recommendations are not considered exhaustive and may be subject to change in light of further evidence.

7.5.1 Recommendation 1: Recognise that environmental noise is a health risk

Policy

Recommended actions	Responsibility	Priority
Consider this review when developing national environmental noise goals	State and territory health agencies	High
State and territory and Australian Government agencies to include noise as an important environmental health issue for strategic and local planning	State and territory health agencies	High
Review adequacy of existing health guidelines in state and territory legislation	enHealth	High

Interventions

Recommended actions	Responsibility	Priority
Promote awareness of the impacts of environmental noise on health	Relevant agencies, stakeholders and non-government organisations	Medium

Information

Recommended actions	Responsibility	Priority
Inform communities and stakeholders of national and international standards and guidelines	State and territory health agencies, other relevant agencies, stakeholders and non-government organisations	Medium

7.5.2 Recommendation 2: Promote measures to reduce environmental noise and associated health impacts

Policy

Recommended actions	Responsibility	Priority
Review consistency of existing legislation across all levels of government	enHealth, state health, environment and planning authorities including the Australian Building and Construction Commission	High

Interventions

Recommended actions	Responsibility	Priority
Review noise arising from transportation, including noise criteria for areas adjacent to transport infrastructure	State health, environment and planning authorities including the Australian Building and Construction Commission	Medium
Promote noise mitigation measures (for example, acoustic barriers or noise insulation in residential buildings) and the use of licensing controls to limit noise impacts	State health, environment, transport and planning authorities including the Australian Building and Construction Commission	Medium

Information

Recommended actions	Responsibility	Priority
Develop a national environmental noise reduction education program, which could be supplemented with additional state-specific campaigns	enHealth, state and territory health agencies	Medium

7.5.3 Recommendation 3: Address environmental noise in planning and development activities

Policy

Recommended actions	Responsibility	Priority
Include environmental noise in the health impact assessment of proposed developments, where warranted	State health, environment and planning authorities including the Australian Building and Construction Commission	High
Determine baseline environmental noise levels to inform planning actions (noise mapping)	State health, environment, transport and planning authorities	High
Review noise control practices and how to further integrate noise control into planning processes, for all levels of government (with attention to future noise research findings)	State health, environment and planning authorities	Medium
Foster national consistency for: • guidelines on how to minimise or prevent environmental noise arising from developments (that is, appropriate attention to layout, design and construction) • limiting noise arising from major sources • methods to set noise limits	State health, environment and planning authorities including the Australian Building and Construction Commission	Medium

Interventions

Recommended actions	Responsibility	Priority
Carry out baseline monitoring of environmental noise levels over time to ascertain existing ambient levels across a broad range of populations and land use areas. This could be used to inform land use planning or burden of disease studies	Environment, transport and health agencies	High
Apply appropriate controls where noise is known to have an effect	Regulatory authorities	High
Develop national and state action plans for both the long and short term to integrate planning and research at all levels of government	enHealth, State health, transport, environment and planning authorities	Medium
Develop guidelines for noise sensitive developments for layout, design and construction	Planning, environment and health agencies	Medium

Information

Recommended actions	Responsibility	Priority
Develop state information strategies to keep communities informed of advances in measures to improve noise	State health, environment and planning authorities including the Australian Building and Construction Commission	Medium

7.5.4 Recommendation 4: Foster research to support policymaking and action

Policy

Recommended actions	Responsibility	Priority
Identify factors giving rise to sensitivity to noise and vulnerability to non-auditory health effects to inform environmental, planning and health policies	State and territory health agencies, enHealth, key researchers	High

Interventions

Recommended actions	Responsibility	Priority
Conduct a rigorous evaluation of national, state and city population exposures to each major noise source	State and territory environment agencies, health agencies, such as National Health and Medical Research Council enHealth, key researchers	High
Support noise mapping projects to determine community noise exposures to each major noise source, which could be used to inform land use planning or burden of disease studies	Health, environment and transport stakeholders	High
Conduct evaluations of noise reduction schemes on community health	State health, environment and planning authorities including the Australian Building and Construction Commission, enHealth, key researchers	Medium
Promote further research on the effects of noise on learning performance in children, sleep disturbance, annoyance and cardiovascular health and mental wellbeing to establish threshold levels	State health, environment and planning authorities including the Australian Building and Construction Commission, enHealth, key researchers	Medium

Information

Recommended actions	Responsibility	Priority
Translate research findings into useful information for community and relevant stakeholders	State health, environment and planning authorities including the Australian Building and Construction Commission, enHealth, key researchers	Medium

Concluding remarks

Although the body of evidence is largely still emerging, there is sufficient evidence to suggest that noise affects health. It is important to consider actions to reduce environmental noise exposure where feasible. This would likely have a positive impact through health benefits.

A number of areas require further investigation and particularly for the Australian context. Environmental noise in rural areas has not been well researched because the low population density makes it difficult to conduct studies with sufficient statistical power to confirm or refute any hypothesis.

Lack of noise mapping and determination of population exposure by noise levels constrains estimates of the burden of disease from noise exposure. Environmental noise therefore needs to be prioritised on the research agenda**.**

Research that would have a direct impact on policy would be intervention studies examining the effects of change in noise exposure on changes in population health. Health agencies have a critical role to play in developing an appropriate research framework with academic institutions, transport, environment and planning agencies.

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8.6 Chapter 6

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APPENDIX A: REVIEW OBJECTIVES AND METHODOLOGY

1. Evidence reviews

NSW Health convened an expert advisory group to assist in developing this document. It also commissioned the Centre for Health Initiatives at the University of Wollongong to do systematic reviews of the evidence for three health outcomes: sleep disturbance, cardiovascular diseases and cognition.

2. Review objectives

The review identified and appraised international evidence on the influence of exposure to environmental noise on sleep, cardiovascular and cognitive outcomes.

The primary research question was: 'What is the evidence for an effect of environmental noise on sleep, cardiovascular and cognitive outcomes?'

Four sub-questions were:

1. Is there a dose–response relationship between environmental noise and sleep, cardiovascular and cognitive outcomes?
2. Is there any evidence that certain populations, such as children, are particularly vulnerable to the effects of environmental noise on sleep, cardiovascular and cognitive outcomes?
3. Does the association between environmental noise and sleep, cardiovascular or cognitive outcomes vary by noise source, such as rail, road and aircraft?
4. Is there any evidence that annoyance is a mediator linking environmental noise exposure to sleep, cardiovascular and cognitive outcomes?

A protocol was developed with guidance from the expert advisory group for this review. This outlined the scope, research questions and criteria for selecting and appraising studies, templates for extracting data, and methods for synthesising the results.

The review followed established guidelines, such as the NHMRC guidelines (1999) and the Cochrane Collaboration guidelines (Higgins and Green, 2011).

It involved six steps:

1. Refining the research question and scope
2. Conducting an extensive search of the academic literature
3. Searching the websites of international agencies and conducting Google searches to identify grey literature
4. Extracting the relevant data
5. Assessing the quality of the selected studies
6. Systematically synthesising the selected studies.

This review informs chapters 3 to 7 of this document.

3. Literature search

A comprehensive and systematic search identified all relevant studies in peer reviewed and grey literature sources published from January 1994 to March 2014. This updates the previous enHealth review published in 2004, which was not a systematic review.

An initial 'scoping search' in December 2013 provided a brief overview of the evidence base and serve as a basis for scoping decisions. The formal search was done in March to June 2014 (bibliographic database searches) and July 2014 (internet searches). The results of the database searches and citations of relevant reports and articles identified in the grey literature search were uploaded to an EndNote library (EndNote X7, www.endnote.com) for appraisal. Full details of the search process are in the chapters addressing sleep, cardiovascular and cognitive outcomes.

4. Grey literature and hand searching

Primary studies published in the grey literature (not in peer reviewed journals) were identified by searching various online sources. Websites of key organisations (identified by the expert advisory group) and Google advanced search were searched. Full details of the search methods and results of the grey literature search are in the chapters addressing sleep, cardiovascular and cognitive outcomes.

Key journals, where a large proportion of included studies were published, were also hand searched by accessing the journal online and browsing archives for the period January 1994 to March 2014. These included:

- Noise and Health
- Journal of Sound and Vibration
- Journal of the Acoustical Society of America
- Applied Acoustics.

The reference lists of included studies and other relevant reviews were scanned for any additional studies.

5. Study selection and appraisal

Studies were selected for inclusion using a two-stage process conducted by two research team members (with 20 per cent random overlap to ensure consistency). The first stage involved scanning titles and abstracts in EndNote and excluding based on obvious deviations from the inclusion criteria. Full texts were retrieved for all remaining citations. The second stage involved reading the full text to ascertain whether the study fully met the inclusion criteria. The culmination of stage two was a final dataset of included studies.

The criteria used to select studies for review are in Table A-1.

Table A-1: Inclusion criteria for the systematic reviews.

Topic	Details
Participants	The review considered all studies that involve human subjects of any age.
Time periods	The review was limited to articles published between January 1994 and March 2014. This time frame was chosen to include the most relevant and recent studies, including those reviewed for the previous enHealth noise and health guidelines (2004).
Language	English language articles were included.
Noise exposure (source and how it was measured)	Studies were included if they specifically addressed environmental sources of noise. While this primarily means noise emitted from road, rail and air traffic, other sources considered relevant for this review included industrial and capital works, ventilation noise emitted from external sources in neighbouring buildings, and general community noise (not emitted from one's own property). Noise sources not within scope included: Occupational noise experienced by employees in the workplace Domestic sources of noise and their effects (e.g. noise from within neighbouring apartments Infra-sound and wind farms. A number of studies looked at classroom acoustics and cognition. Most of these were excluded because the noise source of interest was either within the classroom or emitted from within the school grounds. Studies were included only if the noise source of interest was external to the school and a sufficient measure of exposure was utilised. Studies were also required to include a reliable measure of exposure. This included a broad array of tools from direct measurement to estimates obtained from models or contour maps. Studies were excluded if only proxy measures of noise exposure were used (e.g. noise annoyance, proximity to a roadway).
Sleep outcomes	Studies were included if they addressed one or more sleep disturbance outcomes. These ranged from self-reported sleep quality to polysomnography. Studies assessing sleep disturbance among shift workers, who may not sleep during night time hours, were also included.
Cardiovascular disease outcomes	The specific focus of this review was on outcomes directly relevant to cardiovascular disease; including hypertension, heart disease, stroke and diabetes. Many studies examined blood pressure on a continuum – participants were not categorised into blood pressure categories. These studies were included as they encompass individuals with high blood pressure. Studies that focused solely on changes in hormone levels (such as catecholamines) or stress responses were excluded. These outcomes are related to cardiovascular health, but they do not provide a direct insight into the effects of environmental noise on cardiovascular disease risk. Rather, these measures are likely to be part of the causal pathway linking environmental noise with cardiovascular disease. In addition, there are numerous studies examining the effects of environmental noise on cardiovascular activity during sleep, such as cardiac arousals. These studies were excluded from the review as they are unlikely to provide an indication of risk.

Topic	Details
Cognition outcomes	Cognition may be defined in a number of ways but the relevant outcomes included in this review were those that were indicators of the cognitive functioning of healthy children, adolescents and adults with normal hearing. These include such functions as memory, comprehension, logical processing, attention and vigilance. Speech perception and the way people hear sounds was the focus of a number of studies, but not deemed relevant for this review as it is more of a mediating factor in the association between noise and cognition, rather than a cognitive outcome in itself. Listening and reading comprehension were considered to be cognitive functions and were included. A number of studies used simulated noise delivered while participants slept in a laboratory setting to study the association between noise-disturbed sleep and cognitive performance the next day. These were deemed to be more focused on the effect of the sleep disturbance on cognition rather than noise exposure itself and were therefore excluded.
Study and publication types	A broad range of study types was included. Studies were excluded if they had: no control or comparison group (e.g. descriptive study); intervention studies, except where relevant cross-sectional data (baseline) was available; and animal studies. Peer reviewed articles, official reports, and conference papers were included. Conference abstracts were included only when sufficient information was available to extract necessary data and appraise for risk of bias. Correspondence, editorials and reviews were excluded.

6. Quality assessment

The overall quality assessment process followed GRADE guidelines (Guyatt et al., 2011), informed by relevant recommendations from NHMRC (1999).

GRADE is a structured process for rating quality of evidence in systematic reviews. This process provides a summary of the evidence – the quality rating for each outcome and the estimate of effect, reflecting the extent we can be confident the estimates of effect are correct.

A range of domains were used to appraise the quality of the evidence. Risk of bias is first assessed at the individual study level. The rest are assessed by looking at the entire body of evidence for that outcome. These domains are:

1. Risk of bias – assessed at individual study level. Used to assess limitations with the study and degree of confidence in the findings
2. Inconsistency of results – inconsistency in participants, methodology and outcomes across the body of evidence. An evaluation of the similarity of point estimates and/or extent of overlap of confidence intervals may be used
3. Indirectness of evidence – the differences between study characteristics (such as participants, exposures and outcomes) and those of interest (such as populations of interest) within the body of evidence. The greater the difference, the more indirect the evidence. May be appropriate to use interchangeably with the terms ‘applicability’ and ‘generalisability’
4. Imprecision – an assessment of 95 per cent confidence intervals (CI) to ascertain whether the estimate of effect for the body of evidence is sufficiently precise. This is more difficult if CIs are not reported and is generally only used in meta-analysis
5. Publication bias – suspected when evidence comes from a number of small studies, most of which have been commercially funded

6. Large magnitude of effect – presence may justify increasing the rating for the quality of the body of evidence
7. Plausible confounding, which would reduce a demonstrated effect
8. Dose–response gradient – presence may justify rating up the quality of the body of evidence.

Quality assessment involved two main stages.

First, the risk of bias within each individual study and each individual outcome within the study was assessed. The NHMRC level of evidence for study type was also recorded.

Second, the overall quality of the body of evidence for each individual outcome was assessed. See 'Evidence quality' below.

7. Risk of bias

Risk of bias is the risk that authors will overestimate or underestimate the true effect of a particular exposure (Higgins et al., 2011). Risk of bias is assessed by looking at features of the design and execution of individual studies that have the potential to affect the validity of findings. Risk of bias is distinguished from the 'methodological quality' of a study. The latter may refer only to the extent to which study authors conducted their research to the highest possible standards and not the extent to which results should be believed. A study may be performed to the highest possible standards and yet still have an important risk of bias (Higgins et al., 2011).

Risk of bias assessment was conducted by two researchers, with inter-coder reliability checked on 20 per cent of the sample to ensure consistency, and taking into account that judgements will involve a certain level of subjectivity. Any discrepancies were reviewed by a third researcher.

Assessment of risk of bias was informed by the GRADE guidelines risk of bias criteria (Guyatt et al., 2011); and the Cochrane Collaboration risk of bias tool (Higgins and Green, 2011). Further information on the GRADE criteria is available in sections 10 and 11 of this appendix.

Quality assessment tools such as GRADE are typically developed for the assessment of randomised controlled trials. Where appropriate, GRADE guidelines were modified to be suitable for assessing the studies in this review. This applied particularly to experimental studies, as GRADE guidelines emphasise allocation concealment and blinding in the risk of bias assessment. These criteria may be less relevant to experimental studies that are not randomised control trials. Therefore, we modified GRADE criteria to include a rating of 'randomisation and counterbalancing of allocation'. Studies using an appropriate method of allocation to experimental conditions (such as randomisation or counterbalancing) are rated as having a low risk of bias.

8. Evidence rating

Once risk of bias ratings were completed for all papers for a given outcome, a rating of the overall body of evidence was done. GRADE offers four levels of evidence quality: high, moderate, low and very low. These levels imply a gradient of confidence in estimates of treatment effect, and thus a gradient in the consequent strength of inference. Randomised trials begin as high quality evidence and observational studies as low quality evidence. Quality may be downgraded as a result of limitations in study design or implementation, imprecision of estimates (wide confidence intervals), variability in results, indirectness of evidence, or publication bias. Quality may be upgraded because of a very large magnitude of effect, a dose–response gradient, and if all plausible biases would reduce an apparent treatment effect (appendix A, sections 10 and 11).

To be consistent with the NHMRC, we also appraised the evidence according to NHMRC levels of evidence ratings (Table A-7). These ratings were informed by GRADE ratings as well as study design. Details for interpreting each rating are shown in Table A-2.

Table A-2: NHMRC evidence statements

Evidence rating	Description
A	Findings from the body of evidence can be trusted
B	Findings from the body of evidence can be trusted in most situations
C	The body of evidence has limitations and care should be taken in the interpretation of findings
D	The body of evidence is weak and findings cannot be trusted

9. Data synthesis

Narrative synthesis is a textual approach to synthesis to 'tell the story' of the findings. This was chosen as the most appropriate approach to synthesis, given the diverse range of study types and the nature of the research questions.

Formal guidelines for narrative synthesis are not available. However, current guidelines for the conduct of systematic reviews (CRD, 2009) suggest that synthesis should incorporate these elements:

- developing a theory of how the intervention works, why and for whom
- developing a preliminary synthesis of findings of included studies
- exploring relationships within and between studies
- assessing the robustness of the synthesis.

These features are primarily concerned with systematic reviews of intervention studies. Only the last three elements were therefore used to guide the data synthesis stage.

10. GRADE criteria

The GRADE criteria are different for observational and experimental studies (Table A-3). Criteria 1 for experimental trials have been modified to better suit the types of studies in this review (not randomised controlled trials).

Table A-3: GRADE risk of bias criteria

Criteria	Questions
Risk of bias in experimental trials	
1. Lack of allocation concealment (changed in this review to randomisation/ counterbalancing of allocation)	Was there an adequate method of allocation? (randomisation or counterbalancing)
2. Lack of blinding	Were participants, personnel and outcome assessors 'blind' to intervention?

Criteria	Questions
3. Incomplete accounting of patients and outcome events	Was the trial stopped early? Were patients analysed in the groups to which they were randomised?
4. Selective outcome reporting bias	Is there incomplete or absent reporting of some outcomes and not others on the basis of the results?
5. Other limitations	Were there any other limitations that could affect the validity of the findings?
Risk of bias in observational studies	
1. Failure to develop and apply appropriate eligibility criteria (inclusion of control population)	**Cohort** Was the cohort representative of the population of interest? Were participants in different exposure groups recruited from the same population or matched and over the same period? **Case control** Were cases and controls recruited from the same population or matched and over the same period?
2. Flawed measurement of both exposure and outcome	**All** Was the exposure clearly defined and accurately measured? Were the main outcome measures used accurate (valid and reliable)? Did they use subjective or objective measurements? Were the measurement methods similar in different groups? Were the statistical tests used to assess the main outcomes appropriate? **Cohort** Do the analyses adjust for different lengths of follow-up? **Case control** Period between the intervention and outcome the same for cases and controls?
3. Failure to adequately control confounding	**All** Were all relevant prognostic factors measured? What was missed? (genetic, environmental, socio-economic) All relevant confounders addressed in design and/or analysis?
4. Incomplete follow-up	**All** Was follow-up complete enough? Was follow-up long enough? **Cohort** Anything special about people leaving or entering the cohort? **Cross-sectional** NA

Each study (or outcome, where multiple outcomes were assessed in one study) was given a score of 1, 2 or 3 based on the risk of bias found (see Table A-4 for details of scoring). At this stage the scores were not comparable across study types given that a randomised controlled trial may receive a high risk of bias score and a cross-sectional study may receive a low risk of bias score.

Table A-4: Risk of bias summary scores

Bias Score	Definition
1	Low risk of bias for all key criteria
2	Crucial limitations for one criterion or some limitations for multiple criteria sufficient to lower one's confidence in the estimate of effect
3	Crucial limitation for one or more criteria sufficient to substantially lower one's confidence in the estimate of effect

Both GRADE guidelines and the Cochrane Collaboration recommend against the use of scales yielding a score because calculating a score inevitably involves assigning weights to particular domains, which is not always justifiable (Higgins, Altman et al., 2011). However, summarising risk of bias within individual studies is useful when grading the quality of evidence across studies, which occurs at the data synthesis stage.

11. GRADE levels of evidence

Table A-5: Quality assessment criteria (Guyatt, Oxman et al., 2011)

Study design	Quality of evidence	Lower if	Higher if
Randomised trial	High	Risk of bias -1 Serious -2 Very serious	Large effect +1 Large +2 Very large
	Moderate	Inconsistency -1 Serious -2 Very serious	Dose response +1 Evidence of a gradient
Observational study	Low	Indirectness -1 Serious -2 Very serious	All plausible confounding +1 Would reduce a demonstrated effect or
	Very low	Imprecision -1 Serious -2 Very serious	+1 Would suggest a spurious effect when results show no effect
		Publication bias -1 Likely -2 Very likely	

Table A-6: Quality of evidence grades

Grade	Definition
High	We are very confident that the true effect lies close to that of the estimate of the effect
Moderate	We are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low	Our confidence in the effect estimate is limited: the true effect may be substantially different from the estimate of the effect
Very low	We have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of effect

Table A-7: NHMRC evidence hierarchy (NHMRC 2009)

Level	Intervention	Diagnostic accuracy	Prognosis	Aetiology	Screening intervention
I	A systematic review of level II studies	A systematic review of level II studies	A systematic review of level II studies	A systematic review of level II studies	A systematic review of level II studies
II	A randomised controlled trial	A study of test accuracy with: an independent, blinded comparison with a valid reference standard, among consecutive persons with a defined clinical presentation	A prospective cohort study	A prospective cohort study	A randomised controlled trial
III-1	A pseudo randomised controlled trial (alternate allocation or some other method)	A study of test accuracy with: an independent, blinded comparison with a valid reference standard, among non-consecutive persons with a defined clinical presentation	All or none	All or none	A pseudo randomised controlled trial (alternate allocation or some other method)
III-2	A comparative study with concurrent controls: Non-randomised experimental trial Cohort study Case-control study Interrupted time series with a control group	A comparison with reference standard that does not meet the criteria required for Level II and III-1 evidence	Analysis of prognostic factors among persons in a single-arm of a randomised controlled trial	A retrospective cohort study	A comparative study with concurrent controls: Non-randomised experimental trial Cohort study Case-control study

Level	Intervention	Diagnostic accuracy	Prognosis	Aetiology	Screening intervention
III-3	A comparative study without concurrent controls: Historical control study Two or more single-study Interrupted times series without a parallel control group	Diagnostic case-control study	A retrospective cohort study	A case-control study	A comparative study without concurrent controls: Historical control study Two or more single-arm study
IV	Case series with either post-test or pre-test/post-test outcomes	Study of diagnostic yield (no reference standard)	Case series, or cohort study of persons at different stages of disease	A cross-sectional study or case series	Case series

12. References

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Aviation Noise Impacts White Paper

State of the Science 2019: Aviation Noise Impacts

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**This White Paper represents a summary of the scientific literature review undertaken by researchers and internationally-recognised experts. It does not represent a consensus view of ICAO.*

SUMMARY

This paper provides an overview of the state of the science regarding aviation noise impacts as of early 2019. It contains information on impacts including community noise annoyance, sleep disturbance, health impacts, children's learning, helicopter noise, supersonic aircraft, urban air mobility and unmanned aerial systems. The paper also considers the economic costs of aviation noise. This information was collected during an ICAO/CAEP Aviation Noise Impacts Workshop in November 2017 and in subsequent follow-on discussions.

1. INTRODUCTION

The purpose of this document is to provide an overview of the state of the science in the area of aviation noise impacts. As part of its work programme, CAEP's Impacts and Science Group (ISG) was tasked with providing an updated white paper on the topic of aviation noise impacts. A white paper on aviation noise impacts was provided at the CAEP/10 meeting, and was later published in 2017 as an open access journal article[1], but it did not address some emerging areas in aviation. So instead of merely providing an update, the course taken was to extend the review to the above mentioned topics. An Aviation Noise Impacts Workshop was held for invited scientists and other observers and guests in Montreal, Canada November 1-3, 2017. The purpose of this workshop was to lay the foundation for this white paper, and over 50 attendees participated. One specific topic requested by the CAEP was for ISG to address the non-technical environmental aspects of the public acceptability for supersonic aircraft noise, and ISG began to explore this topic. In addition, the authors found much material on supersonics that had not previously been summarized for CAEP, and these details are provided in a separate document[1]. Subsequent follow-up discussions led to additions to this white paper beyond those discussed at the workshop, and this includes urban air mobility (UAM) and unmanned aerial systems (UAS) noise. The basic of metrics for aircraft noise were defined in a Glossary which can be freely accessed at the ICAO public website[2] and those will not be repeated here.

2. COMMUNITY NOISE ANNOYANCE

2.1 Definition

Community noise annoyance refers to the average evaluation of the annoying aspects of a noise situation by a "community" or group of people. Annoyance, in this context, comprises a response that reflects negative experiences or feelings such as dissatisfaction, anger, disappointment, etc. due to interference with activities (e.g., communication or sleep) or simply an expression of being bothered by the noise.

To facilitate inter-study comparisons standardized annoyance questions and response scales have been introduced by the International Commission on Biological Effects of Noise, ICBEN.[2] These recommendations have been adopted by the International Standards Organization[3], ISO TS 15666, and translated into a number of new languages, following a standard protocol.[4]

2.2 Exposure-response relationships

Over the years, many attempts have been made to relate the percentage of respondents highly annoyed by a specific noise source to the day-night average noise exposure level, L_{dn}, or a similar indicator, e.g., day-evening-night average noise exposure level, L_{den}.[5,6] The standard ISO 1996: 2016 has tables with % HA as a function of L_{dn} and L_{den} for various transportation noise sources.[7] A review by Gelderblom et al.[8] confirms these data for aircraft noise. Another review suggests different relationships, particularly for aircraft noise annoyance.[9]

2.3 Generalized versus local exposure-response relationships

While exposure-response relationships have been recommended for assessing the expected annoyance response in a certain noise situation, they are not applicable to assess the effects of a change in the noise climate. Existing survey results reveal a higher annoyance response in situations with a high rate of change, for instance, where a new runway is opened.[10,11,12] Such heightened annoyance response seems to prevail.

Since airports and communities may differ greatly with respect to acoustic and non-acoustic variables, local exposure–response relationships, if available, may be preferred for predicting annoyance and describing the noise situation with desired accuracy. Still, generalized exposure–response relationships are desirable to allow assessment across communities and to establish recommended limit values for levels of aircraft noise.

2.4 Moderating variables

Analyses show that the common noise exposure variables *per se* explain about one third of the variance of individual annoyance responses. The annoyance response is moderated by a series of other factors, both acoustic and non-acoustic. Acoustic factors can be maximum levels, number of flights, fleet composition, and their respective distribution over time. Non-acoustic factors are for instance, personal noise sensitivity and attitude towards the noise source. In the aviation industry all "non- L_{dn} factors" are commonly referred to as "non-acoustic".

Two old meta-analyses on the influence of non-acoustic factors on annoyance[13,14] showed the factors of fear of

1 www.icao.int/environmental-protection/Noise/Documents/ICAO_Noise_White_Paper_2019-Appendix.pdf
2 www.icao.int/environmental-protection/Noise/Documents/NoiseGlossary2019.pdf

danger of aircraft operations, followed by noise sensitivity and age, had the largest effects. More recent results indicate that fear is no longer a dominating modifying factor. Other important modifying factors may be distrust in authorities and expectations of property devaluation.[15] Guski et al. suggested[9] that the rate of change at an airport with respect to noise and operational procedures could be an important moderating factor. They defined two types: LRC and HRC, low/high rate of change airport. Gelderblom et al. have shown that the average difference in the annoyance response between these two types of airports, LRC and HRC, corresponds to a 9-dB-difference (9 dB ± 4 dB) in the noise exposure.[17] Guski et al. reported a similar, but smaller difference, about 6 dB.[9] The difference between the two studies is likely due to different selections and weighting of survey samples.

An important non-acoustic factor seems to be the attitude towards the noise source and/or its owner. Contrary to common beliefs, people that benefit from the air traffic are not more tolerant to aircraft noise.[18] A lack of trust in the authorities, misfeasance, and a feeling of not being fairly treated will increase the annoyance.[15] People may adapt different coping strategies, i.e. to master, minimize or tolerate the noise situation. Noise sensitive people have more difficulties coping with noise than others.[19]

If the respondents in a survey are selected according to proper random procedures, and the number of respondents is large enough to be an accurate representation of the population, individual factors will have the same effect in all surveys. However, other factors are location specific, for instance number of aircraft movements, prevalence of night time operations, LRC/HRC categorization, etc. The survey results from different airports will therefore vary unless these location specific factors are the same, or that they are accounted for statistically. Hence the search for a common exposure-response function, a “one curve fits all” solution, may not be applicable for all purposes.

2.5 Temporal trends in aircraft noise annoyance

Systematic surveys on aircraft noise annoyance have been conducted regularly over a good half century. Analyses by some researchers indicate that there has been an increase in aircraft noise annoyance over the past decades.[20,21] These authors state that at equal noise exposure levels, people today seem to be more annoyed by aircraft noise than they were 30-40 years ago.

Other researchers, however, claim that they can observe no change provided that the comparisons comprise similar and comparable noise situations.[17] Gelderblom et al. point out that the trend observations made by others can be explained by variations in non-acoustic factors, such as the fact that the prevalence of HRC airports are higher among recent surveys than among older ones. When LRC and HRC airports are analyzed separately they claim that there has been no change in the annoyance response over the past 50 years. Guski et al. on the other hand, claim that even at LRC airports the prevalence of highly annoyed people is higher for all exposure levels compared to older studies.[9]

Survey results from different airports show a large variation in the annoyance response. The result of a trend analysis based on a limited sample of surveys is therefore highly dependent on the selection criteria.

2.6 Noise mitigation strategies

Annoyance due to aircraft noise has been recognized by authorities and policy makers as a harmful effect that should be reduced or prevented. Priority is given to noise reduction at the source (e.g., engine noise, aerodynamic noise) and reducing noise impact by adjusting operational procedures and take-off and landing trajectories. Attempts to modify the noise spectrum to produce a more agreeable “sound” were made in the EU-funded COSMA project.[22] Such changes gave little or no effect. Sound insulation of dwellings is often applied, but such measures have no consequences for the outdoor experience of aircraft noise. The observed influence on annoyance of personal non-acoustic factors such as perceived control, and trust in authorities suggests that communication strategies addressing these issues could contribute to the reduction of annoyance, alongside or even in the absence of a noise reduction.

2.7 Conclusions

There is substantial evidence that there is an increase in annoyance as a function of noise level, e.g., L_{dn} or L_{den}. The noise level alone, however, accounts for only a part of the annoyance. Location and/or situation specific acoustic and non-acoustic factors play a significant role and must be taken into account.

There is conflicting evidence that there has been a change in the annoyance response in recent years. Under equal conditions, people today are not more annoyed at a given noise level than they were 30-40 years ago. However, due to changes in both acoustic and non-acoustic factors (more HRC airports, higher number of aircraft movements, etc.), the average prevalence of highly annoyed people at a given noise level (L_{dn} or L_{den}) seems to be increasing. Existing exposure-response functions should be updated and diversified to account for various acoustic and non-acoustic factors. The difference between a high rate change and a low rate change situation seems to be particularly important.

3. SLEEP DISTURBANCE

3.1 Sleep And Its Importance For Health

Sleep is a biological imperative and a very active process that serves several vital functions. Undisturbed sleep of sufficient length is essential for daytime alertness and performance, quality of life, and health.23,24 The epidemiologic evidence that chronically disturbed or curtailed sleep is associated with negative health outcomes (like obesity, diabetes, and high blood pressure) is overwhelming. For these reasons, noise-induced sleep disturbance is considered one of the most important non-auditory effects of environmental noise exposure.

3.2 Aircraft noise effects on sleep

The auditory system has a watchman function and constantly scans the environment for potential threats. Humans perceive, evaluate and react to environmental sounds while asleep.[25] At the same sound pressure level (SPL), meaningful or potentially harmful noise events are more likely to cause arousals from sleep than less meaningful events. As aircraft noise is intermittent noise, its effects on sleep are primarily determined by the number and acoustical properties (e.g., maximum SPL, spectral composition) of single noise events. However, whether or not noise will disturb sleep also depends on situational (e.g., sleep depth[26]) and individual (e.g., noise sensitivity) moderators.[25]

Sensitivity to nocturnal noise exposure varies considerably between individuals. The elderly, children, shift-workers, and those in ill health are considered at risk for noise-induced sleep disturbance.[24] Children are in a sensitive developmental stage and often sleep during the shoulder hours of the day with high air traffic volumes. Likewise, shift-workers often sleep during the day when their circadian rhythm is promoting wakefulness and when traffic volume is high. Sleep depth decreases with age, which is why the elderly are often more easily aroused from sleep by noise than younger subjects.

Repeated noise-induced arousals impair sleep quality through changes in sleep structure including delayed sleep onset and early awakenings, less deep (slow wave) and rapid eye movement (REM) sleep, and more time spent awake and in superficial sleep stages.[26,27] Deep and REM sleep have been shown to be important for sleep recuperation in general and memory consolidation specifically. Non-acoustic factors (e.g., high temperature, nightmares) can also disturb sleep and complicate the unequivocal attribution of arousals to noise.28 Field studies in the vicinity of airports have shown that most arousals cannot be attributed to aircraft noise, and noise-induced sleep-disturbance is in general less severe than that observed in clinical sleep disorders like obstructive sleep apnea.[29,30] However, noise-induced arousals are not part of the physiologic sleep process, and may therefore be more consequential for sleep recuperation.132 Short-term effects of noise-induced sleep disturbance include impaired mood, subjectively and objectively increased daytime sleepiness, and impaired cognitive performance.[31,32] It is hypothesized that noise-induced sleep disturbance contributes to the increased risk of cardiovascular disease if individuals are exposed to relevant noise levels over years. Recent epidemiologic studies indicate that nocturnal noise exposure may be more relevant for long-term health consequences than daytime noise exposure, probably also because people are at home more consistently during the night.[16,33]

3.3 Noise effects assessment

Exposure-response functions relating a noise indicator (e.g., maximum SPL) to a sleep outcome (e.g., awakening probability) can be used for health impact assessments and inform political decision making. Subjects exposed to noise typically habituate, and exposure-response functions derived in the field (where subjects have often been exposed to the noise for many years) are much shallower than those derived in unfamiliar laboratory settings.[34,35] Unfortunately, sample sizes and response rates of the studies that are the basis for exposure-response relationships were usually low, which restricts generalizability.

Exposure-response functions are typically sigmoidal (s-shaped) and show monotonically increasing effects. Maximum SPLs as low as 33 dB(A) induce physiological reactions during sleep, i.e., once the organism is able to differentiate a noise event from the background, physiologic reactions can be expected (albeit with a low probability at low noise levels).[34] This reaction threshold should not be confused with limit values used in legislative and policy settings, which are usually considerably higher. At the same maximum SPL, aircraft noise has been shown to be less likely to disturb sleep compared to road and rail traffic noise, which was partly explained by the frequency distribution, duration, and rise time of the noise events.[27,36] At the same time, the per cent highly sleep disturbed assessed via self-reports is typically higher for aircraft noise compared to road and rail traffic noise at the same L_{night} level.[37]

Although equivalent noise levels are correlated with sleep disturbance, there is general agreement that the number and acoustical properties of noise events better reflect the degree of sleep disturbance (especially for intermittent aircraft noise). As exposure-response functions are typically without a clearly discernible sudden increase in sleep disturbance at a specific noise level, defining limit values is not straight forward and remains a political decision weighing the negative consequences of aircraft noise on sleep with the economic and societal benefits of air traffic. Accordingly, night-time noise legislation differs between Contracting States.

3.4 Noise mitigation

Mitigating the effects of aircraft noise on sleep is a three-tiered approach. Noise reduction at the source has highest priority. However, as it will take years for new aircraft with reduced noise emissions to penetrate the market (and will thus not solve the problem in the near future), additional immediate measures are needed. For example, noise-reducing take-off and landing procedures can often be more easily implemented during the low-traffic night-time. Land-use planning can be used to reduce the number of relevantly exposed subjects. Passive sound insulation (including ventilation) represent mitigation measures that can be effective in reducing sleep disturbance, as subjects usually spend their nights indoors. At some airports, nocturnal traffic curfews have been imposed by regulation. It is important to line up the curfew period with the (internationally varying) sleep patterns of the population.

3.5 Recent evidence review

For sleep disturbance, a systematic evidence review based on studies published in or after the year 2000 was recently published.[37] According to GRADE[38] criteria, the quality of the evidence was found to be moderate for cortical awakenings and self-reported sleep disturbance (for questions that referred to noise) induced by aircraft noise, low for motility measures of aircraft noise induced sleep disturbance, and very low for all other investigated sleep outcomes. Significant exposure-response functions were found for aircraft noise for (a) sleep stage changes to wake or superficial stage S1 (unadjusted OR 1.35, 95% CI 1.22-1.50 per 10 dB increase in $L_{AS,max}$; based on N=61 subjects of a single study) and (b) per cent highly sleep disturbed for questions mentioning the noise source (OR 1.94, 95% CI 1.61-2.33 for a 10 dBA increase in L_{night}; based on N=6 studies including > 6,000 respondents). For percent highly sleep disturbed, heterogeneity between studies was found to be high (I^2=84%).

4. HEALTH IMPACTS

4.1 Introduction

There is good biological plausibility for health impacts of environmental noise, with potential mechanisms involving sleep disturbance, 'fight and flight' physiological response and annoyance.[39,40] The number of epidemiological studies investigating impacts of environmental noise on disease risk and risk factors has increased greatly since the previous ICAO white paper[1] and these have been used to define exposure-response relationships. Some variability is expected between epidemiological studies due to differences in populations, methodology, exposures and study design. Therefore, a combined estimate from a meta-analysis of studies with a low risk of bias is used to provide a state of the art estimate of the exposure-response relationship.

This section highlights main findings from the systematic literature reviews and meta-analyses published in 2017-2018. These reviews reference the noise and health literature up to August 2015 for cardiovascular outcomes[41] and December 2016 for birth outcomes.[42] This section also considers new publications up to end July 2018, including from the NORAH (http://www.laermstudie.de/en/norah-study/) and SIRENE (http://www.sirene-studie.ch/) studies in Germany and Switzerland respectively. Almost all studies available were conducted in European and North American populations.

In the following paragraphs it is important for the reader to be mindful of scientists' use of the terms association, correlation, and causation. The statistical finding of an association means that two variables are related. It needs additional clarification to say if it is statistically significant. For research investigating links between noise and impacts, linear correlation is usually too strong of a term to use, so the preferred term is association. Hence, associations do not necessarily mean causation. Determining causality requires a combination of evidence including biological plausibility, consistency across studies, and if available from experimental or natural experiment studies.

4.2 Aircraft noise and cardiovascular impacts

The systematic review on cardiovascular and metabolic effects of environmental noise was performed by van Kempen et al.[41] and described in detail in an RIVM (Dutch National Institute for Public Health and the Environment) report.[46] The authors reviewed studies on the association between environmental noise (different source types) and hypertension in adults (none were identified focusing on children), ischaemic heart disease, stroke and obesity published up to August 2015. Findings for aircraft noise were reported to be consistent with findings for road traffic noise, where there are more studies available.

For hypertension: the van Kempen et al.[41] meta-analysis included nine cross-sectional studies and provided an estimated increased risk of 5% (95% confidence intervals -5% to +17%) per 10 dB (L_{den}) aircraft noise (comprising 60,121 residents, including 9487 cases of hypertension). The one cohort study identified[50] (4721 residents and 1346 cases in Sweden published in 2010) did not show an overall association with hypertension incidence, but there were significant associations in subgroup analyses of males and of those annoyed by aircraft noise. The authors of the review ranked the quality of the evidence for noise from air traffic as "low" using the GRADE ranking system, meaning that further research is considered very likely to have both an important impact on confidence in the estimate of effect and to change the size of the estimate. Subsequent to the systematic review, a large case-control study (137,577 cases and 355,591 controls) from the NORAH study[51] found no associations overall for aircraft noise with hypertension, but an increased risk for the subgroup of those who went on to develop hypertension-related heart disease, i.e. more severe cases. A subsequent publication from a small cohort (N=420) with up to 9 years follow-up in Athens who formed part of the original HYENA (Hypertension and Exposure to Noise Near Airports) study found a 2.6-fold increased risk of hypertension in association with a 10 dB increase in night-time aircraft noise.[52]

Hypertension shows a positive but non-statistically significant association overall reflecting inconsistency between studies. This can be a difficult outcome to define precisely – the PURE multi-country study published in 2013 found nearly half of all cases of hypertension were unrecognised.[198] There are various issues about defining hypertension by medication use, and recognised issues about measuring blood pressure in individuals. Also, hypertension may not be the only or most important mechanism contributing to potential impacts of noise on the heart – inflammation, small blood vessel function and sleep disturbance also need to be considered.[196,197]

For ischaemic heart disease (IHD) and heart failure, findings were more consistent than for hypertension: the van Kempen et al. systematic review[41] reported a statistically significant increased risk of new cases of ischaemic heart disease of +9% (95% confidence intervals +4% to +15%) per 10 dB L_{den}, derived from a meta-analysis of two very large registry-based studies of 9.6 million participants and 158,977 cases. Taking into account evidence relating to existing as well as new cases and to mortality, the authors of the systematic review concluded "Overall, we rate the quality of the evidence supporting an association between air traffic noise and IHD as 'low'" [using the GRADE ranking system] "indicating that further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate". Subsequent published analyses from the SIRENE project using data from the Swiss National Cohort covering 4.4 million people[53], reported associations between aircraft noise and myocardial infarction mortality with increased risk of +2.6% (95% confidence intervals +0.4% to +4.8%) per 10 dB L_{den}. Highest associations between noise and IHD were seen with intermittent night-time exposures.[54] A large case-control study in Germany (19,632 cases and 834,734 controls) forming part of the NORAH study found associations of aircraft noise with diagnosis of myocardial infarction at higher noise levels (>55 dB) in the early morning hours, although not for 24 hour average noise levels. A further large NORAH study analysis[55] found a statistically significant linear exposure-response relationship with aircraft noise for heart failure or hypertensive heart disease of +1.6% per 10 dB increase in 24 hour continuous noise level (analysis based on 104,145 cases and 654,172 controls).

For stroke: the van Kempen et al. systematic review[41] considered seven studies of different designs including one cohort study (the Swiss National Cohort). Findings were mixed but the meta-analysis did not show statistically significant associations of aircraft noise with stroke outcomes. This result is consistent with subsequently published SIRENE study findings on stroke mortality also using the Swiss National Cohort but with improved noise exposure estimates.[53]

Comparisons with findings for road traffic noise: findings for aircraft noise and the cardiovascular disease outcomes presented above are consistent with those for road traffic noise as reported in the van Kempen et al systematic review.[41] In particular, for ischaemic heart disease, the systematic review rated the quality of the evidence supporting an association between road traffic noise and new cases of ischaemic heart disease to be high, providing an increased risk of +8% (+1% to +15%) per 10 dB L_{den} road traffic noise (as compared with findings for aircraft noise for this outcome of +9% (+4% to +15%) as noted above). Analogy with road traffic noise is meaningful, because, as well as impacts on annoyance, noise also functions as a non-specific stressor with non-auditory impacts on the autonomic nervous system and endocrine system. These stressor effects are seen with noise from different sources and result in adverse effects on oxidative stress and vascular function in experimental studies.[196,197]

4.3 Aircraft noise and metabolic effects (diabetes, obesity, waist circumference, metabolic biomarkers)

The van Kempen et al. systematic review[41] identified one Swedish cohort study considering aircraft noise,[56] which found a significant association between aircraft noise exposure and increased waist circumference over 8-10 years follow-up, but not for Body Mass Index (BMI) or type 2 diabetes. The authors of the systematic review concluded that further research would be likely to have an important impact on both size and statistical confidence in the estimate of effect. Three more recent publications also report some associations of aircraft noise with metabolic disturbance.[57-59] A 2017 Swiss cohort study analysis forming part of the SIRENE project suggested an approximate doubling of diabetes incidence per 12 dB L_{den} increase in aircraft noise exposure[57] and positive although non-significant associations of aircraft noise exposure with glycosylated haemoglobin, a measure of glucose control over the past three months and a predictor of diabetes.[58] A 2017 study in Korea of 18,165 pregnant women identified through health insurance records,[59] found an association between night-time but not daytime aircraft noise exposure during the first trimester of pregnancy and risk of gestational diabetes mellitus.

Findings are consistent with a hypothesis that noise exposure is related to stress-hormone-mediated deposition of fat centrally and other impacts on metabolic functioning and/or adverse effects of disturbed sleep on metabolic and endocrine function, also with results from a small number of studies considering road traffic noise that also found associations with diabetes, but more studies are needed to strengthen the evidence base for this outcome.

4.4 Aircraft noise and birth outcomes

A systematic review by Nieuwenhuijsen, et al.[42] published in 2017 considered literature published up to December 2016. Six aircraft noise studies were included, but there were too few studies to conduct a meta-analysis. Four studies (published 1973-2001) considered birth weight and all studies found associations with aircraft noise exposure, but noise exposure levels in these studies were high (> 75 dB, various metrics). A further two studies conducted in the 1970s considered birth defects, of which one found significant associations – again, noise levels considered were high. Evidence was considered such that any estimate of effect is very uncertain. The authors commented that "there may be some suggestive evidence for an association between environmental noise exposure and birth outcomes" with some support for this from studies of occupational noise exposure (which were higher than most current environmental aircraft noise exposures), but that further and high quality studies were needed. No further studies relating birth outcomes to aircraft noise have been published to date.

4.5 Aircraft noise and mental health

There remain very few studies of aircraft noise exposure in relation to wellbeing, quality of life, and psychological ill-health. Since the previous ICAO paper and publication[1] in 2017, there has been one major German analysis[60] published from the NORAH study, which found a significant association with depression as recorded in health insurance claims. Risk estimates increased with increasing noise levels to a maximum Odds Ratio (OR) of 1.23 (95% CI=1.19-1.28) at 50-55 dB (24 hour average), but decreased at higher exposure categories. The reason for this is unclear but it may potentially be due to uncertainties related to very small numbers of exposed and cases at higher noise levels. A cohort study following 1185 German school children[61] from age 5-6 to 9-10 years did not find associations of aircraft noise exposure with mental health problems (such as emotional symptoms, hyperactivity and conduct problems), but as the study used parental noise annoyance at place of residence as the measure of exposure as opposed to objectively assessed (modelled or measured) quantitative exposure levels, it is difficult to draw firm conclusions.

4.6 Conclusions

There has been a large increase in studies in recent years examining associations of noise exposure with health outcomes. The best epidemiological evidence relates to cardiovascular disease, which includes analyses from population-based studies covering millions of individuals, in particular for new cases of ischaemic heart disease. Findings for aircraft noise are consistent with those for road traffic noise (for which more studies have been conducted and where the quality of evidence is rated as high). Results from epidemiological studies are also supported by evidence from human and animal field and laboratory experimental studie[45-49] showing biological effects of noise on mechanistic pathways relating to risk factors for cardiovascular disease. This experimental evidence, together with consistency with findings for road traffic noise, supports the likelihood that associations for aircraft noise with heart disease observed in epidemiological studies are causal. However, the exact magnitude of the exposure-response estimate for heart disease varies between studies and best estimates (obtained by combining results from good quality studies in a systematic review) are likely to change as further studies add to the evidence base.

There are important gaps in the evidence base for other outcomes. Perhaps surprisingly, few studies have been conducted in relation to impact of aircraft noise on mental health. There are also few studies relating to maternal health and birth outcomes including birth weight.

Generally, health studies to date have used L_{den}, L_{day} and L_{night} metrics, most likely as these were available and had been extensively validated in annoyance studies. There is a need to examine other noise metrics that may be more relevant to health endpoints – some of the more recent studies are starting to include other metrics, including intermittency ratio,[43] maximum noise level and to examine specific time periods,[44] especially for night-time exposures. These new metrics should be additional, but not replace the standard equivalent metrics (L_{Aeq}, L_{den}) to allow for comparability of results, at least at present while the evidence base is being compiled.

5. CHILDREN'S LEARNING

5.1 Chronic aircraft noise exposure and children's learning

Several studies have found effects of aircraft noise exposure at school or at home on children's reading comprehension or memory skills[62] or standardized test scores.[63,64] The RANCH study (Road traffic and Aircraft Noise and children's Cognition & Health) of 2844 9-10 year old children from 89 schools around London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports found exposure-response associations between aircraft noise and poorer reading comprehension and poorer recognition memory, after taking social position and road traffic noise exposure, into account.[65] A 5 dB increase in aircraft noise exposure was associated with a two month delay in reading age in the UK, and a one month delay in the Netherlands.[66] These associations were not explained by co-occurring air pollution.[67] Night-time aircraft noise at the child's home was also associated with impaired reading comprehension and recognition memory, but night-noise did not have an additional effect to that of daytime noise exposure on reading comprehension or recognition memory.[68] The recent NORAH study of 1242 children aged 8 years from 29 primary schools around Frankfurt airport in Germany found that a 10 dB (L_{Aeq} 08.00am-14.00pm) increase in aircraft noise was associated with a one-month delay in terms of reading age. The RANCH and NORAH studies examine the effect of aircraft noise on children's reading comprehension starting from a very low level of exposure. This enables the studies to adequately assess where effects of aircraft begin (i.e. identify thresholds): we should not be concerned by the inclusion of the examination of such low levels of aircraft noise exposure as both the RANCH and the NORAH study adjust the results for other noise exposures (e.g., road noise in RANCH and road and rail noise in NORAH) making the assessment meaningful in terms of considering other noise exposures and ambient noise exposure per se. Effects of aircraft noise on children's learning have been demonstrated across a range of aircraft noise metrics including L_{Aeq}, L_{max}, number of events above a threshold, and time above a threshold. [64]

Data from the RANCH study and the NORAH study enable the exposure-effect association between aircraft noise exposure and children's reading comprehension to be estimated[69,70] (see Figures 1 and 2). Both studies suggest that the relationship between aircraft noise and reading comprehension is linear, so reducing exposure at any level should lead to improvements in reading comprehension. In the RANCH study, reading comprehension began to

FIGURE 1: Exposure-effect relationship between aircraft noise exposure at school and reading comprehension in the RANCH study. The vertical axis shows the adjusted mean reading z scores and 95% confidence intervals for 5-dB(A) bands of aircraft noise at school (adjusted for age, gender, and country)[66]

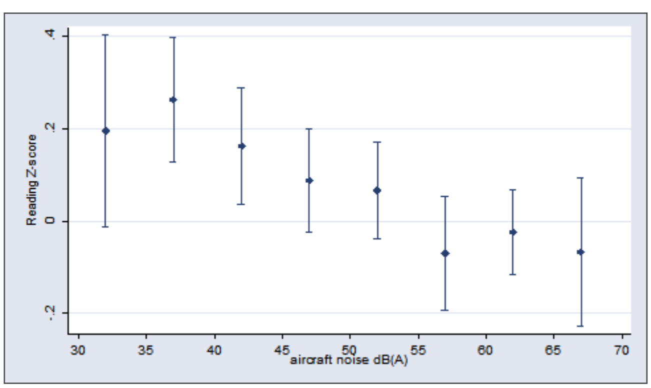
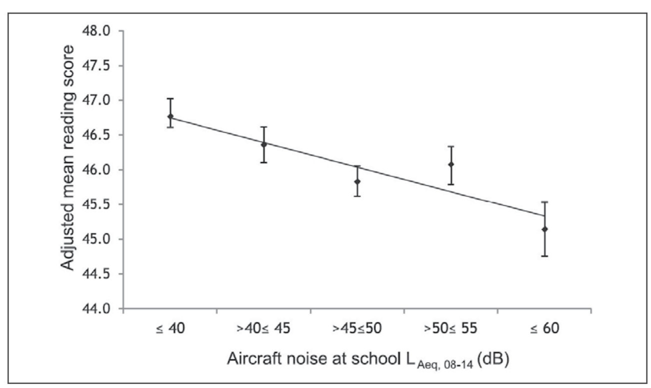


FIGURE 2: Exposure-response function between aircraft noise exposure at school and reading comprehension in the NORAH study [70]



fall below average at exposures greater than 55 dB L_{Aeq} 16 hour at school.

It is possible that children may be exposed to aircraft noise for many of their childhood years, but few studies have assessed the consequences of long-term noise exposure at school on learning or cognitive outcomes. Whilst it is plausible that aircraft noise exposure across a child's education may be detrimental for learning, evidence to support this position is lacking. A six-year follow-up of the UK sample of the RANCH study, when the children were aged 15-16 years of age, failed to find a statistically significant association but did suggest a trend between higher aircraft noise exposure at primary school and poorer reading comprehension at follow-up,[71] as well as a trend between higher aircraft noise exposure at secondary school and poorer reading comprehension at secondary school. This study was limited by its small sample size, which may be why it detects trends rather than significant associations. There remains an urgent need to evaluate the impact of aircraft noise exposure throughout a child's education on cognitive skills, academic outcomes and life chances.

5.2 How might chronic aircraft noise exposure cause learning deficits?

Aircraft noise may directly affect the development of cognitive skills relevant for learning such as reading and memory. A range of other plausible pathways and mechanisms for the effects have also been proposed. Communication difficulties might also account for the effects: teacher behavior is influenced by fluctuations in external noise, with a recent observational study finding associations between aircraft noise events and teacher voice-masking (when the teacher's voice is distorted or drowned out by noise) and teacher's raising their voice).[72] Effects might also be accounted for by teacher and pupil frustration, reduced morale, impaired attention, increased arousal – which influences task performance, and sleep disturbance from home exposure which might cause performance effects the next day.[73,74] Noise causes annoyance, particularly if an individual feels their activities are being disturbed or if it causes difficulties with communication. In some individuals, annoyance responses may result in physiological and psychological stress responses, which might explain poorer learning outcomes.

5.3 Interventions to reduce aircraft noise exposure at school

Studies have shown that interventions to reduce aircraft noise exposure at school do improve children's learning outcomes. The longitudinal Munich Airport study[75] found that prior to the relocation of the airport in Munich, high noise exposure was associated with poorer long-term memory and reading comprehension in children aged 10 years. Two years after the airport closed these cognitive impairments were no longer present, suggesting that the effects of aircraft noise on cognitive performance may be reversible if the noise stops. In the cohort of children living near the newly opened Munich airport impairments in memory and reading developed over the first two-year period following the opening of the new airport. A recent study of 6,000 schools exposed between the years 2000-2009 at the top 46 United States airports (exposed to Day-Night-Average Sound Level of 55 dB or higher) found significant associations between aircraft noise and standardized tests of mathematics and reading, after taking demographic and school factors into account.[64] In a sub-sample of 119 schools, they found that the effect of aircraft noise on children's learning disappeared once the school had sound insulation installed. These studies evidence the effectiveness of the insulation of schools that may be exposed to high levels of aircraft noise.

Sound-field systems, which ensure even distributions of sound from the teacher across the classroom, could provide a solution to improving children's learning in situations of aircraft noise. However, an evaluation of these systems in schools in the UK, which were not exposed to aircraft noise, found that whilst the systems improved children's performance on tests of understanding of spoken language they did not influence academic attainment in terms of test of numeracy, reading or spelling.[76] Whether such systems may be an effective intervention for children attending schools with high levels of aircraft noise exposure remains to be evaluated.

5.4 Conclusions

There is robust evidence for an effect of aircraft noise exposure on children's cognitive skills such as reading and memory, as well as on standardized academic test scores. Evidence is also emerging to support the insulation of schools that may be exposed to high levels of aircraft noise. Whilst a range of plausible mechanisms have been proposed to account for aircraft noise effects on children's learning, future research needs to test these pathways, to further inform decision-making concerning the design of physical, educational and psychological interventions for children exposed to high levels of aircraft noise. Further knowledge about exposure-effect relationships in different contexts, using either individually collected cognitive performance data or standardized school test data, would also further inform decision-making. It would also be productive to derive relationships for a range of additional noise exposure metrics, such as the number of noise events. To date, few studies have evaluated the effects of persistent aircraft noise exposure throughout the child's education and there remains a need for longitudinal lifecourse studies of aircraft noise exposure at school and cognitive skills, educational outcomes and life chances.

6. HELICOPTER NOISE

6.1 Exposure-response relationships

Exposure-response relationships derived for annoyance by aircraft noise were viewed as not necessarily valid for specific sources such as helicopters, low-flying military aircraft or aircraft ground noise.[6] Although relatively little is known on annoyance induced by helicopter noise, some surveys performed in the past have shown that helicopter noise is more often reported as annoying than fixed-wing aircraft noise, at similar or even lower A-weighted outdoor noise levels.[78-82] This was found for heavy military helicopters as well as for lighter civilian helicopters. A more recent survey[83] was done in three residential areas under or adjacent to helicopter corridors that were used by light civilian helicopters. The study was limited to only three surveys, but it was clear that for light civilian aircraft there was not a pronounced difference between response to fixed wing and rotary wing aircraft. The study did show that there was a residual annoyance associated with helicopter operations that was not associated with noise exposure level.

6.2 Role of non-acoustic factors

Some field studies[81,84] have shown that helicopter noise annoyance is heightened by certain non-acoustic factors, in particular fear of a crash, lack of information on the reason of the flights, and low perceived necessity of the helicopter flights themselves (such as when the helicopter is viewed as 'rich person's toy') or of the noise that is produced by them (for instance when it is felt that the pilot or operator could reduce the disturbance by choosing a different flight pattern).

A more recent study[83] also found that for three surveys completed under or near light civil helicopter routes there was 'residual annoyance,' not a function of noise exposure level, an annoyance that was constant for all noise exposures with no evident tendency to approach zero at even very low noise levels. This lack of correlation between noise exposure level; and annoyance was associated with the strong influence of non-acoustic factors. These and earlier findings suggest that observed differences in annoyance between helicopters and fixed-wing aircraft may heavily depend on non-acoustic factors.

6.3 Role of impulse noise

Several laboratory studies have explored whether the degree of impulsiveness of the helicopter noise may contribute to annoyance.[85-89] No consistent differences in annoyance were found between helicopter and aircraft noise, again suggesting that observed differences in the field were partly due to non-acoustic factors, nor did annoyance depend on the degree of impulsiveness. Therefore, the overall consensus is that there is no evidence to justify the application of an impulse correction to the noise level of helicopters with impulsive characteristics.[90-91]

6.4 Role of rattle noise and vibrations

There is evidence that helicopter noise characterized by large low frequency components may impact the building and produce rattle (i.e. sounds of rattling objects or windows within the dwelling) or vibration (the perception of vibrating building elements or furniture), which in turn may lead to increased annoyance by the helicopter noise.[92] While rattle noise and vibration may also be induced by the low-frequency components of ground noise during aircraft landing and take-off,[93,94] it is only sporadically induced by overflying fixed-wing aircraft.[95] In a large field study in the United States[96] it was found that noise from helicopters flying over was rated by subjects (seated in a wooden frame building) as more annoying than a control stimulus, but only when the helicopter induced rattle noise or vibration within the building. The results suggest a decibel offset of at least 10 dB to account for the extra annoyance when rattle or vibration were induced by the helicopter noise (i.e. the control stimulus had to be at least 10 dB higher to induce equal annoyance). An extension of this study suggested similar offset values of 10 and 8 dB for two helicopter types inducing rattle and vibration.[80] A recent study in the Netherlands suggests a lower offset, around 5-6 dB, for helicopter noise in combination with rattle noise induced within the building.[97] This conclusion is not supported for light civil helicopter surveys[83] where survey respondents did not report vibration or rattle as a source of annoyance. The relatively small degree of low frequency energy associated with light civil helicopters as compared to heavy lift helicopters is not expected to produce rattle noise, which is the most plausible explanation for the difference.

7. EN-ROUTE NOISE FROM SUPERSONIC AIRCRAFT

7.1 Introduction

Sonic booms are the unique sounds produced by supersonic aircraft. This section summarizes many of the properties and impacts of sonic booms, as we know them today.

Conventional sonic booms are widely considered to be loud, and this forms the basis of current regulations in many countries that prohibit supersonic overland flight. However, new research has enabled aeronautical engineers the tools to develop quiet “low-boom” aircraft designs that may be available in 5 to 10 years. Hence, sonic boom research needs to clearly distinguish whether the sonic booms are the conventional N-wave sounds, so called because of their letter N pressure versus time shape, or the new low-booms which are considerably smoothed. The low-booms, or “sonic thumps”, can be as much as 35 dB quieter than conventional booms.

7.2 Human response studies

Studies have shown that sonic booms can be reproduced quite accurately in the laboratory, and this makes it possible to perform subjective experiments under controlled conditions. Although no supersonic aircraft has produced a low-boom signature yet, a similar surrogate sound can be created using a special aircraft dive manoeuver. This makes it possible to conduct tests with real aircraft outdoors for either N-waves or low-booms, complementing the laboratory tests.

A number of subjective tests have been conducted. One trend seen in studies from both the U.S. and Japan is that annoyance to sonic boom noise is greater indoors compared to outdoors. The findings show that indoor annoyance can be estimated based on the outdoor sonic boom exposure. There has been recent work to establish that both rattle and vibration contribute to indoor annoyance of sonic booms. One interesting point is that although conventional N-waves can be accompanied by a startle response, it turns out that low-booms are of low enough amplitude that they don’t induce a consistent physiological startle response.

There has been substantial work in recent years to establish metrics to assess sonic boom noise. Out of a list of 70 possible metrics, a group of 6 metrics has been identified for the purposes of use in certification standards and in developing dose-response curves for future community response studies. Clearly the low-booms are much quieter than the conventional N-wave booms, but additional community studies with a low-boom aircraft need to be conducted to assess public response.

7.3 Non-technical aspects of public acceptability for sonic boom

An additional aspect that should be considered for sonic booms includes the non-technical aspects of acceptability. The CAEP Steering Group specifically requested that ISG look into this topic. A preliminary discussion has revealed a strong resemblance to the non-acoustical factors of subsonic aircraft noise, previously mentioned in Section 2 “Community Noise Annoyance” of this white paper. There are currently no peer-reviewed studies on the topic of non-acoustical factors for sonic boom noise, but it seems plausible that the knowledge of subsonic aircraft non-acoustical factors could be extended for application to sonic boom noise non-technical aspects.

7.4 Impacts of sonic boom on animals

Recently there has been renewed interest regarding the impacts of sonic boom noise on animals. Fortunately there is an extensive literature extending from before the days of Concorde to recent years, mostly for conventional N-wave aircraft.

There have been substantial studies for both livestock and other domesticated animals, and detailed studies of some wildlife species. For conventional sonic booms the animals usually show no reactions or minimal reactions, although occasionally they may startle just as humans do. There are no reported problems of developing fish eggs or of avian eggs due to sonic boom exposures. NASA conducted a number of studies in the late 1990s and early 2000s to assess the impact of overwater sonic booms on marine mammals. There is a good bit of knowledge as to how much sonic boom noise transitions from air into water, and fortunately, very little of the sound gets into the water. For the California sea lion, elephant seals, and harbor seals, careful lab experiments showed no temporary hearing shifts in those species.

In 1997 and 1998 a study of a colony of seals exposed to Concorde booms on a regular basis showed that the booms didn't substantially affect the breeding behavior of gray or harbor seals. It instead seems that these animals substantially habituated to hearing these N-wave sonic booms on a routine basis.

Most of what is known about noise impacts on animals comes from the literature of the effects of subsonic aircraft and other anthropogenic noise sources, not sonic booms, on animals. It is well known that human activities can interfere with animal communication, for example.

There have not been many specific studies on the effects of sonic boom noise on animals in recent years. Some species with good low-frequency hearing, such as elephants, have never been evaluated regarding sonic boom noise. But it makes sense that if the already tested animals were not negatively affected by sonic boom noise from conventional N-waves, that they will likely not be affected by the proposed lowbooms of the future. Long-term effects of sonic boom exposure on animals seem unlikely.

7.5 Conclusions

Much progress has been made to model and mitigate the effect of sonic booms from supersonic flight. Ongoing research to assess the impact on the public indicate that new supersonic aircraft designs will create quieter sonic thumps that are much less annoying than conventional sonic booms. Upcoming community tests with a low-boom demonstrator aircraft will collect the data needed on noise exposure and resulting public reactions.

8. UAM/UAS NOISE

8.1 Current status

New aircraft technologies for increased mobility are likely to lead to new sources of community noise. Urban Air Mobility (UAM) refers to a range of vehicle concepts and missions operating in a community, from small Unmanned Aerial Systems (sUAS) to vehicles large enough for several passengers. The sUAS are envisioned for package delivery, surveillance, agriculture, surveying, and other similar applications that can benefit from use of a small and agile autonomous system, while the larger vehicles are envisioned for on-demand urban passenger transportation.[165] Electric propulsion is seen as a key technology that could enable these kinds of systems, across the range of vehicle types and sizes.[165]

UAM vehicles have the potential to alter the community soundscape due to their noise characteristics that are qualitatively different from traditional aircraft.[166-168] In addition, similar to sonic booms from supersonic aircraft en route, the noise may not be concentrated around traditional airports. There is very little scientific research on the human impacts of noise from UAM aircraft, although there have been increased efforts to measure and model the noise generated by them and their components.[167,169-172] Two psychoacoustic studies are briefly described here.

A study[166] was conducted by NASA to evaluate human annoyance to sUAS noise, including the effect of variation in operational factors and a comparison of annoyance to noise from road vehicles. The noise from four commercially available sUAS and four road vehicles, ranging in size from a passenger car to a step van, were recorded and presented to test subjects in a specialized simulation facility. For this limited set of noise sources, a systematic offset was found that indicates the noise of sUAS is more annoying than noise from road vehicles when presented at the same loudness.

Another NASA psychoacoustic study[168] concentrated on annoyance to noise from a simulated distributed electric propulsion (DEP) aircraft. Using auralizations from noise predictions of spatially-distributed, isolated propeller noise sources, the subjective study in a specialized psychoacoustic facility found that the number of propellers and inclusion of time-varying effects were significant factors in annoyance, while variation of the relative revolutions-per-minute (RPM) between propellers was not significant. The study also developed an annoyance model based on loudness, roughness, and tonality for predicting annoyance to these DEP sounds. Despite the limitations in prediction methods and simplifications, the study identified the relevant parameters and metrics that should be studied further.

8.2 Conclusions

Growing interest in UAM aircraft has been observed from different sectors, such as hobbyists, commercial entities, the military, government agencies, and scientists.[165] There is preliminary evidence that the public may be concerned with these new noise sources intended for transportation and package delivery.[173] Although there is only a very limited amount of research on subjective reaction to noise from these new aircraft types, indications that the noise characteristics differ from traditional aircraft warrant further research to understand and predict human perception of these sounds.

9. ECONOMIC COST OF AVIATION NOISE / MONETIZATION

9.1 Introduction

Sleep disturbance, myocardial infarction, annoyance, stroke, dementia, and other health effects are increasingly recognized as economic costs of noise.[174] Recent studies estimating annual noise costs around specific major world airports are useful in considering the scale of the challenge and include: Taipei Songshan Airport €33 million[175] and Heathrow £80.3 million.[176] An unpublished student thesis by Kish (2008) suggests annual costs for aviation noise at 181 airports worldwide in excess of $1 billion, which is not out of line with the individual airport estimates.[177] It is clear that noise can be a key factor when airport expansion is considered. Values of disturbance from aircraft noise are used in analysis and planning decisions affecting airport development and operations. Their main application is in estimating the costs or benefits arising from changes in noise levels and/or exposure. It is therefore important to look at the evidence that underpins these value estimates. There are three main approaches for monetizing noise costs, two of which value the nuisance according to individual preferences: revealed preference, usually hedonic pricing, and stated preference methods, which include contingent valuation and stated choice. The third type of approach, the impact pathway, links health effects of noise nuisance to monetary values from reducing morbidity risks that are typically derived from elsewhere. These are discussed in turn below.

9.2 Hedonic Pricing (HP)

The main method using revealed preference is hedonic pricing whereby the market for an existing good or service, in this case housing, is used to derive the value for components of that good, in this case the noise environment. House price in HP is modelled as a function of property characteristics that should include all social, spatial, and environmental factors. HP then provides the percentage change in house prices resulting from a 1 dB change in noise levels.[178,179] The method has been extensively applied to the problem of aircraft noise, especially in North America. Individual studies yield a wide range of price changes from 0% to 2.3% per dB.[180] Thus a key challenge is to derive values that are applicable or transferable in different contexts.

Meta-analyses have sought to estimate consensus values based on pooled evidence from individual studies.[181-183] These meta-analyses are based on a reasonably small number of, US dominated studies, observations of 30, 29 and 53 respectively. Nelson (2004) and Wadud (2013) converge on 0.5 to 0.6% house price fall in response to a

1 dB increase in aviation noise, with caveats concerning the broad range of estimates and a dearth of studies in less developed countries. Using data on income, Kish (2008) carried out a meta-analysis on US based HP evidence, estimating a model with a low but reasonable fit, which he found did not transfer well to UK data. He et al. (2014) built on this work[184] but their model fit was poor. The evidence from these studies also suggests that values in Canada are higher[182,183] or more generically that values outside the US are higher.[184] Interestingly, Kopsch (2016) reports a meta-analysis including air and road noise, finding that aviation noise increases the NDI by 0.4 to 0.6% relative to road.[185] To conclude, the best available evidence from the HP is that house prices fall by 0.5 to 0.6%, on average, per 1 dBA increase in aircraft noise, and there is also some support for country specific effects.[182,183]

9.3 Stated Preference (SP)

Stated preference approaches have been increasingly applied to value noise nuisance especially in Europe. These involve either direct questioning on value, contingent valuation, or trade-off approaches, stated choice or ranking. As with HP, individual studies exhibit a wide range in values per unit of noise. A data set of 258 values of transportation noise derived from SP studies, adjusted to 2009 prices, yielded an average value per decibel change per household per annum of $141.59, 95% Confidence Interval (CI) +/- $30.24 with a range from $0 to $3,407.67. However the aviation noise values within this data, 69, exhibit less variation with a mean of $292.24 and a CI of +/- $23.10 and smaller range of $15.05 to $1097.83. Such variation in values may reflect genuine variations in preferences, the impact of contextual variables, variations in approach, systematic study or country effects, and changing preferences over time or some combination of these effects.[186] Again, meta-analysis can assist in explaining some of this variation. Only one meta-analysis has been conducted on studies of transportation noise, utilising 258 values derived from 49 studies across 23 countries conducted over a 40-year period.[186] As might be expected, the value of noise reduction or the cost of noise increases were found to be dependent on level of annoyance and income. The income elasticity was close to one, suggesting that the value placed on reduced noise increases broadly in line with income; this is higher than estimates from cross sectional studies. There were no country effects found in this meta-analysis, suggesting that the model and values derived from it are transferable. Additionally, aviation noise was found to have a higher cost per dBA than road and rail noise. A result that is consistent both with studies of annoyance,[6] and HP meta-analysis.[185] Furthermore, comparison with the then HP-based approach applied by the UK Department for Transport at the time (2014) indicated that the values from the SP meta-analysis and the HP-based approach were broadly comparable. [186] This is also supported by the primary research of Thanos *et al.* (2015), applying SP and HP in the same context.[195]

9.4 Impact pathway

The third approach is rather different by exploring the impact pathway (IP) for noise effects on human health, and expressing those endpoints in terms of Disability Adjusted Life Years (DALYs) or Quality Adjusted Life Years QALYs) to quantify healthy life years lost. The World Health Organization adopted this approach[174] and identified disability weights (DW) for cardiovascular disease, sleep disturbance, tinnitus and annoyance resulting from environmental noise. The evidence on the health impacts in all areas has been growing over the years. However, the evidence base underpinning the DWs for sleep disturbance and annoyance is extremely sparse, with a high degree of uncertainty.[180] This is reflected in the WHO (2011, p: 93) weight on annoyance where "a tentative DW of 0.02 is proposed with a relatively large uncertainty interval (0.01-0.12)". This DW is only applicable those who are "highly annoyed", so any individuals experiencing annoyance who are not highly annoyed are assigned a value of zero.

There is uncertainty around the value of a healthy life year lost, which is combined with the DW weights to derive monetary values. In practice, value of life has been derived from stated preference studies of traffic fatalities in the UK,[188] or reduced mortality risk based on stated preference studies in Europe.[189] As these values do not stem from analysing the health risks of noise nuisance, there is an added element of uncertainty regarding transferability of values from diverse contexts. Furthermore, the impact pathway approach has many steps each with potential to add error and uncertainty to the value/cost estimates. As Freeman et al., (2014, p: 441) put it, "significant work is needed to improve and update the values of reducing risks that lead to morbidity and/or mortality."[190] Nevertheless, the method has been adopted into policy analysis by the UK Department of Transport[191] in assessing transport schemes and by the European Commission in evaluating the environmental noise directive.[192]

9.5 The abatement and mitigation costs of dealing with noise

The costs imposed by noise lead to efforts to measure, manage and mitigate. Airports can bear substantial costs, for example at the high end of the scale, Amsterdam Schiphol spent approximately €644.6m largely on insulation between 1984 and 2005.[193] Nevertheless this only amounted to €0.58 per passenger. Whilst manufacturers have produced quieter aircraft, there is a trade-off between achieving energy efficiency and quieter design and operation. The benefits of any mitigation activity should outweigh the costs. The costs of mitigation are relatively straightforward to estimate, as they have a market price of implementation and maintenance, in the case of noise insulation or barriers, or of estimating forgone benefits, for instance, of noise curfews. It is also rational to compare the costs of different routes to achieving a noise reduction target, for example through regulation or market incentives. Once both the costs of noise and any additional costs of mitigation are established; cost benefit analysis (CBA) can be used to guide towards solutions with the highest net benefits.

9.6 Conclusions

Economic valuation of noise nuisance and health effects is necessary and robust values are available. Most importantly, these values are applied and used in decision making. Meta-analysis of both hedonic pricing and stated preference studies suggests that these approaches, when properly applied, deliver robust values of noise nuisance. These preference-based approaches do not capture the health effects of noise that are not perceived by the exposed population. The impact pathway approach provides nonmarket values for these health effects. However, IP does not value annoyance at levels less than "highly annoyed", has a less well developed evidence base than HP and SP, and requires more steps that have the potential to introduce more error. Furthermore, HP and SP meta-analyses have improved the transferability of values providing confidence intervals for their variation, whereas there is no robust evidence on value transferability for the IP approach. This approach should be viewed with caution in the absence of a well-developed evidence base, and especially in the case of annoyance effects perceived by the exposed populations, for which robust values of noise nuisance can be delivered by tested methods.

10. OVERALL CONCLUSIONS AND FUTURE WORK

This paper has provided an overview of the many different aircraft noise impacts. There is substantial evidence that increases in noise levels lead to increases in community annoyance, but there are other nonacoustical contributors to annoyance. In future work, existing exposure-response functions should be updated and diversified to account for various acoustic and non-acoustic factors. The difference between a high rate change and a low rate change situation seems to be particularly important.

Undisturbed sleep is a prerequisite for high daytime performance, well-being and health. Aircraft noise can disturb sleep and impair sleep recuperation. Further research is needed to (a) derive reliable exposureresponse relationships between aircraft noise exposure and sleep disturbance, (b) explore the link between noise-induced sleep disturbance and long-term health consequences, (c) investigate vulnerable populations, and (d) demonstrate the effectiveness of noise mitigation strategies. This research will inform political decision making and help mitigate the effects of aircraft noise on sleep.

Epidemiological evidence from a systematic review published in 2018 covering studies up to 2016 and subsequent published studies involving several million participants show associations of aircraft noise with ischaemic heart disease. This is consistent with the evidence for road traffic noise, with larger numbers of studies. There is biological plausibility for impacts of noise on health and experimental evidence of effects of noise on the mechanistic pathways relating to cardiovascular disease, supporting the likelihood that associations are causal. Associations between aircraft noise and hypertension or stroke are less consistent across epidemiological studies, but other biological mechanisms than hypertension are available to explain associations with heart disease. However, the evidence base for aircraft noise remains limited and further research may result in changes to exposure-response relationships with cardiovascular disease, such as those derived from the systematic review of studies published in 2018. The evidence base is limited for non-cardiovascular outcomes; further research is particularly needed on diabetes and obesity, mental health, and pregnancy and birth outcomes. Further research is also needed using additional noise metrics, including those that better characterise air traffic events than average sound level (e.g., number of events above a certain noise threshold) and that consider time period (e.g., late evening and early morning).

There is robust evidence for an effect of aircraft noise exposure on children's cognitive skills such as reading and memory, as well as on standardized academic test scores. Future research needs to test the different mechanisms and to inform key individuals who can intervene on the behalf of exposed children. Longitudinal studies over the lifecourse need to be conducted.

While some surveys suggest a higher response to helicopter noise than to noise from fixed-wing aircraft, any observed differences in annoyance seem to heavily depend on non-acoustic factors. Overall, there is no evidence for a pronounced difference between response to fixed-wing and to rotary wing aircraft at equal noise levels that would justify a stricter evaluation of helicopter noise. Only when the helicopter noise is characterized by a large degree of low-frequency energy, which may produce rattle noise or vibration in buildings, there is evidence that annoyance is markedly increased. Further research should consider the consequences of rattle noise to the evaluation of helicopter noise, as well as the important role of non-acoustic factors.

Using laboratory simulators and testing in the field with special aircraft manoeuvers, progress has been made on understanding and predicting human response to sonic boom noise from overflight of new proposed quiet supersonic aircraft. To confirm these results and extend the applicability of derived models, a new low boom flight demonstrator aircraft is being built to conduct sonic boom community response studies. Plans are underway for designing these experiments to develop exposure-response models for this new kind of quiet supersonic aircraft. Several aspects of human response to low-boom supersonic flight still remain to be researched. Subjective studies have not fully investigated perception of focus booms, booms from other parts of the trajectory outside the cruise portion, noise in the shadow zone beyond lateral cut-off, Mach cut-off booms, and secondary booms. In addition, sleep disturbance relating to low-boom supersonic cruise flight or any of these other conditions has not been studied. Finally, community studies are needed using quiet supersonic aircraft in areas where people are not accustomed to hearing sonic booms, in order to develop a dose-response relationship for this new sector of commercial transportation. Regarding the non-technical aspects of public acceptability for supersonic aircraft noise, there is nothing in the literature that directly applies. However, it may be possible in the future to draw from the existing literature on the topic of non-acoustical factors for subsonic aircraft noise. We are fortunate that there already have been many studies on how animals react to conventional sonic booms, and current thinking is that the new low-boom aircraft would even have less of an impact. It is still unknown if large animals with good low-frequency hearing such as elephants will respond any differently compared to the medium and small sized animals that have already been studied.

There is preliminary evidence that the public may be concerned with the new UAM noise sources intended for transportation and package delivery. Although there is only a very limited amount of research on subjective reaction to noise from these new aircraft types, indications that the noise characteristics differ from traditional aircraft warrant further research to understand and predict human perception of these sounds.

Evidence from hedonic pricing and stated preference studies suggests that these approaches, when properly applied, deliver robust monetary values of noise nuisance. Although the impact pathway approach additionally provides non-market values for health effects, it should be viewed with caution especially in the absence of a well-developed evidence base and evidence on value transferability. There remains a need for further research to improve the robustness of the impact pathway approach and comparisons with other approaches. A further issue is that of evidence for lower income countries which is very sparse.

Comparisons between aircraft noise impacts and other noise source impacts, such as rail, road, and industrial noise, are beyond the scope of this current white paper. Others have already pointed out some of the similarities and differences in impacts between different types of noise sources, so much of that information is currently available.[194]

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