Adverse Effects of Long Term Exposure to Road Traffic Noise

Acknowledgements

The studies presented in this thesis were performed at the Netherlands Organisation for Applied Scientific Research (TNO), Delft, The Netherlands, in close collaboration with University Medical Center Groningen (UMCG), Groningen, the Netherlands, and ErasmusMC, Rotterdam, The Netherlands.

Part of the studies reported in this thesis have been made possible by financial support from by the Netherlands Ministry of Housing, Spatial Planning and the Environment (VROM).

The GLOBE study is carried out by the Department of Public Health of the Erasmus University Medical Center in Rotterdam, in collaboration with Municipal Public Health Service in the study region (GGD Brabant-Zuidoost). The study has been and is supported by grants of the Ministry of Public Health, Welfare and Sport, the Sick Fund Council, The Netherlands Organization for Advancement of Research, Erasmus University, and the Health Research and Development Council. We thank the Municipality Eindhoven for kindly providing data.

The Prevention of Renal and Vascular End-stage Disease (PREVEND) study is carried out by the University Medical Center Groningen (UMCG). The PREVEND Study has been made possible by grants of the Dutch Kidney Foundation. We thank the Municipality of Groningen for kindly providing data.

Part of the work on the effects of a quiet side was made possible by financial support by the Life+ program of the European Commission (project QSIDE, LIFE09 ENV/NL/000423).

ISBN: 978-94-6299-033-3

Cover design: Ridderprint BV, Ridderkerk, the Netherlands
Lay-out and photography: Erik de Kluizenaar
Printed by: Ridderprint BV, Ridderkerk, the Netherlands

Adverse Effects of Long Term Exposure to Road Traffic Noise

Effecten van langetermijnblootstelling aan wegverkeersgeluid

Proefschrift

ter verkrijging van de graad van doctor aan de

Erasmus Universiteit Rotterdam

op gezag van de

rector magnificus

Prof.dr. H.A.P. Pols

en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op

woensdag 8 april 2015 om 15.30 uur

Yvonne de Kluizenaar

geboren te Eindhoven

Promotiecommissie

Promotoren:	Prof.dr. J.P. Mackenbach
	Prof.dr. P.E. de Jong
Overige leden:	Prof.dr. H. Tiemeier
	Prof.dr. H. Boersma
	Prof.dr. S. Stansfeld
Copromotor:	Dr. H.M.E. Miedema

Contents

Chapter 1

Introduction

1.1 Noise as an environmental health problem

Road traffic is a prominent source of environmental noise exposure in urbanized areas. Because of its common presence, traffic is a source of exposure that is not easy to avoid. As a consequence, it is affecting a substantial proportion of residents in their homes, and in their living environment more in general. In view of reducing the number of people affected by environmental noise exposure, the European Environmental Noise Directive (END) was adopted in 2002, geared towards the assessment and management of environmental noise.

Over the last decades it has become increasingly recognised that environmental noise exposure in the living environment may lead to adverse health effects. Annoyance and sleep disturbance, mainly related to road traffic noise, are considered to be the most prominent noise effects (WHO, 2011). For these effects exposure response relationships have been established (Miedema and Oudshoorn, 2001; Miedema and Vos, 2007). During the last decades, in laboratory studies, field studies and epidemiological studies, it has been studied if and how noise exposure may lead to further adverse health effects. Evidence for a relationship between long term exposure to noise and stress related health effects, including cardiovascular disease, is increasing (Babisch et al., 2008; WHO, 2011; Van Kempen and Babisch, 2012; Basner et al., 2013; Babisch, 2014).

In the Netherlands, road traffic noise has shown to be a prominent source of noise exposure and related annoyance. The 6th national 'Annoyance Inventory' (In Dutch: 'Inventarisatie Verstoringen'), a large face-to-face questionnaire study conducted in 2008 (N > 1200), identified road traffic noise as the main source of noise annoyance in the Netherlands, amongst a broad range of other source types evaluated (including rail and air traffic, neighbour and 'outdoor activity', industry, building and construction, and recreational activity). Furthermore, road traffic noise was found to affect a considerable proportion of inhabitants (with 18 % annoyed; 6 % highly annoyed), followed by noise from neighbours (with 14 % annoyed; 5 % highly annoyed) (Van Poll et al., 2011). The percentage of the population exposed to road traffic noise levels exceeding 55 dB L_{den} has been estimated to be approximately 30 % in the Netherlands (Van Kempen and Houthuijs, 2008). Based on the existing exposure-response relationships for annoyance and sleep disturbance (Miedema and Oudshoorn, 2001; Miedema and Vos, 2007) the number of people highly annoyed and highly sleep disturbed in the Netherlands was estimated at 640,000 and 290,000, respectively (Van Kempen and Houthuijs, 2008).

Because of the large numbers of people affected, the estimated total burden of disease attributable to environmental noise is rather high. The WHO estimated the amount of healthy life years that are lost every year due to traffic related noise in the Western part of Europe to be at least one million. From all health effects that were taken into account in this study, sleep disturbance and annoyance, mostly related to road traffic noise exposure, were estimated to comprise the main burden of environmental noise (WHO, 2011).

Noise takes a prominent place between other environmental risk factors. In 2011, the European Environmental Burden of Disease (EBoDE) working group estimated the environmental burden of disease for nine prominent environmental stressors, in six European countries, including the Netherlands. For the Netherlands, this study estimated traffic noise to be the second most important environmental stressor, after particulate matter, amongst a range of environmental stressors considered, including particulate matter (PM2.5), traffic noise, second hand smoke (SHS), radon, dioxins, lead, ozone, benzene, and formaldehyde (Hanninen and Knol eds., 2011). In a RIVM report on trends in the environmental burden of disease (Knol and Staatsen, 2005), the burden related to road traffic noise was estimated to increase between 2000 and 2020, up to a level comparable to the burden related to traffic accidents.

Despite abatement measures, road traffic noise is expected to be a persistent environmental health problem in the Netherlands. While between 2000 and 2010 noise exposure from main roads in the Netherlands (In Dutch: rijkswegen) and railway traffic has decreased by measures such as the use of lower emitting road surface types and placement of noise screens, road traffic noise exposure related to the other parts of the road network, particularly in the built environment, typically has increased over the years (CBS, PBL and Wageningen UR, 2012). With the current trend of increasing urbanization (Hilbers et al, 2011; Cohen, 2006), and the large numbers of residents involuntary affected, road traffic noise exposure may be expected to be a persistent environmental health problem not only in the Netherlands, but worldwide. With the increasing amount of information becoming available on the adverse effects of environmental noise, the need for a higher level of protection of residents is becoming more widely recognised.

A working group of noise experts, set up by the European Commission to provide guidance on cost-effectiveness of noise reduction measures, recommended that to effectively reduce road traffic noise exposure a combination of both (internationally defined) source oriented measures and exposure oriented measures is needed. It was

concluded that, while source related measures may have the potential to be by far the most effective, especially for road traffic, exposure measures are necessary in addition to effectively tackle the problem (WG HSEA, 2005).

1.2 Pathways for health effects of long term noise exposure

The hypothesized pathway leading from noise exposure to cardiovascular health effects involves stress responses that may, in the long term, cause adverse health effects (Figure 1.1). Noise can be viewed as a stressor, inducing physiological effects either directly or indirectly through disturbance of sleep, communication, or activities. Exposure to noise may affect the autonomic nervous system and the endocrine system, subsequently inducing biological responses such as changes in heart rate and levels of stress hormones (e.g., Evans and Lepore, 1993; Ising et al., 1999; Babisch, 2002; WHO, 2011). It has been hypothesized that this may, possibly in combination with other factors, lead to increases in biological risk factors (e.g., blood lipids, blood pressure, blood glucose, blood viscosity), which may in the long term increase the risk of manifestations of cardiovascular diseases such as hypertension, arteriosclerosis, ischemic heart disease and stroke (Babisch, 2001, Babisch, 2002; Basner et al., 2013). Long term cardiovascular health endpoints in relation to environmental noise exposure that have been studied mostly, include hypertension and ischemic heart disease (Basner et al., 2013). Recently, epidemiological studies have found indications for an association between road traffic noise and stroke (Sørensen et al., 2011; Floud et al., 2013). The number of large epidemiological studies is however still limited, and one important potential confounder that has not been taken into account in most studies is air pollution, which has also been linked to cardiovascular outcomes. This has raised the question if and to what extent associations found for road traffic noise in epidemiological studies, may in part be explained by air pollution and vice versa.

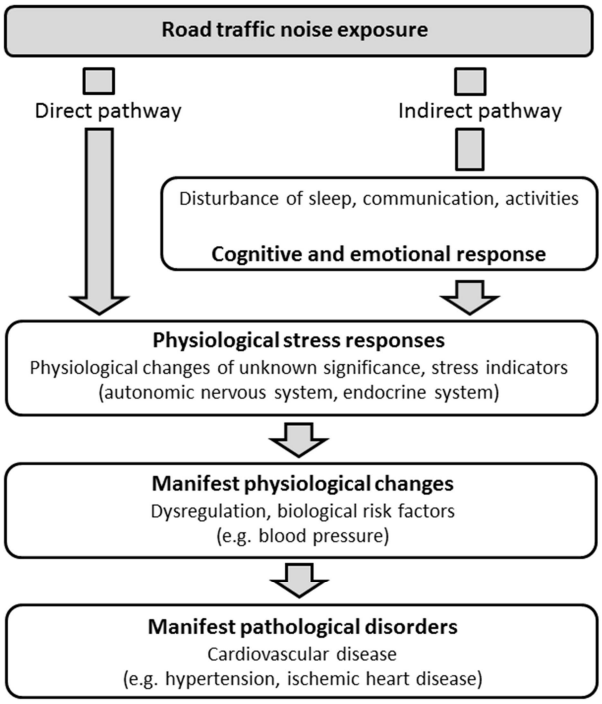

Figure 1.1 *The noise reaction model: hypothesized pathway for the effects of road traffic noise (adapted from Babisch, 2002)*

1.3 Objectives

This thesis focuses on the long term effects of road traffic noise. Central research questions that are investigated are:

1. What is the association between long term night time road traffic noise exposure (L_{night}) and self-reported sleep problems, including the after effect (medication use, morning tiredness)?

2a. What is the association between road traffic noise and the prevalence of hypertension, taking air pollution into account?

2b. What is the association between road traffic noise and the incidence of cardiovascular events, taking air pollution into account?

3. Does a relatively quiet façade reduce adverse effects of exposure: How does exposure at the least exposed side of dwellings affect annoyance?

The first aim contributes to further exploring the hypothesized mechanism for the effects of road traffic noise. The second aim contributes to increasing insight in the effects of road traffic noise, taking into account air pollution as a potentially important confounder. The third aim contributes towards a more complete characterisation of personal exposure, as well as providing insight into the potential impact of reducing noise exposure at the least exposed side, as an effect abatement measure. In the following paragraphs (1.4, 1.5 and 1.6) these 3 topics are discussed in more detail.

1.4 Noise induced sleep disturbance as a pathway

One of the above mentioned hypothesized pathways through which noise exposure may lead to adverse health effects in the long term, involves the disturbance of sleep (Babisch et al., 2002; WHO, 2009).

Sleep is commonly recognised as important for human functioning. During sleep people recover both physically and mentally, and there is increasing evidence that sleep benefits memory consolidation (Marshall and Born, 2007; Drosopoulos et al., 2007). It has become commonly recognised that sleep affects cognitive performance. In addition, experimental studies have shown effects of sleep loss on changes in the immune and endocrine systems, as well as inflammatory changes. Insufficient sleep related alterations in established cardiovascular risk factors (e.g., blood pressure and inflammation) have been hypothesised to underlie the relationship with cardiovascular pathogenesis (e.g., Mullington et al., 2009; Faraut et al., 2012). In line with the findings from experimental studies, epidemiological studies have shown associations between long term sleep complaints and increased morbidity, including cardiovascular disease (Schwartz et al., 1999; Leineweber et al., 2003; Mullington et al., 2009; Faraut et al., 2012).

It is well known that exposure to noise can adversely affect sleep (WHO, 2009). Laboratory studies and field studies have shown effects of night time noise exposure on several aspects of sleep (Passchier-Vermeer and Passchier, 2000; HCN, 2004; WHO, 2009). Effects include arousal responses during sleep (e.g., Carter et al., 1994), self-reported noise induced awakenings, and reduced sleep quality (e.g., Öhrström et al., 2006a; Passchier-Vermeer et al., 2007), body movements (e.g., Horne et al., 2004; Passchier-Vermeer et al., 2007), heart rate responses (e.g., Griefahn et al., 2008) and

indices of autonomic nervous system responses (e.g., Graham et al., 2009). From a review of available evidence, the WHO concluded that there is sufficient evidence for the following biological effects of noise during sleep: changes in heart rate, arousals, sleep stage changes and awakening. Furthermore, evidence was considered sufficient for a causal relationship between night time noise exposure and self-reported sleep disturbance, increased medicine use, increase in body movements and (environmental) insomnia (WHO, 2009).

While some responses, such as awakening reactions, may be subject to some extent of habituation, autonomic and endocrine responses have been observed to not completely habituate over time (Griefahn, 2008; Review by Pirrera et al., 2010), and noise induced cardiac responses and motility were found in residents that have lived near a major road for years (Hofman et al., 1995; Passchier-Vermeer et al., 2007; Graham et al., 2009).

What the long term effects are of chronic noise exposure on sleep and health, however, cannot be fully answered by short term laboratory experiments or field studies alone. To date, only a limited number of epidemiological studies have investigated the relationship between long-term exposure to road traffic and road traffic noise at home and sleep problems in the general population. Kageyama et al (1997), for example, found an association between living near a busy road and insomnia, based on cross sectional analyses of survey data of 3600 Japanese women. They found an exposure response relationship between night time traffic volume and the risk of insomnia for subjects living close to main roads. In this study however, — although it seems plausible that this association may be explained by night time traffic noise — no noise exposure data was available to further investigate this association. Furthermore, it remains unclear to what extent this association may be generalised to other populations and other countries. Bluhm et al (2004) studied the association between road traffic noise and noise related sleep disturbances (awakenings and/or difficulty falling asleep) in a Swedish survey of approximately 657 subjects. They found an association between road traffic noise exposure and self-reported traffic noise related sleep disturbance. However, in this survey, questions explicitly referred to traffic noise, and it is not clear to what extent the subjects attitude towards the source may have affected the results. Furthermore, it is unclear if and to what extent these reported disturbances may affect subjects the next day.

1.5 Combined exposure: road traffic noise and air pollution

Some health endpoints, including cardiovascular health effects, have been associated to both noise and air pollution. From the literature there is support for a causal role of both exposures. For environmental noise exposure, this has been discussed in 1.1. For air pollution exposure however, there is also an increasingly large body of evidence, linking both short term increases of air pollution as well as long term exposure to air pollution, to cardiovascular morbidity (reviews by Brook et al., 2010; Brook and Rajagopalan, 2010; Janssen et al., 2011; WHO, 2012). As road traffic is not only a major source of noise, but also a source of air pollution components (e.g., particulate matter), in urban areas these exposures are to some extent related (e.g., Allen et al., 2009; Davies et al, 2009; Can et al., 2011; Foraster et al., 2011). A topic that has received growing interest in recent years is the effect of combined exposure to environmental noise and air pollution, as it has now become more broadly recognised that these exposures may confound or interact with each other. To date however, still only a limited number of studies have investigated the relationship between exposure and their effects on cardiovascular health outcomes in combination (e.g., review by Tetreault et al., 2013). Insight in the relative contribution of road traffic noise and air pollution is relevant to policy makers, as reduction of road traffic noise exposure and air pollution may require different types of measures. Measures designed to reduce air pollution exposure, may not affect noise exposure and vice versa. For example, emission control measures such as the catalytic converter to reduce vehicular emissions of air pollution, are not designed to reduce noise exposure and its adverse health effects.

1.6 Beneficial effects of a relatively quiet side to the dwelling

Conventional measures that may be implemented locally to reduce exposure to road traffic noise, include lower emission road pavement, noise screens, or traffic related measures (e.g., speed control, reducing traffic intensity, reducing heavy duty traffic in urban areas etc.).

Typically, in residential areas, there may be practical limitations to the suitability and applicability of such measures. For example, for obvious reasons, noise screens may generally not be desirable in residential areas, as they may adversely affect accessibility and visual quality. At the same time, even after the application of lower emission road pavement, noise exposure levels may still remain (too) high. Furthermore, road surface

measures require maintenance to remain effective. Therefore, smart combination of multiple measures may be required to optimize the sound environment and thereby reduce the adverse effects of noise exposure.

Currently, exposure is typically characterised by the noise level at the most exposed façade of dwellings. The above measures are designed to reduce this noise level. However, in addition there is a range of factors not affecting this noise level, while having an effect on the total personal exposure of residents (and thereby the effects), such as the level of acoustical insulation of the building envelope, exposure at the least exposed façade etc. From previous studies, there are indications that the availability of a quiet side to the dwelling, access to quietness in the surrounding living area, and insulation may have the potential to significantly reduce effects (Öhrström et al., 2006b; Gidlöf-Gunnarsson et al., 2007 and 2010; Amundsen et al., 2011). However, insight in the effects of these factors on noise exposure related adverse effects is still limited.

Reducing exposure not only at the most exposed façade, but also at the least exposed façade may be an effective way to reduce adverse effects. It has been hypothesized, that the availability of a relatively quiet façade to a dwelling may reduce adverse effects of noise exposure by offering a 'way out' from the noise to the inhabitants (Miedema and Borst, 2006). For example, by providing the option to spend time or sleep at the quieter side of the dwelling. While there is support for this hypothesis (Öhrström et al., 2006b), to date evidence is still limited. To allow evaluation of effectiveness of measures, confirmation of previous findings as well as a better quantification of the effect of exposure at the 'quiet' side is needed.

1.7 Important challenges when investigating the research questions

Studying the long term effects of road traffic noise is challenging in many ways. A number of challenges are described below.

First of all, the relative contribution of environmental exposures (including environmental noise and air pollution) to manifest diseases (including cardiovascular morbidity), is typically small compared to the well-known prominent risk factors (e.g., obesity, smoking, inactive life style). This complicates the identification and quantification of the effects. The implication of this difficulty, is that a design is needed which allows such investigation. It means for instance, that a large population is needed, with a sufficient number of 'cases' of the health effect being studied, and adequate

information is needed on this endpoint. Furthermore, for the investigation of long term health effects of exposure, preferably a prospective design is used, as prospective studies are better capable to take into account the sequence in time: If persons with higher exposure show a higher risk of developing the disease under study as compared to persons with a lower exposure, there is more ground to assume that exposure and effect may indeed be causally related.

In addition, detailed information is needed on the variation in individual exposure of subjects within the study population. Assessment of exposure for a large population is not straightforward. While theoretically, it might be preferable to have measurement data on individual long term road traffic noise exposure at the home, this is practically and cost wise not feasible. Over the last decade, the development of advanced GIS (Geographic Information System) techniques and exposure modelling has created new opportunities for research on the association between (differences in) long term traffic noise and air pollution exposure levels and adverse health effects.

Spatial differences in exposure are important, as a population of residents of an urban agglomeration experiences similar fluctuations in time. However, as spatial differences in exposure may be related to spatial differences in population characteristics (e.g., socio economic status, life style, etc.), which in turn may be risk factors for the health effect under study, adjustment for potential confounding is needed.

Furthermore, similar exposure has different effects on different persons, with stronger effects in certain potentially more vulnerable groups (e.g., elderly, persons with pre-existing disease). This underlines the importance of not restricting the investigation of effects of exposure to the general population only, but in addition paying attention to potentially vulnerable subgroups.

1.8 Outline of thesis

This thesis is divided into six chapters. **Chapter 2** describes results from a large population study into the association between long term night time road traffic noise exposure and self-reported sleep problems. **Chapter 3** presents results of a large population study into the association between road traffic noise and hypertension. **Chapter 4** describes the results of our study into the association between road traffic noise and air pollution and the incidence of cardiovascular events. **Chapter 5** investigates the potential beneficial effect of having a relatively quiet façade to the dwelling. Finally,

Chapter 6 comprises of a general discussion of our results and the results of previous studies performed in this research area, and provides suggestions for future research.

References

Allen RW, Davies H, Cohen MA, Mallach G, Kaufman JD, Adar SD. The spatial relationship between traffic-generated air pollution and noise in 2 US cities. Environ Res. 2009;109(3):334–342.

Amundsen AH, Klaeboe R, Aasvang GM. The Norwegian façade insulation study: the efficacy of façade insulation in reducing noise annoyance due to road traffic. J Acoust Soc Am. 2011;129:1381-1389.

Babisch W, Fromme H, Beyer A, Ising H. Increased catecholamine levels in urine in subjects exposed to road traffic noise. The role of stress hormones in noise research. Environ Int. 2001;26:475–481.

Babisch W. The Noise/Stress Concept, Risk Assessment and Research Needs. Noise Health 2002;4(16);1–11.

Babisch W. Road traffic noise and cardiovascular risk. Noise Health 2008;10(38):27–33.

Babisch W. Updated exposure-response relationship between road traffic noise and coronary heart diseases: A meta-analysis. Noise Health 2014;16:1–9.

Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, Stansfeld S. Auditory and non-auditory effects of noise on health. Lancet 2013; doi: 10.1016/S0140-6736(13)61613-X.

Bluhm G, Nordling E, and Berglind N. Road traffic noise and annoyance—An increasing environmental health problem. Noise Health 2004;6:43–49.

Brook RD, Rajagopalan S, Pope CA, Brook JR, Bhatnagar A, Diez-Roux AV, Holguin F, Hong Y, Luepker RV, Mittleman MA, Peters A, Siscovick D, Smith SC, Whitsel L, Kaufman JD and on behalf of the American Heart Association Council on Epidemiology and Prevention, Council on the Kidney in Cardiovascular Disease, and Council on Nutrition, Physical Activity and Metabolism. Particulate Matter Air Pollution and Cardiovascular Disease: An Update to the Scientific Statement From the American Heart Association. Circulation 2010;121:2331–2378.

Brook RD, and Rajagopalan S. Particulate matter air pollution and atherosclerosis. Curr Atheroscler Rep. 2010;12:291–300.

Can A, Rademaker M, Van Renterghem T, Mishra V, Van Poppel M, Touhafi A, Theunis J, De Baets B, Botteldooren D. Correlation analysis of noise and ultrafine particle counts in a street canyon. Science Total Environ. 2011;409;564–572.

CBS, PBL, Wageningen UR (2012). Geluidsbelasting woningen door weg- en railverkeer, 2000-2010 (indicator 0295, versie 07, 19 september 2012). *www.compendiumvoordeleefomgeving.nl.* CBS, Den Haag; Planbureau voor de Leefomgeving, Den Haag/Bilthoven en Wageningen UR, Wageningen.

Cohen B. Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. Technol Soc. 2006;28:63–80.

Davies HW, Vlaanderen JJ, Henderson SB, Brauer M. Correlation between coexposures to noise and air pollution from traffic sources. Occup Environ Med. 2009;66:347–350.

Drosopoulos S, Schulze C, Fischer S and Born J. Sleep's function in the spontaneous recovery and consolidation of memories. J Exp Psychol Gen. 2007;136:169–183.

European Commission, DG Environment. 2002. Directive 2002/49/EC of the European Parliament and of the Council. Brussels: EU/DG Environment. http://ec.europa.eu/environment/noise/

Evans GW and Lepore SJ. Non-auditory Effects of Noise on Children: A Critical Review. Child Youth Environ. 1993;10(1):42-72.

Faraut B, Boudjeltia KZ, VanHamme L, Kerkhofs M. Immune, inflammatory and cardiovascular consequences of sleep restriction and recovery. Sleep Med Rev. 2012;16;137–149.

Floud S, Blangiardo M, Clark C, De Hoogh K, Babisch W, Houthuijs D, Swart W, Pershagen G, Katsouyanni K, Velonakis M, Vigna-Taglianti F, Cadum E and Hansel AL. Exposure to aircraft and road traffic noise and associations with heart disease and stroke in six European countries: a cross-sectional study. Environ Health 2013;12(89):11pp.

Foraster M, Deltell A, Basagana X, Medina-Ramon M, Aguilera I, Bouso L, Grau M, Phuleria HC, Rivera M, Slama R, Sunyer J, Targa J, Künzli N. Local determinants of road traffic noise levels versus determinants of air pollution levels in a Mediterranean city. Environ Res. 2011;111:177–183.

Gidlöf Gunnarsson A. and Öhrström E. Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. Landscape Urban Plan. 2007;83:115–126.

Gidlöf-Gunnarsson A. and Öhrström E.: Attractive "quiet" courtyards: a potential modifier of urban residents responses tot road traffic noise? Int J Environ Res. Public Health 2010;7:3359–3375.

Graham JMA, Janssen SA, Vos H, and Miedema HME. Habitual traffic noise at home reduces cardiac parasympathetic tone during sleep. Int J Psychophysiol. 2009;72:179–186.

Griefahn B, Bröde P, Marks A, and Basner M. Autonomic arousals related to traffic noise during sleep. Sleep. 2008;31;569–577.

Hänninen O and Knol A (Eds). EBoDE-Report. European Perspectives on Environmental Burden of Disease. Estimates for Nine Stressors in Six European Countries. National Institute for Health and

Welfare (THL), Report 1/2011. 86 pp. Helsinki, Finland 2011. ISBN 978-952-245-412-6 (printed), ISBN 978-952-245-413-3 (PDF).

HCN. (Health Council of The Netherlands; Gezondheidsraad). The influence of night.time noise on sleep and health. Report No. 2004/14E, HCN, 2004 Den Haag.

Hilbers H, Snellen D, Daalhuizen F, De Jong A, Ritsema van Eck J, Zondag B. (PBL) Nederland in 2040: een land van regio's. Ruimtelijke Verkenning 2011, Den Haag, 2011: Planbureau voor de Leefomgeving. PBL publicatienummer: 500169001.

Hofman WF, Kumar A, and Tulen JHM. Cardiac reactivity to traffic noise during sleep in man. J Sound Vib. 1995;179:577–589.

Horne JA, Pankhurst FL, Reyner LA, Hume K, and Diamond ID. A field study of sleep disturbance: Effects of aircraft noise and other factors on 5,742 nights of actimetrically monitored sleep in a large subject sample. Sleep 1994;17:146–159.

Ising H, Babisch W, Günther T. Work noise as a risk factor in myocardial infarction. J Clin Basic Cardiol. 1999;2:64–68.

Janssen NAH, Hoek G, Simic-Lawson M, Fischer P, Van Bree L, Ten Brink H, Keuken M, Atkinson RW, Anderson HR, Brunekreef B, and Cassee FR. Black carbon as an additional indicator of the adverse health effects of airborne particles compared with PM10 and PM2.5. Environ Health Perspect. 2011;119(12):1691–1699.

Kageyama T, Kabuto M, Nitta H, Kurokawa Y, Taira K, Suzuki S, and Takemoto T. A population study on risk factors for insomnia among adult Japanese women: A possible effect of road traffic volume. Sleep. 1997;20:963–971.

Knol AB and Staatsen BAM. Trends in the environmental burden of disease in the Netherlands 1980 – 2020. RIVM report 500029001, 2005.

Leineweber C, Kecklund G, Janszky I, Akerstedt T, Orth-Gomer K. Poor sleep increases the prospective risk for recurrent events in middle-aged women with coronary disease The Stockholm Female Coronary Risk Study. J Psychosom Res. 2003;54:121– 127.

Marks, A. and Griefahn, B. Associations between noise sensitivity and sleep, subjectively evaluated sleep quality, annoyance, and performance after exposure to nocturnal traffic noise. Noise Health. 2007;9:1–7.

Marshall L and Born J. The contribution of sleep to hippocampus-dependent memory consolidation. Trends Cogn Sci. 2007;11:442–450.

Miedema H.M.E. and Oudshoorn C.G.M. Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect. 2001;109:409–416.

Miedema, H. M. E., and Borst, H. C. (2006). Rating environmental noise on the basis of noise maps. Proceedings of Euronoise 2006, Tampere, Finland.

Miedema H.M.E. and Vos H. Associations between selfreported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behav Sleep Med. 2007;5:1–20.

Mullington JM, Haack M, Toth M, Serrador JM and Meier-Ewert HK. Cardiovascular, inflammatory, and metabolic consequences of sleep deprivation. Prog Cardiovasc Dis. 2009;51(4):294-302.

Öhrström E. Sleep disturbance, psycho-social and medical symptoms—A pilot survey among persons exposed to high levels of road traffic noise. J Sound Vib. 1989;133:117–128.

Öhrström E. Sleep disturbances caused by road traffic noise—Studies in laboratory and field. Noise Health. 2000;2:71–78.

Öhrström E, Hadzibajramociv E, Holmes M, and Svensson H. Effects of road traffic noise on sleep: Studies on children and adults. J Environ Psychol. 2006a;26:116–126.

Öhrström, E., and Skanberg, A. Sleep disturbances from road traffic and ventilation noise—Laboratory and field experiments. J Sound Vib. 2004;271:279–296.

Öhrström E., Skånberg A., Svensson H., Gidlöf Gunnarsson A. Effects of road traffic noise and the benefit of access to quietness. J Sound Vib. 2006b;295:40–59.

Passchier-Vermeer, W., and Passchier, W. F. Noise exposure and public health. Environ Health Perspect. 2000;108:123–131.

Passchier-Vermeer W, Vos H, Janssen SA and Miedema HME. Slaap en verkeersgeluid (Sleep and traffic noise). 2007, TNO Report No. 2007-D-R0012/A, TNO, Delft, The Netherlands.

Schwartz S. McDowell Anderson W, Cole SR, Cornoni-Huntley J, Hays JC, Blazer D. Insomnia and heart disease: a review of epidemiologic studies. J Psychosom Res. 1999;47(4):313–333.

Sørensen M, Hvidberg M, Andersen ZJ, Nordsborg RB, Lillelund KG et al. Road traffic noise and stroke: a prospective cohort study. Eur Heart J. 2011;32(6);737–744.

Tetreault LF, Perron S, Smargiassi A. Cardiovascular health, traffic-related air pollution and noise: are associations mutually confounded? A systematic review. Int J Public Health 2013;58:649–666.

Van Kempen E, Babisch W. The quantitative relationship between road traffic noise and hypertension: a meta-analysis. J Hypertens. 2012;30:1075–1086.

Van Kempen EEMM and Houthuijs DJM. Omvang van de effecten op gezondheid en welbevinden in de Nederlandse bevolking door geluid van weg- en railverkeer. RIVM rapport 630180001, 2008.

Van Poll HFPM, Breugelmans ORP, Devilee JLA. Hinder, bezorgdheid en woontevredenheid in Nederland: Inventarisatie Verstoringen 2008. RIVM Rapport nr. 630741001, 2011.

WG HSEA. Working Group Health and Socio-Economic Aspects. Working paper on the effectiveness of noise measures. 2005. http://ec.europa.eu/environment/noise/pdf/13825_workingpaper.pdf

WHO. Night noise guidelines for Europe. World Health Organization Regional Office for Europe. WHO, Copenhagen, Denmark, 2009.

WHO. World Health Organization Regional Office for Europe and JRC European Commission: Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. WHO, Copenhagen, Denmark, 2011.

WHO. Health effects of black carbon. By: Janssen NAH, Gerlofs-Nijland ME, Lanki T, Salonen RO, Cassee F, Hoek G, Fischer P, Brunekreef B, Krzyzanowski M. The WHO European Centre for Environment and Health, Bonn, WHO Regional Office for Europe, 2012.

Chapter 2

Long term road traffic noise exposure is associated with an increase in morning tiredness.

Yvonne de Kluizenaar
Sabine A. Janssen
Frank J. van Lenthe
Henk M.E. Miedema
Johan P. Mackenbach

Adapted from: J. Acoust. Soc. Am. 2009; 126(2): 627-633

Abstract

This study investigates the association between night time road traffic noise exposure (L_{night}) and self-reported sleep problems. Logistic regression was performed in a large population based cohort study (GLOBE), including over 18,000 subjects, to study the association between exposure at the dwelling façade and sleep problems. Measures of sleep problems were collected by questionnaire with two questions: “Do you in general get up tired and not well rested in the morning?” and “Do you often use sleep medication or tranquillizers”. After adjustment for potential confounders, a significant association was found between noise exposure and the risk of getting up tired and not rested in the morning. Although prevalence of medication use was higher at higher noise levels compared to the reference category (L_{night} < 35 dB), after adjustment for covariates this association was not significant. Long-term road traffic noise exposure is associated with increased risk of getting up tired and not rested in the morning in the general population. This result extends the earlier established relationship between long term noise exposure and self-reported sleep disturbance assessed with questions that explicitly referred to noise and indicates that road traffic noise exposure during the night may have day-after effects.

2.1 Introduction

Undisturbed sleep is important for human functioning. During sleep, people recover mentally and physically from their activities, and process information they have acquired during the day (Siegel, 2005; Marshall and Born, 2007; Drosopoulos et al., 2007). Insufficient sleep is associated with feelings of sleepiness and fatigue during the daytime (Scott et al., 2007; Elmenhorst et al., 2008), and with decreased cognitive performance (Carter, 1996; Ouis, 1999; Raidy and Scharff, 2005, Murphy et al., 2006). Furthermore, sleep deprivation has been associated with changes in physiological parameters, such as metabolic and endocrine function (Spiegel et al., 1999), altered cardiac autonomic nervous system activity (Holmes et al., 2002), and reduced acute immune system responses during stress (Wright et al., 2007). One of the key features of subjective sleep quality is morning tiredness (Harvey et al., 2008). Complaints of non-restorative sleep (not feeling rested after sleep for at least three to four times a week) have been shown to be correlated to daytime impairment such as irritability and mental fatigue (Ohayon, 2005).

Environmental noise may disturb recuperation by activating the organism during sleep. Transportation is a prolific source of environmental noise during the night-time in urban areas, and has been identified as a major cause of sleep disturbance (Berglund et al., 1999; Muzet, 2007). Exposure to transportation noise has been shown to induce both objectively measured and self-reported sleep disturbance (e.g. Pearsons et al., 1995; Aasvang et al., 2008; Basner et al., 2006; Michaud et al., 2007; Miedema and Vos, 2007). Considering the continuing growth of vehicular traffic and the large number of people exposed, disturbance of sleep by road traffic noise has become an increasingly important cause of concern.

Effects of night time road traffic noise exposure on aspects of sleep have been found in both laboratory studies and in field studies with subjects exposed to habitual noise in their home situation (Passchier-Vermeer and Passchier, 2000; Franssen and Kwekkeboom, 2003; HCN, 2004). The observed effects include awakenings or sleep stage changes (Carter, 1994), autonomic responses (Di Nisi et al., 1990; Hofman et al., 1995; Griefahn, 2008; Graham et al., 2009), body movements (Horne et al., 1994; Passchier-Vermeer et al., 2007), and self-reported noise-induced awakenings, difficulty falling asleep, and reduced sleep quality (Öhrström, 2000; Öhrström et al., 2006a; Passchier-Vermeer et al., 2007; Marks and Griefahn, 2007). While awakening reactions may be subject to habituation (Thiessen and Lapointe, 1983; Öhrström, 2000), traffic noise has been found to induce cardiac responses and motility in people who have lived in the vicinity of a major road for years (Hofman et al., 1995; Passchier-Vermeer et al., 2007). Furthermore, long-term effects of road traffic noise have been found on self-reported

noise-related sleep disturbance and general sleep quality, as reported in questionnaires (HCN, 2004; Bluhm et al., 2004), although few studies adjusted for potential confounders (Franssen and Kwekkeboom, 2003). On the basis of the pooled original data sets from 24 community surveys, exposure-effect relationships have been presented for the association between long-term night time transportation noise exposure and self-reported noise-related sleep disturbance (Miedema and Vos, 2007). In addition, some field studies have found next-day effects, such as tiredness in the morning and depressed mood as indicated in sleep logs, as well as poorer performance on reaction time tasks (Carter, 1996; Ouis, 1999; HCN, 2004).

Thus, there seems to be sufficient evidence that long-term traffic noise exposure is associated with self-reported noise-related sleep disturbance. However, little is known about the impact of long-term road traffic noise exposure on problems related to sleep such as morning tiredness and medication use. Although several field studies have been carried out (e.g. Öhrström, 1989; Öhrström and Skanberg, 2004; Passchier-Vermeer et al., 2007), few epidemiological studies have assessed the relationship between long-term exposure to residential road traffic noise and sleep problems in the general population (e.g. Langdon and Buller, 1977; Kageyama et al., 1997; Bluhm et al., 2004). Furthermore, in previous studies results may, to some extent, have been distorted by limitations in the study sample (e.g. non-random selection or relatively small sample), exposure assessment, or control for potential confounders. Moreover, in field studies and surveys designed specifically to investigate the community effects of noise, participants were usually aware of the noise focus of the study, and their response to questions concerning aspects of sleep may have been biased by their attitude towards the local road traffic exposure. The objective of the present study is to investigate the relationship between night time road traffic noise exposure (L_{night}) and self-reported sleep problems in a population based cohort study. As far as the authors know, this study is the first to investigate the relationship between night time road traffic noise exposure and morning tiredness and sleep medication use in such a large population based sample. In this study objective measures are used for noise exposure, and odds ratios (ORs) are studied with adjustment for a broad spectrum of potential confounders. Furthermore, since the population study and questionnaire were not directed towards studying the effect of noise and noise exposure was determined independently, the subjects' attitude towards the local road traffic exposure is unlikely to have affected the results.

2.2 Methods

2.2.1 Study population

The GLOBE study is a prospective cohort study carried out in the Netherlands, with the primary aim of explaining socio-economic inequalities in health. GLOBE is the Dutch acronym for Health and Living Conditions of the Population of Eindhoven and surroundings. Baseline data were collected in 1991. Details of the study protocol have been described elsewhere (Mackenbach et al., 1994), and will only be briefly summarised here.

In 1991, an a-select sample (stratified by age, degree of urbanization and socio-economic position) of 27,070 non-institutionalized subjects (aged 15 to 74 years) was drawn from 18 municipal population registers in the south-eastern part of The Netherlands and was asked to participate in the study. With a response rate of 70.1%, baseline information was collected from 18,973 individuals using a postal questionnaire. The area of study included the city of Eindhoven, which was the fifth largest city of The Netherlands in 1991.

2.2.2 Health outcome and covariates

The data collection comprised a broad range of potential confounders including sociodemographic variables (age, gender, marital status, and education), lifestyle factors (smoking, alcohol use, physical activity, Body Mass Index [BMI]), and living conditions (employment status, financial problems). Data for measures of sleep problems were available from the following questions in the questionnaire: “Do you in general get up tired and not well rested in the morning?” and “Do you often use sleep medication or tranquillizers?”. The response format is: “yes” or “no”.

2.2.3 Noise exposure

The road traffic noise exposure of the subjects was calculated at the most exposed façade of the baseline home address with standard method SKM2 in accordance with requirements of the EU Environmental Noise Directive (END). For the analyses, the authors used the EU standard noise metric L_{night}. L_{night} (night level) is defined as the A-weighted “average” sound level (International Standards Organization, 2002) over a year during the period 23 – 7 h assessed at the façade of a dwelling with the highest overall exposure (i.e., most exposed façade). SKM2 is the sophisticated version of the Netherlands’ standard method for noise modelling and producing noise maps in

compliance with the END (VROM, 2006a). SKM2 is implemented in Urbis (Borst and Miedema, 2005) that was used here for the exposure calculations. Noise calculations are carried out in two steps calculating first the emission and then the transmission. The emission calculations take into account traffic characteristics, including traffic intensities, traffic composition (percentages motorbikes, light duty, medium duty, and heavy duty vehicles), speed, road height and road surface type. The transmission calculations take into account the distance between source (road) and dwelling façade, air attenuation, effects of (yearly) meteorological conditions, ground attenuation, object screening, reflection of objects opposite the dwelling, and statistical diffraction for transmission. Noise exposure is calculated at the height of the centre of the dwelling façade of the exposed subject. Very low noise exposure levels (below 35 dB(A)) were recoded as 35 dB(A) since this can be considered to be a lower limit of the night time ambient noise in most surroundings involved.

Input data for the noise emission calculations was a detailed digital map describing the geographic location of roads and the traffic characteristics for each road segment (including traffic intensities for each vehicle category, speed, and road surface type), provided by the local authorities of Eindhoven for the current situation (2004). Although traffic intensities may have increased, the road network is assumed to be rather stable, with only small (if any) but equal changes in noise exposure across the population. Traffic data were attached as attributes to the road segments for a dense network of roads, including highways, arterial roads, main streets, and principal residential streets.

Basis for the noise transmission calculations was digital maps with precise information on geographic location of buildings and ground characteristics (Topographic Service data [TOP10]) provided by the Netherlands Ministry of Housing, Spatial Planning and the Environment - Directoraat-Generaal Ruimte (VROM/DGR). Building height was derived from the Actual Height Information Netherlands (AHN), a 5 x 5 m^2 grid with height information based on laser altimetry. The geographic location of noise screens with their height was provided by the local authorities of Eindhoven. The geographical location of dwellings within the building contours (Topographic Service data [TOP10]) was identified with the use of address coordinates.

2.2.4 Statistical analysis

Logistic regression was performed to investigate the association between night time residential road traffic noise exposure (L_{night}) and self-reported sleep problems (getting up tired and not well rested in the morning and the use of sleep- or tranquillizing

medication). Estimated ORs are presented as approximation of relative risks, together with their corresponding 95% confidence intervals (CIs).

In the model, factors were included that were hypothesized *a priori* to potentially confound the relationship between traffic exposure and sleep problems. These variables are age, sex, BMI, physical activity, marital status, employment status, financial problems, alcohol use, smoking, and self-reported level of education. A *P* value of at most 0.05 was considered to be significant, a *P* value of 0.05–0.1 was considered an indication of a relationship.

Age was entered as a continuous variable, while gender, BMI, physical activity, marital status, employment status, financial problems, alcohol use, smoking, and education, were entered as categorical variables. BMI (body weight divided by height squared) was categorised into four groups (underweight [BMI <20], normal weight range [BMI 20–25], overweight [BMI 25–30], obese [BMI >30]). Physical activity was available in four categories (none, little, moderate, and much physical activity). Marital status was categorised into four groups (married or living together, unmarried, divorced, widow/widower). Employment status was categorised in three categories, including "unemployed". Three categories of financial problems were distinguished (no difficulty, some difficulty, large difficulty). Alcohol use was categorised into three groups (moderate, abstainer, and excessive). Data on smoking was available from the following question in the questionnaire: "Do you smoke?" The response format is: "Yes", "No, but I have smoked in the past," "No, I never smoked," coded in three categories (current smoker, former smoker, and never smoker). Highest attained level of education was distinguished into four different categories (primary education, lower professional and intermediate general education, intermediate professional and higher general education, and higher professional education and university).

A sensitivity analysis was carried out to explore the effect of the inclusion of additional variables. In this analysis, a measure of occurrence of major life events, number of children living at home, and measures of cold or draught (answer categories: yes or no) and dampness (answer categories: yes or no) inside the dwelling were taken into account in the model in addition to age, sex, BMI, exercise, marital status, work situation, financial difficulties, smoking, alcohol use, and education. For major life events, a sum-score was used as the number of times respondents answered "yes" to one of nine questions on occurrence of major life events experienced during the last 12 months. These events included (1) moving house; (2) substantial decrease in financial situation; (3) being the victim of serious crime (robbery, theft, physical abuse, or rape); (4) becoming unemployed; (5) partner or other family member (member of household) becoming unemployed; (6) serious disease of partner or family member (member of

household) or parents (in law); (7) death of partner; (8) death of parent (in law), child, brother of sister or close friend; (9) divorce.

Missings in potential confounding variables (the percentage of missings for all confounding variables was below 5.6 %) were imputed, replacing the missing values with the most common category. All analyses were performed with SPSS (version 11.0.1).

2.3 Results

Figure 2.1 shows the distribution of subjects over night time road traffic noise exposure classes (L_{night}) for the GLOBE study sample at their 1991 home address. The spatial variation in road traffic noise exposure is substantial and shows a difference in exposure between the lowest and highest 5% of dwellings exceeding 20 dB (L_{night}), ranging from about 35 dB (urban background) to more than 55 dB (L_{night}) in the vicinity of roads.

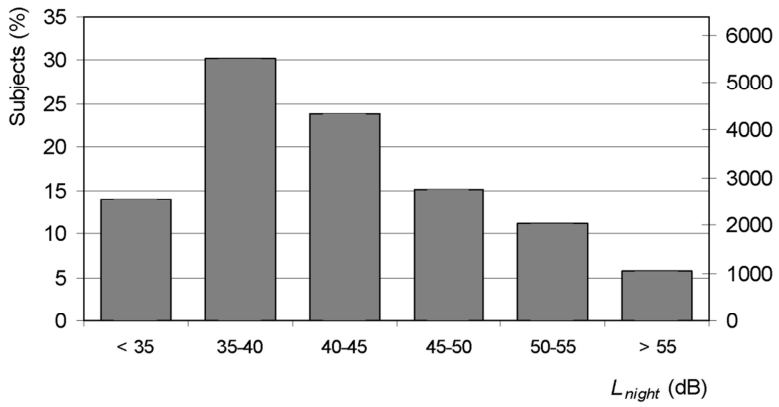

Figure 2.1 *Distribution of long-term average road traffic noise (L_{night}) [dB] exposure at the 1991 home address.*

Table 2.1 shows the distribution of the total study sample over the road traffic noise exposure categories. Before adjustment for potential confounders, the prevalence of both markers of sleep problems (getting up tired and not rested in the morning; use of sleep or tranquillizing medication) seems higher at higher night time noise levels (Figure 2.2).

Table 2.1 *Characteristics of the GLOBE cohort by road traffic noise (L_{night}) [dB] exposure category (unadjusted).*

L_{night} [dB]	< 35	35–40	40–45	45–50	> 50
N	2547	5514	4325	2742	3085
Age (*years*)	45.7	46.8	47.9	48.3	49.0
Sex: Male *(%)*	49.6	48.3	48.3	47.6	48.3
BMI (QI > 30) *(%)*	5.3	6.3	6.4	6.2	5.8
Physical activity: much *(%)*	35.1	33.0	32.7	33.1	30.8
Marital (married/live together) *(%)*	74.2	74.6	75.4	72.8	67.8
Work situation: unemployed *(%)*	9.9	10.4	10.8	8.7	10.9
Financial: much difficulty *(%)*	4.7	4.7	4.3	3.6	3.6
Smoking *(%)*	35.8	37.2	35.7	35.0	36.9
Alcohol use: excessive *(%)*	8.8	8.0	7.8	7.8	9.0
Education low *(%)*	18.3	21.0	22.3	20.5	22.6
Not rested in the morning *(%)*	17.9	19.4	20.3	21.0	20.2
Sleep/tranquillizing medication *(%)*	5.4	6.6	6.9	7.1	7.3

Variables are described by means, and percentages in case of dichotomous variables.
Abbreviations are: BMI (Body Mass Index); and L_{night} (road traffic noise - night level) (dB).

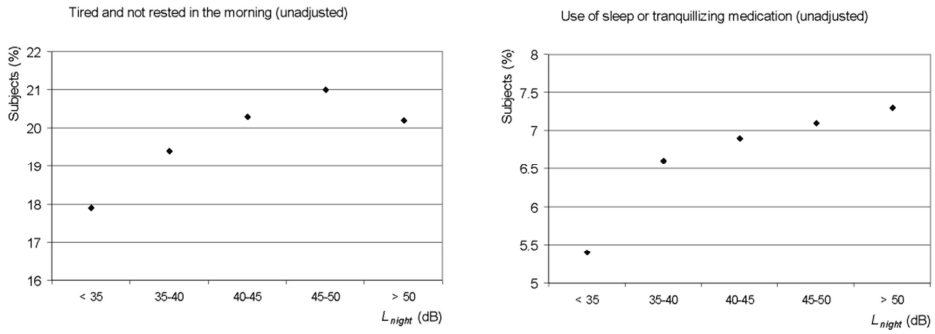

Figure 2.2 *Prevalence of self-reported sleep problems in subjects of the GLOBE study sample in relation to night time road traffic noise exposure at the home (L_{night}) [dB] unadjusted for confounders.*

Table 2.2 *ORs for night time road traffic noise exposure (L_{night}) (dB) , for markers of self-reported sleep problems (tired and not rested in the morning, use of sleep or tranquillizing medication) in the GLOBE study sample after adjustment for potential confounders. ORs from logistic regression are shown, adjusted for age, sex, BMI, exercise, marital status, work situation, financial difficulties, smoking, alcohol use, education.*

Group	N	OR L_{night}<35	OR L_{night} 35–40	OR L_{night} 40–45	OR L_{night} 45–50	OR L_{night} > 50
Tired, and not rested in the morning	17,821	1.00	1.08 (0.95–1.22)	1.18 (1.03–1.34)*	1.26 (1.09–1.45)**	1.15 (1.00–1.33)*
Use of sleep- or tranquillizing medication	17,855	1.00	1.14 (0.92–1.41)	1.16 (0.93–1.44)	1.21 (0.96–1.54)	1.15 (0.92–1.45)

*Significant relationship (P < 0.05)
**[b]Significant relationship (P < 0.01)

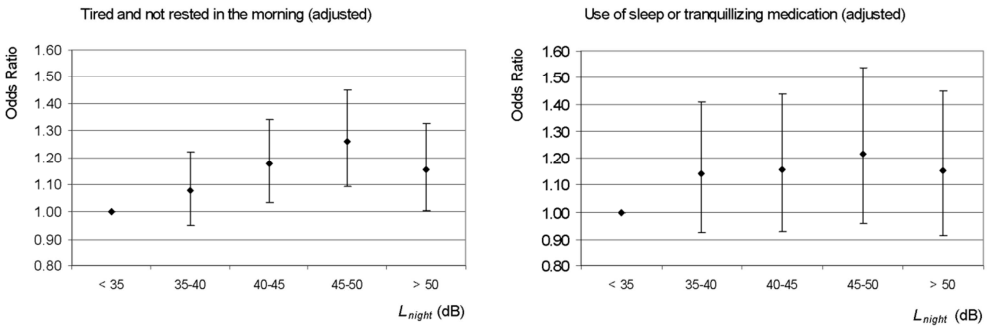

Figure 2.3 *ORs for night time road traffic noise exposure for markers of self-reported sleep problems (tired and not rested in the morning, use of sleep or tranquillizing medication) in the GLOBE study sample after adjustment for confounders.*

As shown in Table 2.2 and Figure 2.3, in the GLOBE study sample an association was found between road traffic noise exposure *(L_{night})* and getting up tired and not rested in the morning. Compared to the reference category (L_{night} < 35 dB), the OR was higher in all higher noise exposure categories. The ORs were found to increase with increasing noise level, but showed a slight decrease in the highest exposure category. Overall, an OR of 1.08 was found (95% CI: 1.02–1.14) per 10 dB increase in L_{night}. A sensitivity analysis was carried out to explore the effect of the inclusion of additional variables. Additional

adjustment for major life events, and number of children living at home, and cold or draught and dampness inside the dwelling did not substantially affect the association for night time road traffic noise and getting up tired and not rested in the morning.
While the unadjusted results indicate there may be an association between road traffic noise exposure and the use of sleep medication or tranquillizers, after adjustment for potential confounders this relationship was not significant.

Table 2.3 shows the ORs for covariates, for markers of self-reported sleep problems (tired and not rested in the morning, use of sleep or tranquillizing medication) in the GLOBE study sample, in the adjusted models for the association between night time road traffic noise exposure and sleep problems.

Table 2.3 *ORs for covariates for markers of self-reported sleep problems (tired and not rested in the morning; use of sleep or tranquillizing medication) in the GLOBE study sample in the adjusted models for the association between night time road traffic noise exposure and sleep problems. ORs from logistic regression are shown.*

	Tired, not rested in the morning	Sleep- or tranquillizing medication use
Covariate	OR	OR
Age *(year)*	0.99**	1.04**
Sex *(female)*	1.23**	1.99**
BMI		
QI < 20	1.00	1.00
QI 20–25	0.95	0.72**
QI 25–30	0.96	0.70**
QI > 30	1.12	0.65**
Exercise		
None	1.00	1.00
Little	0.71**	0.87
Moderate	0.56**	0.61**
Much	0.45**	0.55**
Marital Status		
Married	1.00	1.00
Unmarried	1.14*	0.98
Divorced	1.41**	1.88**
Widow(er)	1.10	1.38**
Work Situation		
Unemployed	1.00	1.00
Working/Study	0.56**	0.38**
Other	0.57**	0.40**
Financial		
No difficulty	1.00	1.00
Some difficulty	1.43**	1.27**
Much difficulty	2.01**	1.56**
Smoking		
Never	1.00	1.00
Former	1.09	1.31**
Current	1.36**	1.73**
Alcohol		
Moderate	1.00	1.00
Abstainer	1.25**	1.60**
Excessive	1.05	1.16
Education[1]		
Category 1	1.00	1.00
Category 2	1.00	1.25
Category 3	0.98	1.32*
Category 4	1.19*	1.65**

*Significant relationship (P < 0.05)

**Significant relationship (P < 0.01)

[1]Highest attained level of education was distinguished into four different categories (higher professional education and university, intermediate professional and higher general education, lower professional and intermediate general education, and primary education).

2.4 Discussion and conclusions

This study investigated the relationship between road traffic noise exposure during night time and two indicators of sleep problems: getting up tired and not rested in the morning, and the use of sleep or tranquillizing medication. After adjustment for potential confounders, a significant association was found between road traffic noise exposure at the home and the risk of getting up tired and not rested in the morning. Although the prevalence of use of sleep or tranquillizing medication was higher at higher noise levels compared to the reference category (L_{night} <35 dB), after adjustment for potential confounders this association was not significant. Thus, no evidence was found of an effect of road traffic noise on sleep medication, although the findings do not contradict the significant increase in prevalence with increasing *aircraft* noise exposure during the late evening found by Franssen et al. (2004). The present finding on morning tiredness adds to the evidence from community surveys and field studies that long-term traffic noise is associated with self-reported sleep disturbance (Miedema and Vos, 2007) and may adversely affect self-reported sleep quality (Franssen and Kwekkeboom, 2003). Furthermore, the present results lend support to earlier indications from field studies that traffic noise may have after-effects the following day (Carter, 1996; Ouis, 1999; Öhrström, 1989; Öhrström and Skanberg, 2004). In addition, the results show that noise exposure plays a role among all possible causes of sleep problems, a conclusion that cannot be drawn on the basis of analyses with sleep disturbance questions explicitly referring to noise, as in Miedema and Vos (2007). Night time road traffic volume has previously been shown to be a risk factor for insomnia, and the prevalence of morning tiredness was increased in the insomniacs as compared to the non-insomniacs (Kageyama et al., 1997). The description of the different severity criteria of insomnia (mild, moderate, and severe) includes “an almost nightly complaint of.... not feeling rested after the habitual sleep episode” (The International Classification of Sleep Disorders; ICSD). Since in our study night time road traffic noise exposure was found to be associated with morning tiredness (getting up tired and not rested in the morning), road traffic noise exposure may be hypothesized to induce or aggravate symptoms of insomnia.

A slight decrease in relative risk estimate was found for the highest noise exposure category. Similar to these findings, Öhrström et al. (2006a) found a decreasing effect of L_{night} on self-reported sleep quality in the highest noise category, which they attributed to the increased tendency to sleep with closed windows. In a field study by Griefahn et al. (2000), window closing behaviour was the primary variable associated with noise levels outside. A survey by Öhrström et al. (2006b) showed that L_{night} reduced both sleep quality and sleeping with open window. Another factor that may explain this decrease in effect is the self-selection of people less bothered by noise, particularly in areas with very high exposures (noise sensitive subjects moving away from high exposure areas).

Effects of high noise exposure may be partly masked by this selection mechanism. In addition, better sound insulation of the dwellings of most exposed subjects, and choice of bedroom location away from the source in reaction to exposure may affect relative risk estimates, particularly in the highest noise exposure category. Unfortunately, no data were available on noise sensitivity, dwelling insulation, choice of bedroom location, or window opening behaviour to take these factors into account.

A limitation of the exposure assessment in this study is that road traffic noise data for the current situation (2004) were used. Unfortunately, no historic data for 1991 were available on traffic intensity and road characteristics such as road surface type and noise screens. Although traffic intensities may have increased, the road network is assumed to be rather stable, with only small (if any) changes in noise exposure across the population. For example, a recent study showed that correlations between road traffic intensities for a ten year period (1986-1996) in The Netherlands were high (>0.9) (Beelen et al., 2009). If there is any effect of this limitation, it may be assumed that the actual association may be slightly stronger than found.

No data were available on noise exposures inside the bedrooms of the respondents. L_{night} at the most exposed façade as metric characterises the exposure on one side of the dwelling, while the subject may sleep on another side of the dwelling, which may be less exposed. Having access to a quiet side of the dwelling has been found to reduce self-reported sleep disturbance and tiredness (Bluhm et al., 2004; Öhrström et al., 2006b). In addition to window opening behaviour of subjects, the difference between this outside exposure level and the level inside the bedroom depends on the insulation of the façade. However, the tendency of people to sleep with their windows open is expected to reduce the variability in the outdoor – indoor difference.

Data for measures of sleep problems were available as dichotomous variables (response format: “yes” or “no”). Refined measurement of the effects might have refined the findings. If there would be an effect, it may be assumed the association found in this study may be stronger still.

Strengths of the study include a number of aspects. First, the investigation was carried out in a large random sample drawn from the general population. The large sample size increases the power of the statistical analysis, while the population based design of the study increases the possibility to extrapolate the results to the general population, as compared to studies with smaller or non-random samples. In addition, the study was carried out for a large region, including Eindhoven City, which was the fifth largest city of The Netherlands at the start of the cohort study. As a result, there was a large variety in road traffic noise exposure, which may be expected to be representative for urbanized areas in general. The exposure was assessed with detailed noise models that take into

account the relevant small scale intra-urban spatial variation in the study area. This approach reduces misclassification errors of noise exposure, which may occur in studies where exposure is based on subjective information (e.g., questionnaire reporting on traffic density or annoyance). Another strong point of this study was that it was not directed to noise and its effects; thus no bias was introduced by subjects being triggered to focus on road traffic noise exposure. Finally, we were able to minimise confounding by adjusting for a large range of potential risk factors in the model, including age, sex, BMI, exercise, marital status, work situation, financial difficulties, smoking, alcohol use, and education. A sensitivity analysis was carried out to explore the effect of the inclusion of additional variables. Additional adjustment for major life events, number of children living at home, and cold or draught and dampness inside the dwelling did not substantially affect the association between night time road traffic noise and morning tiredness.

In conclusion, our results show that road traffic noise during the night is associated with after-effects: an increased risk of subjects getting up tired and not rested in the morning. These findings add to the evidence that residential road traffic noise exposure may cause sleep disturbance and could be interpreted as a signal that noise-induced sleep disturbance has significant implications for daily life in the general population. Furthermore, noise exposure may induce or aggravate symptoms of insomnia. It therefore appears to be important to increase awareness of transportation noise as a factor affecting sleep. Reduction of these effects may require specialized advice, for example, with respect to choice of bedroom location or measures of improving the sound insulation of the bedroom.

References

Aasvang GM, Moun T, Engdahl B. Self-reported sleep disturbances due to railway noise: Exposure-response relationships for nighttime equivalent and maximum noise levels. J Acoust Soc Am. 2008;124(1):257–268.

Basner M, Samel A, Isermann U. Aircraft noise effects on sleep: Application of the results of a large polysomnographic field study. J Acoust Soc Am. 2006;119(5): 2772–84.

Beelen R, Hoek G, Houthuijs D, Van den Brandt P, Goldbohm RA, Fischer P, Schouten LJ, Armstrong B, Brunekreef B. The joint association of air pollution and noise from road traffic with cardiovascular mortality in a cohort study. Occup Environ Med. 2009;66:243–250.

Berglund B, Lindvall T, Schwela DH. (1999). Guidelines for Community Noise. World Health Organization: Protection of the Human Environment.

Bluhm G, Nordling E, Berglind N. Road traffic noise and annoyance — an increasing environmental health problem. Noise Health 2004;6:43–49.

Borst HC, Miedema HME. Comparison of noise impact indicators, calculated on the basis of noise maps of DENL. Acta Acustica 2005;91:378–385.

Carter NL, Hunyor SN, Crawford G, Kelly D, Smith AJ. Environmental noise and sleep — a study of arousals, cardiac arrhythmia and urinary catecholamines. Sleep 1994;17:298–307.

Carter NL. Transportation noise, sleep, and possible after-effects. Environ Int. 1996;22:105–116.

Di Nisi J, Muzet A, Ehrhart J, Libert JP. Comparison of cardiovascular responses to noise during waking and sleeping in humans. Sleep 1990;13:108–120.

Drosopoulos S, Schulze C, Fischer S, Born J. Sleep's function in the spontaneous recovery and consolidation of memories. J Exp Psychol Gen. 2007;136(2):169–83.

Elmenhorst EM, Elmenhorst D, Luks N, Maass H, Vejvoda M, Samel A. Partial sleep deprivation: Impact on the architecture and quality of sleep. Sleep Med. 2008;9:840–850.

Franssen EAM, Kwekkeboom JMI. Effecten van geluid door wegverkeer op de slaap. Een systematische review van studies in de woonomgeving. (Effects of road traffic noise on sleep. A systematic review of studies in de residential environment). Bilthoven: RIVM, 2003. Report 715120010/2003.

Franssen EAM, van Wiechen CMAG, Nagelkerke NJD, Lebret E. Aircraft noise around a large international airport and its impact on general health and medication use. Occup Environ Med. 2004;61:405–413.

Graham JMA, Janssen SA, Vos H, Miedema HME. Habitual traffic noise at home reduces cardiac parasympathetic tone during sleep. Int J Psychophysiol. 2009;72(2):179-186.

Griefahn B, Schuemer-Kohrs A, Schuemer R, Moehler U, Mehnert P. Physiological, subjective and behavioural responses during sleep to noise from rail and road traffic. Noise Health. 2000;3:59–71.

Griefahn B, Bröde P, Marks A, Basner, M. Autonomic arousals related to traffic noise during sleep. Sleep. 2008;31:569–577.

Harvey AG, Stinson K, Whitaker KL, Moskovitz D, Virk H. The subjective meaning of sleep quality: a comparison of individuals with and without insomnia. Sleep. 2008;31:383–393.

HCN (Health Council of the Netherlands). (2004). The influence of night time noise on sleep and health. Den Haag: Report 2004/14E.

Hofman WF, Kumar A, Tulen JHM. Cardiac reactivity to traffic noise during sleep in man. J Sound Vib. 1995;179:577–589.

Holmes AL, Burgess HJ, Dawson D. Effects of sleep pressure on endogenous cardiac autonomic activity and body temperature. J Appl Physiol. 2002;92:2578–2584.

Horne JA, Pankhurst FL, Reyner LA, Hume K, Diamond ID. A field study of sleep disturbance: effects of aircraft noise and other factors on 5,742 nights of actimetrically monitored sleep in a large subject sample. Sleep. 1994;17:146–159.

International Standards Organization. (2002). Acoustics—Description, measurement and assessment of environmental noise: Part 2. Determination of environmental noise levels. Rep. No. ISO/CD1996–2. Geneva, Switzerland.

Kageyama T, Kabuto M, Nitta H, Kurokawa Y, Taira K, Suzuki S, Takemoto T. A population study on risk factors for insomnia among adult Japanese women: a possible effect of road traffic volume. Sleep. 1997;20(11):963–971.

Langdon FJ, Buller IB. Road traffic noise and disturbance to sleep. J Sound Vib. 1977;50:13–28.

Mackenbach JP, Mheen H, Stronks K. A prospective cohort study investigating the explanation of socioeconomic inequalities in health in The Netherlands. Soc Sci Med. 1994;38:299–308.

Marks A and Griefahn B. Associations between noise sensitivity and sleep, subjectively evaluated sleep quality, annoyance, and performance after exposure to nocturnal traffic noise. Noise Health. 2007;9:1–7.

Marshall L, Born J. The contribution of sleep to hippocampus-dependent memory consolidation. Trends Cogn Sci. 2007;11(10):442–450.

Michaud DS, Fidell S, Pearsons K, Campbell KC, Keith SE. Review of field studies of aircraft noise-induced sleep disturbance. J Acoust Soc Am. 2007;121(1):32–41.

Miedema HME, Vos H. Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behav Sleep Med. 2007;5(1):1–20.

Murphy TI, Richard M, Masaki H, Segalowitz SJ. The effect of sleepiness on performance monitoring: I know what I am doing, but do I care? J Sleep Res. 2006;15: 15–21.

Muzet A. Environmental noise, sleep and health. Sleep Med Rev. 2007;11:135–142.

Öhrström E. Sleep disturbance, psycho-social and medical symptoms — a pilot survey among persons exposed to high levels of road traffic noise. J Sound Vib. 1989;133:117–128.

Öhrström E. Sleep disturbances caused by road traffic noise – studies in laboratory and field. Noise Health. 2000;2(8):71–78.

Öhrström E, Skanberg A. Sleep disturbances from road traffic and ventilation noise—laboratory and field experiments. J Sound Vib. 2004;271:279–296.

Öhrström E, Hadzibajramociv E, Holmes M, Svensson H.. Effects of road traffic noise on sleep: studies on children and adults. J. Environ. Psych. 2006a;26:116–126.

Öhrström E, Skanberg A, Svensson H and Gidlöf-Gunnarsson A. Effects of road traffic noise and the benefit of access to quietness. J Sound Vib. 2006b;295:40–59.

Ohayon MD. Prevalence and correlates of nonrestorative sleep complaints. Arch Intern Med. 2005;165:35–41.

Ouis D. Exposure to nocturnal road traffic noise: Sleep disturbance and its after effects. Noise Health. 1999;4:11–36.

Passchier-Vermeer W, Passchier WF. Noise exposure and public health. Environ Health Perspect. 2000;108:123–131.

Passchier-Vermeer W, Vos H, Janssen SA, Miedema HME. (2007). Slaap en verkeersgeluid (Sleep and traffic noise). Delft. TNO report 2007-D-R0012/A.

Pearsons KS, Barber DS, Tabachnick BG, Fidell S. Predicting noise-induced sleep disturbance. J Acoust Soc Am. 1995;97:331–338.

Raidy DJ, Scharff LF. Effects of sleep deprivation on auditory and visual task. Percept Mot Skills. 2005;101:451–467.

Scott LD, Hwang WT, Rogers AE, Nysse T, Dean GE, Dinges DF. The relationship between nurse work schedules, sleep duration and drowsy driving. Sleep. 2007;30:1801–1807.

Siegel JM. Clues to the functions of mammalian sleep. Nature. 2005;437:1264–1271.

Spiegel K, Leproult R, Van Cauter E. Impact of sleep debt on metabolic and endocrine function. Lancet. 1999;354:1435–1439.

Thiessen GJ, Lapointe AC. Effect of continuos traffic noise on percentage of deep sleep, waking and sleep latency. J Acoust Soc Am. 1983;73(1):225–229.

VROM. (2006). Meet- en rekenvoorschrift geluidhinder 2006 (Prescribed measurement and calculation methods for noise annoyance 2006). Staatscourant 21 december 2006[a]: 249, 84.

Wright CE, Erblicht J, Valdimarsdottir HB, Bovbjerg DH. Poor sleep the night before an experimental stressor predicts reduced NK cell mobilization and slowed recovery in healthy women. Brain Behav Immun. 2007;21:358–363.

Chapter 3

Hypertension and road traffic noise exposure

Yvonne de Kluizenaar
Ronald T. Gansevoort
Henk M.E. Miedema
Paul E. de Jong

*Adapted from: J. Occup. Environ. Med. 2007; 49: 484-492**

**The text of this article has been updated with respect to current insights of the effects of combined exposure.*

Abstract

Objective: The purpose of this study was to assess the relationship between road traffic noise exposure at home and the prevalence of hypertension.

Methods: We conducted cross-sectional analyses in a large random sample (N = 40,856) of inhabitants of Groningen City, and in a subsample (the Prevention of Renal and Vascular End-Stage Disease [PREVEND] study cohort; N = 8592).

Results: Before adjustment for confounders, road traffic noise exposure was associated with self-reported use of antihypertensive medication in the city of Groningen sample (odds ratio [OR] = 1.31 per 10 dB increase in L_{den}). Adjusted ORs were significant for the subjects between 45 and 55 years old in the full model when adjusted for PM10 (OR = 1.19) and at higher exposure (L_{den} > 55 dB) only (OR= 1.21; with adjustment for PM10, OR = 1.31). In the PREVEND cohort, the unadjusted odds ratio was 1.35 for hypertension (systolic and diastolic blood pressure > 140 and > 90 mmHg, respectively, or use of antihypertensive medication). Again, the adjusted odds ratio was significant for the subjects between 45 and 55 years old (OR = 1.27; with adjustment for PM10, OR = 1.39).

Conclusions: Exposure to road traffic noise may be associated with hypertension in subjects who are between 45 and 55 years old. Associations seemed to be stronger at higher noise levels.

3.1 Introduction

There are indications that living near a major road can induce adverse health effects. It is well-known that exposure to noise can cause noise annoyance and sleep disturbance. For these effects, exposure-effect relationships have been presented (Miedema and Oudshoorn, 2001; Pearsons et al., 1995). Over the last few decades, studies have been conducted to determine if and how noise exposure may cause further adverse health effects. Currently, there is increasing evidence that exposure to environmental noise can induce stress-related health effects including hypertension and cardiovascular diseases (Berglund et al., 2000; Gezondheidsraad; 2004; Babisch et al., 2000; Passchier-Vermeer et al., 2000; Kempen et al., 2002; Babisch et al., 2001).

Early laboratory studies reviewed by Passchier-Vermeer (1993), have shown momentary changes in the cardiovascular system induced by exposure to noise, including vasoconstriction, electrocardiographic abnormalities and changes in heart rate. Occupational noise studies provided evidence for an effect of noise exposure in the working environment on hypertension (Passchier-Vermeer, 1993). Although these findings indicate a link between noise exposure and cardiovascular effects, they give no information as to what extent long-term noise exposure in the living environment may affect cardiovascular health.

Few epidemiological studies have assessed the relationship between exposure to transportation noise in the living environment and hypertension. Recent studies have focussed on the effects of aircraft noise exposure and reported an association with hypertension. In a meta-analysis, Van Kempen et al. (2002) concluded that there is a significant association of aircraft noise exposure and hypertension, with an estimated relative risk of 1.14 per 5 dB noise increase. However, from studies on the effects of transportation noise on annoyance, it is known that people react to aircraft noise and road traffic noise differently (Miedema et al., 2001). Therefore, it may be expected that effects of exposure to road traffic noise are different. For road traffic noise, no conclusion on how the exposure may affect hypertension can yet be drawn, and no general exposure-response relationships have been derived (Kempen et al., 2002).

In previous studies on the effect of road traffic noise on hypertension, results may, to some extent, have been distorted by limitations in the study sample (e.g., non-random selection or relatively small sample), exposure assessment (e.g., subjectively defined exposure), effect measure (e.g., subjectively defined hypertension), or control for confounders. To our knowledge, one potentially important confounder that has not been taken into account in road traffic noise effect studies is air pollution. Epidemiological studies have been published that showed effects of road traffic-related air pollution on cardiovascular endpoints (Pope et al., 2004; Hoek et al., 2002). Studies on the

cardiovascular effects of air pollution have identified particulate matter (PM) as an important pollutant in this respect. In addition to noise, road traffic is an important source of air pollution. Therefore, in the study of the effects of road traffic noise on hypertension, air pollution should be taken into account.

The objective of this study was to assess the relationship between road traffic noise exposure at the home and hypertension. As far as we know, this study is the first to investigate the relationship between road traffic noise exposure and hypertension in such a large, population based sample (N = 40,856). We used objective measures for noise exposure, and odds ratios are studied with adjustment for potential confounders, taking air pollution into account in addition to common cardiovascular risk factors. In a subsample, for which more detailed information on both the effect variables and confounders was available, further analysis was carried out with objective measures for hypertension and additional control for confounding. As noise annoyance meta-analysis has revealed that the influence of noise is age dependent, with the strongest effects in people around the age of 50 years compared with the effects in younger and older age groups (Groothuis-Oudshoorn and Miedema, 2006), specific attention was paid to the moderating role of age.

3.2 Material and Methods

3.2.1 Study population

We performed this study in the subjects who were participating in the Prevention of Renal and Vascular ENd-Stage Disease (PREVEND) study. The PREVEND study was designed to prospectively investigate the natural course of microalbuminuria and its relation to renal and cardiovascular disease in a large cohort drawn from the general population. Baseline data were collected in 1997 and 1998. Details of the study protocol have been described elsewhere (Pinto-Sietsma et al., 2000), and will only be briefly summarised here.

3.2.2 City of Groningen sample

All inhabitants of the city of Groningen (the Netherlands) between the age of 28 and 75 years, in total 85,421 subjects, were sent a one-page postal questionnaire on demographics, use of medication, smoking behaviour, family history of cardiovascular disease, and pregnancy. They also received a vial to collect an early morning urine sample. Altogether, 40,856 people (47.8%) responded (referred to as the city of Groningen sample). The subjects were defined as having hypertension when they

reported using medication for elevated blood pressure, and were classified as smokers if they reported smoking or having smoked cigarettes during the previous 5 years. A family history of cardiovascular disease was considered present if at least one first-degree relative had documented angina pectoris, a myocardial infarction or a stroke before the age of 65 years.

3.2.3 PREVEND cohort

Further analyses were carried out on a selection of subjects that visited the outpatient clinic. This study cohort consists of all responding subjects with a morning urinary albumin concentration of 10 mg/L or more, together with a randomly selected control group of the total study population with morning urinary albumin excretion of <10 mg/L, and who gave informed consent to participate in a long-term follow-up program. Subjects with insulin-dependent diabetes and pregnant women were excluded. Altogether 8592 subjects underwent a screening program of two visits in an outpatient clinic. These visits included anthropometric measurements and fasting blood samples. Both visits included blood pressure measurements with an automatic Dinamap device (GE Medical Systems Information Technologies, Inc., Milwaukee, WI). Blood samples were taken for various measurements, including fasting plasma levels of cholesterol. All 8592 subjects completed an extensive questionnaire on demographics; cardiovascular, renal, and family medical history; use of antihypertensive medication; and smoking status. Systolic and diastolic blood pressure measurements were calculated as the mean of the last two of 10 successive measurements of the two visits. Hypertension was defined as systolic blood pressure ≥ 140 mmHg, diastolic blood pressure of ≥ 90 mmHg, or the use of antihypertensive medication based on pharmacy reports. Smoking was defined as currently smoking or having stopped smoking less than 1 year ago. Education was coded in two categories: university or higher professional education versus other. A family history of cardiovascular heart disease (CHD) was considered present if at least one parent had CHD before the age of 65. The PREVEND study was approved by the Medical Ethics Committee and conducted in accordance with the guidelines of the Declaration of Helsinki.

3.2.4 Environmental data

The road traffic noise exposure of the subjects was calculated at the most exposed façade of the dwelling with standard method SKM2 (Standaard Karterings Methode 2) in accordance with requirements of the European Environmental Noise Directive (END). For the analyses, we used the EU standard noise metric L_{den}. L_{den} (day, evening, night level) is

an “average” sound level for 24 hours in which sound levels during the evening and the night are increased by 5 dB(A) and 10 dB(A), respectively. SKM2 is the sophisticated version of the Netherlands’ standard method for noise modelling and producing noise maps (VROM, 2004) in compliance with the END. SKM2 is implemented in Urbis (Borst and Miedema, 2005) that was used here for the exposure calculations. Noise calculations are carried out in two steps: calculating first the emission and then the transmission. The emission calculations take into account traffic characteristics, including traffic intensities, traffic composition (percentages of motorbikes, light-, medium-, and heavy-duty vehicles), speed, type of road height and surface. The transmission calculations take into account the distance between source (road) and dwelling façade, air attenuation, effects of yearly meteorological conditions, ground attenuation, object screening, reflection of objects opposite the dwelling, and statistical diffraction for transmission. Noise exposure was calculated at the height of the centre of the dwelling façade of the exposed subject. Very low levels of noise exposure (< 45 dB(A)) were recoded as 45 dB(A) since this was considered to be a lower limit of the ambient noise in urban surrounding.

Input for the noise emission calculations were detailed digital maps describing traffic characteristics for each road segment. The geographic location of roads in these maps was extracted from the National Road Network (NWB; containing all streets, country roads, and highways) obtained from the Netherlands Ministry of Housing, Spatial Planning and the Environment / Directoraat-Generaal Ruimte (VROM/DGR). The traffic flow data attached as attributes to the road segments were obtained from the local authorities of Groningen for a dense network of roads, including highways, arterial roads, main streets, and principal residential streets. The basis for the noise transmission calculations was digital maps with precise information on the geographic situation of buildings and ground characteristics (Topographic Service data [TOP10]^{2} obtained from VROM/DGR). Building height was derived from the Actual Height Information Netherlands (AHN), a 5 x 5 m grid with height information based on laser altimetry. In addition, a data set on the geographical location of noise screens with their height was obtained from the local authorities. The geographic location of dwelling facades was derived from the building façade dimensions, divided into dwellings on the basis of the address coordinates available from the local authorities of Groningen.

In addition, we assessed exposure to air pollution to adjust for possible confounding. We obtained PM10 concentrations using a combination of measurement data and modeling techniques. Regional background concentrations based on measurement data were used, supplemented with the calculated contribution of the local road traffic, to account for the spatial variation within the city. Regional background concentrations were available from the National Institute for Public Health and the Environment (RIVM), which annually estimates the background concentrations based on measurement data of

the national air quality monitoring network (RIVM, 1993). Combining these monitoring data and nation-wide air pollution modeling, each year they generate a national map (1 km x 1 km) of annual average concentrations for the most important components of air pollution. Taking into account spatial gradients within the city, we obtained exposure concentrations by summing the regional background concentration and the local traffic contribution using the Netherlands' standard Dutch models for local air pollution calculations: the street model CAR II (e.g., Eerens et al., 1993; Boeft et al., 1996; Teeuwisse, 2003) for the contribution of a street to locations in that street, and a Gaussian (plume) dispersion model based on "Pluim" (the Netherlands' national model which is the default used to calculate annual average concentration contributions, (Hanna et al., 1982) for all other contributions to a location from within the urban area. PM10 emissions for the different vehicle categories (light-, medium-, and heavy duty vehicles and busses), were calculated by multiplication of the amount of vehicles per category by the speed-dependent national emission factor for that category, available from the RIVM. The exposure to air pollution is described with the annual average concentration, expressed in $\mu g\ m^{-3}$.

For the purpose of this study, additional data were collected on socio-economic status (SES). Local indicators of poverty were available on a neighbourhood scale, from the Central Bureau of Statistics (CBS) for 1997 (income distribution).

3.2.5 Statistical analysis

We performed logistic regression analysis to determine the association between exposure to road traffic noise and hypertension. First, the association of noise with hypertension was evaluated in the overall city of Groningen sample, in which the presence of hypertension was defined by self-reported use of blood pressure-lowering agents. Then, the association between noise and hypertension was further investigated in the PREVEND cohort, for which more detailed data on both the effect variables and confounders was available. Analysis was carried out with strictly objective measures of hypertension: systolic blood pressure ≥ 140 mmHg diastolic blood pressure ≥ 90 mmHg, or use of antihypertensive medication based on pharmacy reports.
Furthermore, additional adjustment for confounders was made. Various models were fitted: first a model with noise exposure as the only predictor; second, a model additionally adjusting for age and sex; third, a model additionally consisting of age, sex, SES, family history of cardiovascular disease, smoking, and – for the PREVEND cohort – body mass index (BMI), plasma cholesterol, and level of education. Finally a model was used that, in addition, adjusted for air pollution. Missing values were excluded listwise. Results are expressed as odds ratios (ORs) as an approximation of relative risk with the

corresponding 95 % confidence intervals (CIs). A *P* value of at most 0.05 was considered to be significant, and a *P* value between 0.05 and 0.1 was considered an indication of a trend. Age, SES, BMI and cholesterol were entered as a continuous variable, whereas sex, family history of smoking and education were entered as categorical variables. Subgroup analyses were performed to investigate the moderating role of age, and to explore differences between men and women, and possible differences at higher exposure of noise. In addition, we investigated if there was a difference in effect between high and low morning urinary albumin excretion, the inclusion criterion for the PREVEND cohort. We performed analyses using the statistical software package SPSS version 12.01 (SPSS Inc., Chicago, IL).

3.3 Results

Table 3.1a shows the characteristics of the city of Groningen sample and the PREVEND cohort, respectively. The table shows that average noise levels (L_{den} in dB) are higher in subjects with hypertension. Furthermore, people with hypertension more frequently have a noise exposure (L_{den}) greater than 55 dB. They are generally older, seem to smoke less frequently, are less likely to have university or higher professional education, and live in an area with a neighbourhood SES below average.

Table 3.1b shows the population characteristics of the city of Groningen sample and the PREVEND cohort, respectively, by exposure. The table shows that within subjects with higher road traffic noise exposure, the prevalence of hypertension is higher. Furthermore, the average age, BMI, and cholesterol level are higher, and subjects less often have university or higher professional education, and subjects more often live in an area with a neighbourhood SES below average.

At higher noise exposure, the strongest increase of prevalence of hypertension is found in the 45 to 55 years-old age group; the oldest group showed a decrease. In the city of Groningen sample, the prevalence antihypertensive medication changed from 1.9% to 2.2% (younger than 45 years), 8.8% to 9.8% (45 to 55 years), 19.9% to 20.4% (55 to 65 years), and 31.2% to 28.6% (older than 65 years). In the PREVEND cohort prevalence of hypertension changed from 15.6% to 16.8% (younger than 45 years), 34.8% to 39.9% (45 to 55 years), 59.9% to 59.0% (55 to 65 years), and 77.2% to 77.0% (older than 65 years) for *Lden* < 55 dB versus *Lden* > 55 dB.

Figure 3.1 shows the distribution of subjects over road traffic noise exposure classes and pollution exposure classes (PM10; $\mu g\ m^{-3}$), for the city of Groningen sample and the PREVEND cohort, respectively.

Table 3.1a *Characteristics of the City of Groningen sample (n = 40,856) and the PREVEND cohort (n = 8592) by hypertension*[ab]

	City of Groningen sample		*PREVEND cohort*	
	No AHT	AHT	No HT	HT
N	34,492	4357	4437	2827
Male *(%)*	45.9	41.6***	41.7	58.6***
Age (*years*)	48.0 (12.4)	61.1 (9.7)***	45.5 (11.1)	57.9 (11.4)***
Smoking *(%)*	43.5	29.0***	42.0	31.1***
SES > mean *(%)*	38.0	26.8***	41.3	31.9***
Fam. hist. CVD (1st degree relative) *(%)*	29.3	41.0***	28.9	37.8***
L_{den} mean (*dB*)	53.3 (6.9)	54.6 (7.0)***	52.8 (6.8)	54.3 (7.0)***
L_{den} ≥ 55 dB *(%)*	39.6	47.6***	36.8	46.2***
PM10 median ($\mu g\ m^{-3}$)	33.5 (32.8-37.5)	33.6 (32.9-37.6)***	33.4 (32.8-37.1)	33.6 (32.8-37.5)***
PM10 > 34 *(%)*	31.3	36.8***	29.0	35.2***
Self reported AHT *(%)*	0	100***	0.8	34.4***
Caucasian *%*	NA	NA	96.1	97.4**
BMI kg/m^2	NA	NA	25.2 (3.9)	28.0 (4.3)***
Cholesterol *mmol/L*	NA	NA	5.5 (1.1)	6.0 (1.1)***
SBP *mmHg*	NA	NA	118.6 (11.1)	149.9 (18.8)***
DBP *mmHg*	NA	NA	70.1 (7.3)	81.9 (9.4)***
Education: university/higher professional *(%)*	NA	NA	45.9	26.5***
Pharmacy based AHT *(%)*	NA	NA	0	47.2***

* P<0.05 versus no (A)HT; ** P<0.01 versus no (A)HT; *** P<0.001 versus no (A)HT

[a]Variables are described by means (SD), or median (range 5th and 95th percentiles) in case of skewed distribution, and percentages in case of dichotomous variables.

[b]Groups of cases are compared by chi-square (percentages) and Mann-Whithey statistics (means and medians).

AHT= antihypertensive treatment; SES = social economic status; CVD = cardiovascular disease; L_{den} noise:day-evening-night level; PM10 = particulate matter; BMI = body mass index; SBP = systolic blood pressure; DBP = diastolic blood pressure; NA = not available; PREVEND = Prevention of Renal and Vascular End-Stage Disease study.

Table 3.1b *Characteristics of the City of Groningen sample (n = 40,856) and the PREVEND cohort (n = 8,592) by road traffic noise exposure*[ab]

	City of Groningen sample		PREVEND cohort	
	Lden < 55	*Lden* > 55	*Lden* < 55	*Lden* > 55
N	23134	15715	4325	2939
Male *(%)*	46.1	44.7**	49.7	50.2
Age (*years*)	48.0 (12.2)	51.7 (13.4)***	47.7	51.6***
Smoking *(%)*	43.0	40.6***	38.2	36.9
SES > mean *(%)*	38.9	33.1***	40.4	33.7***
Fam. hist. CVD (1st degree relative) *(%)*	30.3	30.9	31.5	32.4
PM10 median ($\mu g\ m^{-3}$)	33.3 (32.8-34.0)	34.6 (33.4-38.9)***	33.3 (32.8-34.0)	34.6 (33.4-38.9)***
PM10 > 34 *(%)*	4.0	73.0***	4.2	72.5***
Self reported AHT *(%)*	9.9	13.2***	10.0	13.6***
Caucasian *%*	NA	NA	96.3	97.0
BMI kg/m^2	NA	NA	26.0 (4.2)	26.3 (4.2)***
Cholesterol *mmol/L*	NA	NA	5.6 (1.1)	5.7 (1.1)**
SBP *mmHg*	NA	NA	127.7 (19.6)	131.3 (21.2)***
DBP *mmHg*	NA	NA	73.7 (9.7)	74.6 (9.9)***
Education: university/higher professional *(%)*	NA	NA	43.3	37.4***
Pharmacy based AHT *(%)*	NA	NA	14.9	19.9***
Hypertension (%)			35.1	44.5***

* P<0.05 versus no (A)HT; ** P<0.01 versus no (A)HT; *** P<0.001 versus no (A)HT

[a]Variables are described by means (SD), or median (range 5th and 95th percentiles) in case of skewed distribution, and percentages in case of dichotomous variables.

[b]Groups of cases are compared by χ^2 (percentages) and Mann-Whithey statistics (means and medians)

AHT= antihypertensive treatment; SES = social economic status; CVD = cardiovascular disease; L_{den} noise:day-evening-night level; PM10 = particulate matter; BMI = body mass index; SBP = systolic blood pressure; DBP = diastolic blood pressure; NA = not available; PREVEND = Prevention of Renal and Vascular End-Stage Disease study.

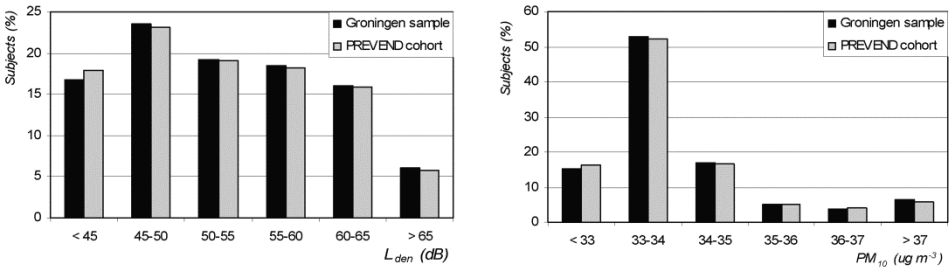

Figure 3.1 *Distribution of exposure of subjects at their home for the City of Groningen sample (%) and the PREVEND cohort over road traffic noise classes (L_{den}) [dB] and over air pollution classes (PM10; µg m^{-3}).*

In Groningen the spatial variation in noise exposure is substantial, with a difference in exposure between the lowest and highest 5% of dwellings in the city exceeding 20 dB(A) for road traffic noise *(L_{den})*, ranging from about 45 dB (urban background) to more than 65 dB (L_{den}) in the vicinity of busy roads. The variation in annual average PM10 concentration is much smaller. The total concentration in Groningen, as in many cities, is dominated by the contribution of sources outside the city (regional background) and is, to a much smaller extent, affected by the local traffic contribution. Exposure ranged from around 33 µg m^{-3} for the lowest 5%, to more than 37.5 µg m^{-3} for the highest 5%, respectively. The correlation between road traffic noise and PM10 is r = 0.72.

In the city of Groningen sample, an association was found between exposure toroad traffic noise (day-evening-night level; L_{den}) and hypertension (defined as self-reported use of antihypertensive medication). A significant odds ratio was found of 1.31 (95% CI = 1.25-1.37) per 10 dB(A) increase in noise level. However, after adjustment for confounders, the odds ratio became smaller and non-significant. Odds ratios and 95% confidence intervals obtained by logistic regression are presented in Table 3.2, for four different models. Odds ratios are shown for the sample as a whole and also for subgroups within the sample. In the unadjusted model, significant associations were found in most subgroups (OR = 1.10 to 1.40), but not for the age groups of subjects younger than 45 and older than 65 years. After adjustment for age, sex, smoking, family history of CVD, and SES, odds ratios were highest for the 45- to 55-years-old age group with 1.08 (95% CI = 0.97–1.20) and the subgroup with “high” noise exposure ($L_{den} \geq 55$) with 1.21 (95% CI = 1.05-1.38). When additionally adjusting for air pollution, the effects of road traffic noise did not wane, with odds ratios of 1.19 (95% CI = 1.02-1.40) and 1.31 (95% CI = 1.08-1.59) respectively. No differences were found between men and women. Furthermore, no differences were found between the subgroups with high (UAC ≥ 10 mg L^{-1}) and low (UAC < 10 mg L^{-1}) morning Urinary Albumin Excretion.

Table 3.2 *Odds ratios for a 10 dB increase of road traffic noise exposure (day-evening-night level; L_{den}) for self reported use of medication for hypertension in pre-specified subgroups of the City of Groningen sample. Odds ratios from logistic regression in each subgroup are shown, for different models: (1) unadjusted; (2) adjusted for age and sex; (3) adjusted for age, sex, smoking, family history CVD, SES; (4) and the same model including adjustment for air pollution (PM10).*

	N	**OR (unadjusted)**	**OR (age,sex adjusted)**	**OR (full model)**	**OR (full model + PM10)**
All	*38849*	1.31 (1.25-1.37)**	1.01 (0.96-1.06)	1.01 (0.96-1.06)	1.03 (0.96-1.11)
Sex					
Male	*17652*	1.22 (1.14-1.31)**	0.99 (0.92-1.06)	0.99 (0.92-1.07)	1.03 (0.92-1.15)
Female	*21197*	1.38 (1.30-1.46)**	1.03 (0.97-1.10)	1.02 (0.95-1.09)	1.03 (0.94-1.13)
Age (year)					
< 45	*15562*	0.96 (0.81-1.15)	1.00 (0.84-1.19)	1.00 (0.84-1.19)	1.12 (0.90-1.40)
45-55	*9637*	1.13 (1.02-1.26)**	1.10 (0.99-1.22)*	1.08 (0.97-1.20)	1.19 (1.02-1.40)**
55-65	*7089*	1.10 (1.01-1.20)**	1.08 (0.99-1.18)*	1.07 (0.98-1.17)	1.02 (0.90-1.17)
> 65	*6561*	0.95 (0.88-1.03)	0.94 (0.87-1.01)	0.94 (0.87-1.01)*	0.93 (0.83-1.04)
Noise (L_{den},dBA)					
< 55	*23134*	1.40 (1.23-1.61)**	1.02 (0.88-1.19)	1.06 (0.91-1.23)	1.09 (0.94-1.27)
≥ 55	*15715*	1.31 (1.16-1.48)**	1.21 (1.06-1.39)**	1.21 (1.05-1.38)**	1.31 (1.08-1.59)**
UAC (mg/L)					
< 10	*29363*	1.36 (1.29-1.44)**	1.04 (0.99-1.11)	1.03 (0.97-1.09)	1.03 (0.95-1.12)
≥ 10	*9485*	1.19 (1.10-1.29)**	0.93 (0.85-1.02)	0.94 (0.86-1.04)	1.02 (0.89-1.17)

* Indication of a trend ($p < 0.1$)

** Significant relationship ($p < 0.05$)

When we studied these relationships in greater detail in the PREVEND cohort, using the more detailed data on both effect parameters and confounders, we found similar results for overall hypertension (systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg or the use of antihypertensive medication based upon pharmacy reports). Table 3.3 shows significant associations between road traffic noise exposure and hypertension for the cohort as a whole, as well as in most subgroups (unadjusted odds ratios ranging from 1.24 to 1.42). For the PREVEND cohort, the unadjusted odds ratio was 1.35 (95% CI = 1.27-1.45) per 10 dB(A) increase in exposure to road traffic noise. After adjustment for age, sex, BMI, smoking, cholesterol, family history of CVD, education, and SES, associations were still significant in the 45 to 55year-old age group, with an adjusted odds ratio of 1.27 (95% CI = 1.08 – 1.49). With additional adjustment for

air pollution, the effects of road traffic noise did not wane, with an odds ratio of 1.39 (95% CI = 1.08-1.77) per 10 dB(A) increase in noise level. Results of the cohort analysis are consistent with the results in the city of Groningen sample, showing effects in the group of subjects around the age of 50 years (age group 45 to 55 years). Statistical tests showed this interaction was significant in the PREVEND cohort, but not in the city of Groningen sample. No differences in effect were found between men and women.

Table 3.3 *Odds ratios for a 10 dB increase of road traffic noise exposure (day-evening-night level; L_{den}) for hypertension (systolic blood pressure ≥ 140 mmHg or diastolic blood pressure of ≥ 90 mmHg or the use of antihypertensive medication based upon pharmacy reports) in pre-specified subgroups in the PREVEND cohort. Odds ratios from logistic regression in each subgroup are shown, for different models: (1) unadjusted; (2) adjusted for age and sex; (3) adjusted for age, sex, BMI, smoking, cholesterol, family history CVD, education, SES; (4) and the same model including adjustment for air pollution (PM10).*

	N	**OR (unadjusted)**	**OR (age,sex adjusted)**	**OR (full model)**	**OR (full model+PM10)**
All	*7264*	1.35 (1.27-1.45)**	1.06 (0.98-1.14)	1.07 (0.98-1.18)	1.08 (0.95-1.23)
Sex					
Male	*3507*	1.37 (1.25-1.51)**	1.12 (1.00-1.24)*	1.09 (0.97-1.23)	1.07 (0.90-1.28)
Female	*4237*	1.35 (1.22-1.48)**	0.99 (0.88-1.11)	1.03 (0.90-1.18)	1.08 (0.88-1.31)
Age (year)					
< 45	*2705*	0.96 (0.82-1.13)	1.00 (0.85-1.18)	0.97 (0.81-1.17)	0.95 (0.73-1.24)
45-55	*1858*	1.24 (1.08-1.42)**	1.22 (1.06-1.40)**	1.27 (1.08-1.49)**	1.39 (1.08-1.77)**
55-65	*1368*	0.97 (0.83-1.14)	0.98 (0.84-1.15)	1.00 (0.83-1.21)	1.08 (0.82-1.43)
> 65	*1333*	0.99 (0.83-1.18)	0.96 (0.80-1.15)	0.98 (0.79-1.21)	0.90 (0.69-1.18)
Noise (L_{den},dBA)					
< 55	*4325*	1.35 (1.11-1.65)**	1.06 (0.84-1.32)	1.12 (0.86-1.44)	1.01 (0.76-1.34)
≥ 55	*2939*	1.24 (1.02-1.52)**	0.99 (0.79-1.25)	1.03 (0.79-1.34)	1.20 (0.81-1.77)
UAC (mg/L)					
< 10	*2105*	1.42 (1.24-1.62)**	1.08 (0.92-1.25)	1.04 (0.87-1.24)	1.03 (0.82-1.31)
≥ 10	*5158*	1.31 (1.21-1.42)**	1.04 (0.95-1.14)	1.08 (0.97-1.20)	1.09 (0.93-1.28)

** Significant relationship ($p < 0.05$)

* Indication of a trend ($p < 0.1$)

3.4 Discussion and Conclusions

Without adjustment for confounders, an association was found between exposure to road traffic noise and hypertension. Unadjusted odds ratios ranged from 1.31 to 1.35 per 10 dB increase in noise level (L_{den}) in the total samples. However, after adjustment for confounders, these odds ratios became smaller and not significant.

Investigation by analyses per subgroup of a possible moderating effect of age showed strongest associations in the age group of subjects between 45 and 55 years old. After adjustment for confounders, odds ratios were highest in this age group for self-reported antihypertensive medication use in the city of Groningen sample. Further analysis in the PREVEND cohort showed similar results. Significant associations for hypertension were shown for the subjects who were between 45 and 55 years old. Thus, our results suggest an interaction between exposure to noise and age, with effects occurring in middle-aged adults (45 to 55 years). Statistical tests showed the interaction was significant in the PREVEND cohort, but not in the city of Groningen sample.

Relative risk estimates for subjects younger than 45 years were not significant. This might be explained by a lack of power, as a result of low prevalence of hypertension at a younger age. Furthermore, some of the subjects in this age group might suffer from secondary hypertension. At an older age, hypertension is relatively common. It is not clear why the estimated relative risk is not significantly different in subjects older than 55 years, although the risk does seem to be elevated in the respondents between 45 and 55 years old. A possible explanation is that the influence of environmental exposure might become relatively less dominant compared with that of other risk factors, by an overall decrease in health status in the older population. Alternatively, it might be a true effect that subjects who are between 45 and 55 years old might be more sensitive to exposure to road traffic noise, compared with younger and older subjects. This would be consistent with noise annoyance studies. A large meta analysis showed an inverted U-shaped relationship of noise annoyance with age, with highest effects occurring around the age of 50 years (Groothuis-Oudshoorn and Miedema, 2006).

We explored if noise effects were different at higher noise levels. After adjustment for confounders, a stronger association was found for subjects exposed to higher noise levels (L_{den} > 55 dB) in the city of Groningen sample. In analogy, further analysis in the PREVEND cohort showed higher adjusted odds ratios when adjusted for PM10 at higher noise levels for hypertension, although this did not reach significance. A stronger reaction to higher noise exposure may be explained by a threshold for effects, or by a non-linear exposure-effect relationship. However, in further analysis, this could not be conclusively confirmed.

No differences in effect between men and women were found. Previous studies on road traffic noise and hypertension reported higher prevalence of hypertension in men who reported to live in a busier street (Herbold et al., 1989) and higher self reported use of antihypertensive medication use in men who reported a higher annoyance score (Belojevic and Saric-Tanaskovic, 2002). On the other hand, a large recent Swedish study reported an association between noise and self reported hypertension for women, but not for men (Björk et al, 2006). An older study reported no significant differences in hypertension between noisy and quiet streets for housewives between 40 and 49 years old (Knipschild et al., 1979); men were not included in the study. In these studies no actual noise levels were available, and subjective measures of exposure were used. In the Cearphilly and Speedwell studies, effects of road traffic noise on cardiovascular health (ischemic heart disease) were examined in middle-aged men. These studies did assess actual levels of noise exposure at the home, although they did not specifically focus on the relationship of noise exposure to hypertension. They presented results for blood pressure as a cardiovascular risk factor. Both positive and negative associations for noise exposure and measured blood pressure were reported (Babisch et al., 1988; Babisch, et al., 1993; Babisch et al., 1999). To our knowledge, the use of blood pressure-lowering medication was not included in the analysis. Because a substantial percentage of middle aged men uses anti-hypertensive medication, this may have influenced the findings.

The present results show that the effects of road traffic noise on hypertension do not wane when we adjust for air pollution; instead, they seem to become even more pronounced. These outcomes strongly suggest that effects of noise on hypertension cannot be explained by an association between noise and air pollution, and air pollution being the true cause of effects.

Recently, a number of new studies have become available investigating the relationship between road traffic noise and hypertension, taking into account air pollution (Foraster et al., 2014; Babisch et al., 2014; Sørensen et al., 2011). In addition, a number of studies have become available focusing on the association between traffic noise and blood pressure, while taking air pollution into account (Liu et al., 2014; Bilenko et al., 2013; Dratva et al., 2012). In a recent systematic review of studies into cardiovascular effects of traffic related noise and air pollution, Tetreault et al. (2013) concluded that the available studies suggest that confounding between noise and air pollution is limited, in line with the results of this study. However, the number of studies that is currently available is still limited, and there are large methodological differences between studies. Therefore, it still seems too early for strong conclusions on potential confounding or interaction. More studies are needed to assess the relative contribution of road traffic noise and air pollution.

The pathway for cardiovascular health effects of environmental noise exposure is hypothesized to involve stress reactions related to noise exposure (Ising et al., 1999). After disturbance of activities, communication or sleep, exposure to noise may directly or indirectly lead to activation of the sympathetic system and the endocrine system (hypothalamus-pituary-adrenal [HPA] axis), resulting in increased heart rate with reduced variability and elevated levels of cortisol. This might, possibly in combination with other factors, lead to increases in biological risk factors (e.g., increase in blood lipids, blood pressure, blood glucose, and blood viscosity). Increases in biological risk factors may induce manifest diseases (e.g., hypertension, arteriosclerosis, ischemic heart disease) (Babisch et al., 2001; Babisch et al., 2003). Associations between long-term exposure to environmental noise in the residential environment and cardiovascular health have been found previously. Epidemiological studies indicate that environmental noise exposure increases the risk for cardiovascular diseases in adults (Babisch et al., 2000; Van Kempen et al., 2002; Babisch et al., 1999; Babisch et al., 2003; Babisch et al., 2004; Babisch et al., 2005). Our results suggest that hypertension in middle-aged people (45 to 55 years old) may mediate the influence of noise on cardiovascular disease.

When generalizing the relative risk estimates for the population in the city of Groningen to other cities, some aspects need consideration. Results of this study have to be confirmed in different populations. Potentially relevant differences with other cities may include traffic composition, exposure, and population characteristics. Traffic composition in Groningen may be fairly representative for that in an average sized city. Groningen comprises a large variety in road types, including a number of highways, large arterial roads, and a busy ring road. The population of Groningen is relatively homogenous. There is little ethnic variety. More than 95% of the population is Caucasian.

There was a limited variation in exposure to air pollution (PM10) within the population of Groningen. This may be why no significant contribution to the relative risk for hypertension was found for exposure to air pollution. As far as there were variations in exposure to air pollution, these were accounted for in our most extended models.

The location of busy roads may influence the social structure of the population, for example, by attraction of people with a lower social economic status to noisy areas through lower housing prices. To account for this, we adjusted for a neighborhood indicator of poverty, and in the PREVEND cohort, we added education as an indicator of SES and BMI as anindicator of lifestyle. After adjustment for age and sex, additionally adjusting for other variables did not substantially change relative risk estimates.

The PREVEND cohort is a subsample of the initial random city of Groningen sample, consisting of the subjects with a morning urinary albumin concentration greater than 10 mg L^{-1}, supplemented with a random subsample. It is unknown to what extent this

enrichment for albuminuria may have affected relative risk estimates. However, results show no substantial differences in relative risk estimates between subjects with low and subjects with elevated morning UAC.

To our knowledge, this is the first time that the effects of road traffic noise exposure in the residential environment on hypertension are studied in such a large random sample. Instead of using subjective measures, as in some previous studies (e.g., self-reported annoyance or road type), we used objectively assessed levels of road traffic noise, enabling us to quantitate relative risk estimates by increase in noise level. A unique aspect of this study on the effects of exposure to road traffic noise was that, in addition to common cardiovascular risk factors, exposure to air pollution was taken into account. Thus, the investigation of an independent contribution of exposure to road traffic noise to hypertension was made possible.

The PREVEND cohort provided an additional opportunity for further analysis. In this subsample, more detailed information on both the effect variables and confounders was available. For the subjects in this cohort, measurements of systolic and diastolic blood pressure were available. In addition, pharmacy-based data on use of antihypertensive medication were available. Combined, these data form a strictly objective measure of overall hypertension. This measure may be most accurate in capturing all people with hypertension (also those who do not know they have hypertension), because it includes both people who are on hypertensives and those who are not.

Although the relative risks estimates for the age group between 45 and 55 years old may be rather small, the public health impact may be substantial. Because hypertension is common at this age, and a large percentage of the population is exposed to substantial levels of road traffic noise, a relative risk of 1.2 to 1.4 may yield a substantial increase in the prevalence of hypertension and possibly cardiovascular disease. This study shows that it is plausible that, like aircraft noise (Rosenlund et al., 2001; Franssen et al., 2004), road traffic noise may be associated with hypertension. In the general population, compared with aircraft noise, a relatively high percentage of people are exposed to road traffic noise. Therefore, the latter may even be more of a public health problem.

References

Babisch W, Gallacher JE, Elwood PC, Ising H. Traffic noise and cardiovascular risk. The Caerphilly study, first phase. Outdoor noise levels and risk factors. Arch Environ Health. 1988;43:407-414.

Babisch W, Ising H, Gallacher JE, Sharp DS, Baker IA. Traffic noise and cardiovascular risk: the Speedwell study, first phase. Outdoor noise levels and risk factors. Arch Environ Health. 1993;48:401-405.

Babisch W, Ising H, Gallacher JE, Sweetnam PM, Elwood PC. Traffic noise and cardiovascular risk: the Caerphilly and Speedwell studies, third phase--10-year follow up. Arch Environ Health. 1999;54:210-216.

Babisch W. Traffic Noise and Cardiovascular Disease: Epidemiological Review and Synthesis. Noise Health. 2000; 2:9-32.

Babisch W, Fromme H, Beyer A, Ising H. Increased catecholamine levels in urine in subjects exposed to road traffic noise. The role of stress hormones in noise research. Environ Int. 2001;26:475-481.

Babisch W, Ising H, Gallacher JE. Health status as a potential effect modifier of the relation between noise annoyance and incidence of ischaemic heart disease. Occup Environ Med. 2003;60:739-745.

Babisch W. Health aspects of extra-aural noise research. Noise Health. 2004;6:69-81.

Babisch W, Beule B, Schust M, Kersten N, Ising H. Traffic noise and risk of myocardial infarction. Epidemiology. 2005;16:33-40.

Babisch W, Wolf K, Petz M, Heinrich J, Cyrys J, Peters A. Associations between traffic noise, particulate air pollution, hypertension, and isolated systolic hypertension in adults: the KORA study. Environ Health Perspect. 2014;122(5):492-8.

Belojevic G, Saric-Tanaskovic M. Prevalence of Arterial Hypertension and Myocardial Infarction in Relation to Subjective Ratings of Traffic Noise Exposure. Noise Health. 2002;4:33-37.

Berglund, B, Lindvall, T, Schwela, D, and Goh, KT. Guidelines for Community Noise. Geneva: Word Health Organization; 2000.

Bilenko N, Rossem LV, Brunekreef B, Beelen R, Eeftens M, Hoek G, et al. Traffic-related air pollution and noise and children's blood pressure: results from the PIAMA birth cohort study. Eur J Prev Cardiol. 2013; DOI: 10.1177/2047487313505821.

Björk J, Ardö J, Stroh E, Lövkvist H, Östergen P, Albin M. Road traffic noise in southern Sweden and its relation to annoyance, disturbance of daily activities and health. Scand J Work Environ Health. 2006;32(5):392-401.

Boeft J. den, Eerens H.C., Tonkelaar W.A.M. den, and ZandVeld P.Y.J. CAR International: A simple model to determine city street air quality. Sci Total Environ 1996: 190:321–326.

Borst, HC and Miedema HME. Comparison of noise impact indicators, calculated on the basis of noise maps of DENL. Acta Acust. 2005;91, 378–385.

Dratva J, Phuleria HC, Foraster M, Gaspoz JM, Keidel D, Künzli N, Liu LJ, Pons M, Zemp E, Gerbase MW, Schindler C. Transportation noise and blood pressure in a population-based sample of adults. Environ Health Perspect. 2012; 120(1):50-5.

Eerens, HC, Sliggers, CJ, and Van den Hout, KD. The CAR model: The Dutch method to determine city street air quality. Atm Environ. 1993; 27b[4]: 389-399.

Foraster M, Künzli N, Aguilera I, Rivera M, Agis D, Vila J, Bouso L, Deltell A, Marrugat J, Ramos R, Sunyer J, Elosua R, Basagaña X. High blood pressure and long-term exposure to indoor noise and air pollution from road traffic. Environ Health Perspect. 2014;122(11):1193-200.

Franssen EAM, van Wiechen CM, Nagelkerke NJ, Lebret E. Aircraft noise around a large international airport and its impact on general health and medication use. Occup Environ Med. 2004;61:405-413.

Gezondheidsraad. The influence of night-time noise on sleep and health. Den Haag: Gezondheidsraad; 2004/14E, 1-196.

Groothuis-Oudshoorn, K. and Miedema, HME. Multilevel grouped regression for analyzing self-reported health in relation to environmental factors: the model and its application. Biometrical Journal. 2006; 48[1]: 67-82.

Hanna S.R., Briggs G.A. and Hosker R.P. jr., Handbook on Athmospheric Diffusion, US DOE, 1982.

Herbold M, Hense HW, Keil U. Effects of road traffic noise on prevalence of hypertension in men: results of the Luebeck Blood Pressure Study. Soz Praventivmed. 1989;34:19-23.

Hoek G, Brunekreef B, Goldbohm S, Fischer P, van d. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. Lancet. 2002;360:1203-1209.

Ising H, Babisch W, Günther T. Work noise as a risk factor in myocardial infarction. J Clin Basic Cardiol. 1999;2:64-68.

Kempen EEEM, Kruize H, Boshuizen HC, Ameling CB, Staatsen BA, de Hollander AE. The association between noise exposure and blood pressure and ischemic heart disease: a meta-analysis. Environ Health Perspect. 2002;110:307-317.

Knipschild P, Salle H. Road traffic noise and cardiovascular disease. A population study in The Netherlands. Int Arch Occup Environ Health. 1979;44:55-59.

Liu C, Fuertes E, Tiesler CM, Birk M, Babisch W, Bauer CP, Koletzko S, von Berg A, Hoffmann B, Heinrich J; GINIplus and LISAplus Study Groups. The associations between traffic-related air pollution and noise with blood pressure in children: results from the GINIplus and LISAplus studies. Int J Hyg Environ Health. 2014;217(4-5):499-505.

Miedema HME, Oudshoorn CGM. Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect. 2001;109:409-416.

Passchier-Vermeer W, Passchier WF. Noise exposure and public health. Environ Health Perspect. 2000;108:123-131.

Passchier-Vermeer, W. Noise and health: review. Den Haag: Gezondheidsraad; 1993: Report nr A93/02E.

Pearsons KS, Barber DS, Tabachnick BG, Fidell S. Predicting noise-induced sleep disturbance. J Acoust Soc Am. 1995;97:331-338.

Pinto-Sietsma SJ, Janssen WMT, Hillege HL et al. Urinary albumin excretion is associated with renal functional abnormalities in a nondiabetic population. J Am Soc Nephrol. 2000;11:1882-1888.

Pope CA, Burnett RT, Thurston GD et al. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. Circulation. 2004;109:71-77.

Rosenlund M, Berglind N, Pershagen G, Jarup L, Bluhm G. Increased prevalence of hypertension in a population exposed to aircraft noise. Occup Environ Med. 2001;58:769-773.

Sørensen M, Hvidberg M, Hoffmann B, Andersen ZJ, Nordsborg RB, Lillelund KG, Jakobsen J, Tjønneland A, Overvad K, Raaschou-Nielsen O. Exposure to road traffic and railway noise and associations with blood pressure and self-reported hypertension: a cohort study. Environ Health. 2011;10:92.

Teeuwisse SD. 2003. Handbook on the software package CAR II, versie 2.0, TNO. Report R2003/118; 2003.

Tetreault LF, Perron S, Smargiassi A. Cardiovascular health, traffic-related air pollution and noise: are associations mutually confounded? A systematic review. Int J Public Health 2013; 58: 649–666

Chapter 4

Road traffic noise, air pollution components, and cardiovascular events

Yvonne de Kluizenaar
Frank J. van Lenthe
Antoon J.H. Visschedijk
Peter Y.J. Zandveld
Henk M.E. Miedema
Johan P. Mackenbach

Adapted from Noise Health 2013; 15(67):388-397

Abstract

Traffic noise and air pollution have been associated with cardiovascular health effects. Until date, only a limited amount of prospective epidemiological studies is available on long-term effects of road traffic noise and combustion related air pollution. This study investigates the relationship between road traffic noise and air pollution and hospital admissions for ischemic heart disease (IHD: International Classification of Diseases (ICD9) 410-414) or cerebrovascular disease (cerebrovascular event [CVE]: ICD9 430-438). We linked baseline questionnaire data to 13 years of follow-up on hospital admissions and road traffic noise and air pollution exposure, for a large random sample (N = 18,213) of inhabitants of the Eindhoven region, The Netherlands. Subjects with cardiovascular event during follow-up on average had higher road traffic noise day, evening, night level (L_{den}) and air pollution exposure at the home. After adjustment for confounders (age, sex, Body Mass Index [BMI], smoking, education, exercise, marital status, alcohol use, work situation, and financial difficulties), increased exposure did not exert a significant increased risk of hospital admission for IHD or cerebrovascular disease. Relative risks (RRs) for a 5^{th} to 95^{th} percentile interval increase were 1.03 (0.88-1.20) for L_{den}; 1.04 (0.90-1.21) for particulate matter (PM10); 1.05 (0.91-1.20) for elemental carbon (EC); and 1.12 (096-1.32) for nitrogen dioxide (NO_2) in the full model. While the risk estimate seemed highest for NO_2 , for a 5^{th} to 95^{th} percentile interval increase, expressed as RRs per 1 $\mu g/m^3$ increases, hazard ratios seemed highest for EC (RR 1.04 [0.92-1.18]). In the subgroup of study participants with a history of cardiovascular disease, RR estimates seemed highest for noise exposure (1.19 [0.87-1.64] for L_{den}); in the subgroup of elderly RR seemed highest for air pollution exposure (RR 1.24 [0.93-1.66] for NO_2).

4.1 Introduction

Road traffic is a major source of both environmental noise and air pollution exposure in urban areas. Both road traffic noise and air pollution have been related to cardiovascular health effects. (Babisch, 2008; Van Kempen and Babisch, 2012; Janssen et al., 2011; Brook et al., 2010) The continuing urbanization, the large number of people exposed and cardiovascular morbidity as a major cause of mortality in modern societies, create a need for better insight in the long-term effects of road traffic on cardiovascular morbidity.

4.1.1 Noise exposure

Noise exposure can cause annoyance and sleep disturbance. (Miedema and Oudshoorn, 2001; Miedema and Vos, 2007) During the last decades, it has been studied if and how noise exposure may cause further adverse health effects. The pathway from noise exposure to cardiovascular health effects is hypothesized to involve stress reactions that may cause adverse health effects in the long-term. Exposure to noise may - directly or indirectly through disturbance of sleep, communication or activities - affect the autonomic nervous system and the endocrine system, resulting in biological responses such as changes in heart rate and levels of stress hormones. (e.g., Ising et al., 1999; Babisch, 2002; WHO, 2011) This may, possibly in combination with other factors, lead to increases in biological risk factors (e.g., blood lipids, blood pressure, blood glucose, blood viscosity), which then may eventually result in manifest diseases such as arteriosclerosis and ischemic heart disease (IHD) (Babisch, 2001; Babisch 2002). Currently, there is increasing evidence that long-term exposure to environmental noise can induce stress related health effects including cardiovascular diseases. (Babisch et al., 2005; Babisch, 2008; Barregard et al., 2009; Bluhm et al., 2007; Bodin et al., 2009; de Kluizenaar et al., 2007; Floud et al., 2011; Huss et al., 2010; Gan et al., 2012; Van Kempen and Babisch, 2012; Sorensen et al., 2012b, WHO, 2011)

4.1.2 Air pollution

A large body of epidemiological studies shows associations between particulate matter (PM10) and a wide range of adverse health effects, including cardiovascular health effects. (Brook et al., 2010; Brook and Rajagopalan, 2010; WHO, 2012) Different pathways to cardiovascular endpoints have been hypothesized for PM10, including (1)

pulmonary oxidative stress and inflammatory responses that by "spill over" lead to systemic oxidative stress and inflammatory responses, (2) perturbation of autonomic nervous system balance, and (3) particles or particle constituents passing through the lungs, thus entering the systemic circulation and provoking "direct" extra-pulmonary effects (Brook et al., 2010). A majority of studies linking air pollution with cardiovascular effects focus on PM10 air pollution. Epidemiological studies on the effects of long-term exposure have shown associations with cardiovascular morbidity and mortality (e.g., Beelen et al., 2009; Chen et al., 2005; Hoffmann et al., 2007; Naess et al., 2007; Miller et al., 2007; Puett et al., 2009).

Road traffic noise and air pollution share road traffic as a source; therefore, they are to some extent related (e.g., Allen et al., 2009; Can et al., 2011; Davies et al, 2009). In recent years, efforts have been made to study the association between cardiovascular morbidity and road traffic noise and air pollution exposure in combination. Studies have focused on various cardiovascular outcomes, including blood pressure, hypertension, myocardial infarction, stroke, and cardiovascular mortality (Beelen et al., 2009; Belojevic et al., 2008; de Kluizenaar et al., 2007; Dratva et al., 2012; Fuks et al., 2011; Gan et al., 2012; Selander et al., 2009; Sorensen et al., 2011a, Sorensen et al., 2011b, Sorensen et al., 2012a). Available studies carefully suggest independent effects of road traffic noise and air pollution.

Until date, however, only a small number of prospective epidemiological studies is available into effects of long-term exposure of road traffic noise and air pollution. With regard to air pollution, particles originating from combustion sources (including traffic) are of specific interest as it has been suggested that these particles are particularly relevant for human health (Janssen et al., 2011; Peng et al., 2009; Ostro et al., 2007; WHO, 2012). However, to date, only a limited number of epidemiological studies is available that have studied the impact of long-term exposure to combustion related particle fractions, of which elemental carbon (EC) is an indicator (Janssen et al., 2011). Previous studies have shown that subjects with pre-existing disease and the elderly may be susceptible groups for the effects of exposure (Brook et al., 2010; Chiusolo et al., 2011). This study investigates the relationship between road traffic noise and air pollution components, PM10, nitrogen dioxide (NO_2), and EC and hospital based incidence of IHD or cerebrovascular disease.

4.2 Methods

4.2.1 Study population

The GLOBE study is a prospective cohort study carried out in the Netherlands, with a primary aim of explaining socio-economic inequalities in health. GLOBE is the Dutch acronym for Health and Living Conditions of the Population of Eindhoven and surroundings. Baseline data were collected in 1991. Details of the study protocol have been described elsewhere (Mackenbach, et al., 1994) and will only be briefly summarized here.

In 1991, a sample (stratified by age, degree of urbanization, and socio-economic position) of 27,070 non-institutionalized subjects (aged 15 - 74 years), was drawn from 18 municipal population registers in the south-eastern part of the Netherlands and asked to participate in the study. With a response of 70.1 %, baseline information was collected from 18,973 individuals using a postal questionnaire. The area of study included the city of Eindhoven, which was the fifth largest city of The Netherlands in 1991.

4.2.2 Health outcome and covariates

The data collection comprised a broad range of potential confounders including socio-demographic variables (age, gender, marital status, and education), life-style factors (smoking, alcohol use, physical activity, and BMI) and living conditions (employment status, and financial problems). A history of cardiovascular disease at baseline (1991) was defined by a positive answer to one of the following questions in the questionnaire: "Did you have a heart disease or infarction during the last 5 years?" and "Did you have a cerebrovascular accident - or experience its consequences - during the last 5 years?"

Health outcome data were obtained from the national database on hospital admissions. The study population was tracked annually through municipal population registers in and outside the study area from the start of the study. These registers virtually completely cover the population and are maintained continuously with respect to deaths and changes of address. It allowed us to link our database to the National Medical Registry, a national database on hospital admissions, available for the period from 1991 to 2003, to obtain information on the incidence of hospital-based IHD (International Classification of Diseases [ICD9] 410-414) and cerebrovascular disease (ICD9 430-438) in the study population. In case of re-admission during follow-up, the first admissions were selected.

The five hospitals in the area where the GLOBE participants lived at baseline gave their permission to use their data from the national data set. Record linkage was carried out on the key variables zip-code, gender, and date of birth. Approval for the record linkage was received from the Medical Ethical Commission. Details on the record linkage procedure have been described elsewhere (Van Lenthe et al., 2002).

Age was entered as a continuous variable while gender, BMI, smoking, education, physical activity, marital status, alcohol use, employment status, and financial problems were entered as categorical variables. BMI (body weight divided by height squared) was categorized into four groups: (underweight [BMI < 20], normal weight range [BMI 20-25], overweight [BMI 25-30], and obese [BMI > 30]). Smoking was coded in three categories (current smoker, former smoker, and never smoker). The highest attained level of education was distinguished into four different categories: (primary education; lower professional and intermediate general education; intermediate professional and higher general education; and higher professional education and university). Physical activity was available in four categories: (none, little, moderate, and much physical activity). Marital status was categorized into four groups: (married or living together, unmarried, divorced, and widow/widower). Alcohol use was categorized into three groups: (moderate, abstainer, and excessive). Employment status was categorized in three categories, including unemployed, otherwise not gainfully employed nor studying (incl. e.g., house wife/house man, pensioner, etc.), working (incl. studying, military service). Three categories of financial problems were distinguished: (no difficulty, some difficulty, and large difficulty). Missing values in potential confounding variables (the percentage of missing values for all confounding variables was below 5.6 %) were imputed, replacing the missing values with the most common category.

4.2.3 Environmental exposure

The road traffic noise exposure of the subjects was calculated at the most exposed façade of the dwelling with the standard method SKM2 ("Standaard Karterings Methode 2") in accordance with requirements of the EU Environmental Noise Directive (END). For the analyses, we used the EU standard noise metric day, evening, night level (L_{den}). L_{den} is an "average" sound level over 24 h in which sound levels during the evening and the night are increased by 5 dB(A) and 10 dB(A), respectively. SKM2 is the Netherlands' standard method for noise modeling and producing noise maps in compliance with the END (VROM, 2006a). SKM2 is implemented in Urbis (Borst and Miedema, 2005), that was

used here for the exposure calculations. Noise calculations are carried out in two steps, calculating first the emission and then the transmission. The emission calculations take into account traffic characteristics, including traffic intensities, traffic composition, speed, road height, and road surface type. The transmission calculations take into account the distance between source (road) and dwelling façade, air attenuation, effects of (yearly) meteorologic conditions, ground attenuation, object screening, reflection of objects opposite the dwelling, and statistical diffraction for transmission. Noise exposure is calculated at the height of the center of the dwelling façade of the exposed subject. Very low noise exposure levels (L_{den} below 45 dB(A)) were recoded as 45 dB(A) since this can be considered to be a lower limit of the ambient noise in urban surrounding.

Air pollution exposure was also assessed at the most exposed façade. The annual average exposure concentration at a certain location is defined by the sum of the regional and urban background concentration, supplemented with the calculated contribution of the local road traffic, to account for the small scale spatial variation within the city. Background concentrations are estimated annually by the National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu, RIVM), based on measurement data of the Dutch National Air Quality Monitoring Network. Combining these monitoring data with nationwide air pollution modeling, they each year generate a national map (1 km X 1 km) of annual average concentrations for the most important air pollution components, including PM10 and NO_2 . The empirical relationship proposed by Schaap and Denier van der Gon (2006) has shown that black smoke (BS) may act as a suitable indicator of EC concentrations. Here, this relationship was employed to derive background EC concentrations from the background BS concentrations, measured by two regional monitoring stations within the study area (as part of the National Air Quality Monitoring Network). The local traffic-related EC emission contributions were estimated on the basis of the fuel-specific EC content of exhaust PM10 emission (Schauer et al. 2006). These data were input for the calculation of local EC concentrations, assuming an absence of other relevant local EC sources. An inventory on the near-by industrial activities indicated that traffic is indeed the dominating EC source in the Eindhoven region, although some minor contributions may originate from e.g., wood combustion. The dispersion dynamics of EC are implicitly assumed to be identical to PM10. PM10, NO_2, and EC concentration gradients were obtained using the Netherlands' standard models for local air pollution calculations: CAR II for gradients in a street caused by the contribution of that street and "Pluim Snelweg" for gradients caused by the contributions of highways (VROM, 2006b). Concentration

levels were calculated for the year 2004, the end of follow-up, to represent the long-term average spatial variation in air pollution concentrations.

Input data for emission calculations consisted of a detailed digital map describing the geographic location of roads and the traffic characteristics for each road segment (including traffic intensities for each vehicle category, speed, and road surface type), provided by the local authorities of Eindhoven for the year 2004. Traffic data were attached as attributes to the road segments for a dense network of roads, including highways, arterial roads, main streets, and principal residential streets.

Input for the noise transmission calculations consisted of digital maps with precise information on the geographic location of buildings and ground characteristics (Topographic Service data [TOP 10]) provided by the Netherlands Ministry of Housing, Spatial Planning and the Environment (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (VROM) / DGR). Building height was derived from the Actual Height Information Netherlands (AHN), a 5 m X 5 m grid with height information based on laser altimetry. The geographic location of noise screens with their height was provided by the local authorities of Eindhoven. The geographical location of dwellings within the building contours (Topographic Service data [TOP 10]) was identified with the use of address coordinates.

In a recent study, the performance of a similar dispersion modeling approach for calculation of air pollution concentrations in Rotterdam, The Netherlands was evaluated. This study showed a good agreement between annual average NO_2 concentrations, estimated by dispersion modeling, and measured NO_2 concentrations at eighteen sites in the Rotterdam area (Pearson correlation coefficient $\rho = 0.77$) (Beelen et al., 2010).

4.2.4 Statistical analysis

Cox proportional hazard analysis was performed to investigate the association between residential road traffic exposure (road traffic noise and air pollution) and hospital based incidence of cardiovascular diseases (IHD: ICD9 410-414 or cerebrovascular disease: ICD9 430-438). Results are expressed as relative risks (RRs) with the corresponding 95 % confidence intervals (CI) for the time to the first cardiovascular event. For participants who were admitted to a hospital for IHD or cerebrovascular disease, who died, or moved away from the 1991 baseline address, time in the study was calculated as the difference between the start of study and date of the event. For those who had no event, time in

the study was calculated as the difference between the start and end of follow-up. Median follow-up time was 8.7 years.

We used different models: (1) unadjusted model; (2) model adjusted for age and sex; (3) full model, where factors were included that were hypothesized a priori to potentially confound the relationship between traffic exposures and cardiovascular disease, including: age, sex, BMI, smoking, level of education (as a measure of social economic position), physical activity, marital status, alcohol use, employment status, and financial problems; and (4) models that, in addition, adjusted for road traffic noise respectively air pollution. All analyzes were carried out for the full population and for three specific subgroups of the population: (1) subjects without a history of cardiovascular disease, (2) subjects with a history of cardiovascular disease, and (3) elderly subjects (age 65 years and older). Analyses were performed with IBM SPSS Statistics version 20.

4.3 Results

Table 4.1 shows the characteristics of the study sample by the event of hospital admission for (IHD: ICD9 410-414) or cerebrovascular disease (cerebrovascular event [CVE]: ICD9 430-438) during follow-up. Table 4.1 shows that subjects who had an event during follow-up on average have a higher age, more often are males, obese (BMI > 30), smokers, and lower educated, less often exercise much, more often are married or living together, more often are unemployed, and exposure to road traffic noise (L_{den}) and air pollution (PM10 and EC) at home is higher. In addition, subjects in this group more often reported a history of cardiovascular disease.

Tables 4.2a and b show the RRs for hospital admission for IHD or cerebrovascular disease for road traffic noise exposure, for a 10 dB increase of L_{den} (Table 4.2a) and for a 5^{th} to 95^{th} percentile interval change (Table 4.2b). Results are presented for the full population and for the three specific subgroups, for the four different models.
Tables 4.2a and b show that in the GLOBE study sample, in the unadjusted models, with increasing road traffic noise level, a significantly elevated risk for the incidence of IHD or cerebrovascular disease was found with RR 1.12 (95 % CI: 1.04-1.21) and RR 1.27 (95 % CI: 1.09-1.47), for a 10 dB increase in L_{den} and a 5^{th} to 95^{th} percentile interval increase, respectively). However, after adjustment for confounders in the full model, these relationships were smaller and not significant with RR 1.01 (95 % CI: 0.94-1.09) and RR 1.03 (0.88-1.20), for a 10 dB increase in L_{den} and a 5^{th} to 95^{th} percentile interval increase,

respectively). The RR seemed highest in the subgroup with a history of cardiovascular disease, although not significant with RR 1.09 (95 % CI: 0.93-1.27) and RR 1.19 (95 % CI: 0.87-1.64) for a 10 dB increase in L_{den} and a 5^{th} to 95^{th} percentile interval increase, respectively). However, CIs are overlapping. The association seemed not affected by additional adjusting for PM10.

Table 4.1 *Characteristics of the GLOBE cohort by event*

Characteristics	Study population (N = 18,213)	
	No Event	**Event**
N	16,666	1547
Age (*years*)	46.4 (15.9)	59.3 (9.1)***
Sex: Male *(%)*	47.0	63.9***
BMI (QI > 30) (%)	5.8	8.9***
Smoking *(%)*	35.9	40.2**
Education low *(%)*	20.1	32.9***
Physical activity: much *(%)*	33.8	23.4***
Marital (married/live together) (%)	72.4	83.0***
Alcohol use: excessive (%)	8.2	8.4
Work situation: unemployed (%)	9.6	17.6***
Financial: much difficulty (%)	4.2	5.0
L_{den} mean (*dB*)	52.7 (6.7)	53.2 (6.6)***
PM10 mean long-term ($\mu g\ m^{-3}$)	27.79 (1.03)	27.81 (0.97)*
EC mean long-term ($\mu g\ m^{-3}$)	1.16 (0.40)	1.17 (0.38)*
NO_2 mean long-term ($\mu g\ m^{-3}$)	32.10 (4.37)	32.22 (4.23)
No history of cardiovascular disease (%) (N=17,235)	96.2	77.8***
History of cardiovascular disease (%) (N = 978)	3.8	22.2***

Variables are described by means (standard deviation) and percentages. Groups of cases are compared by $\chi 2$ (percentages) and Mann–Whitney statistics (means and medians).
*P < 0.05, **P < 0.01, ***P < 0.001. Abbreviations are: BMI, Body Mass Index; Lden, road traffic noise day-evening-night level (dB); PM10, particulate matter; EC, elemental carbon; NO2, nitrogen dioxide; IHD, ischemic heart disease; CVE cerebrovascular event.

Table 4.2a *Hazard ratios for road traffic noise exposure (for a 10 dB increase of L_{den}) for ischemic heart disease or cerebrovascular disease (hospital admission for ICD9 410–414 or 430–438) respectively, in pre-specified subgroups of the GLOBE study sample.*

Group[a]	**RR** ***unadjusted***	**RR** ***adjusted: age, sex***	**RR** ***adjusted: full model***	**RR** ***adjusted: full model and PM10***
GLOBE study sample	1.12 (1.04–1.21)**	1.02 (0.94–1.10)	1.01 (0.94–1.09)	1.00 (0.91–1.10)
No history of cardiovascular disease	1.10 (1.01–1.19)*	1.00 (0.92-1.09)	0.99 (0.91–1.08)	0.99 (0.89–1.10)
History of cardiovascular disease	1.10 (0.95–1.28)	1.07 (0.92-1.25)	1.09 (0.93–1.27)	1.09 (0.90–1.32)
Aged 65 and over	1.03 (0.91-1.17)	1.04 (0.91-1.17)	1.04 (0.92-1.18)	1.00 (0.85-1.18)

[a]Relative risks from Cox proportional hazard analysis are shown, for four different models: (1) unadjusted; (2) adjusted for age and sex; (3) full model: adjusted for age, sex, Body Mass Index, smoking, education, exercise, marital status, alcohol use, work situation, financial difficulties; (4) full model with additional adjustment for air pollution (PM10).
† Indication of an association (P < 0.1); * significant relationship (P < 0.05); ** significant relationship (P < 0.01).

Table 4.2b *Hazard ratios for road traffic noise exposure (for a 5^{th} to 95^{th} percentile interval increase of L_{den}) for ischemic heart disease or cerebrovascular disease (hospital admission for ICD9 410–414 or 430–438) respectively in pre-specified subgroups of the GLOBE study sample.*

Group[a]	***RR unadjusted***	***RR adjusted: age, sex***	***RR adjusted: full model***	***RR adjusted: full model and PM10***
GLOBE study sample	1.27 (1.09–1.47)**	1.04 (0.89- 1.21)	1.03 (0.88-1.20)	1.00 (0.83-1.22)
No history of cardiovascular disease	1.21 (1.02-1.43)*	1.00 (0.84-1.19)	0.98 (0.82-1.17)	0.97 (0.78-1.21)
History of cardiovascular disease	1.22 (0.90-1.66)	1.15 (0.84-1.58)	1.19 (0.87-1.64)	1.20 (0.80-1.79)
Aged 65 and over	1.06 (0.82-1.38)	1.08 (0.83-1.39)	1.08 (0.83-1.41)	1.01 (0.72-1.42)

[a]Relative risks from Cox proportional hazard analysis are shown, for four different models: (1) unadjusted; (2) adjusted for age and sex; (3) full model: adjusted for age, sex, Body Mass Index, smoking, education, exercise, marital status, alcohol use, work situation, financial difficulties; (4) full model with additional adjustment for air pollution (PM10).
† Indication of an association (P < 0.1); * significant relationship (P < 0.05); ** significant relationship (P < 0.01).
5^{th} to 95^{th} percentile interval: 20.6 dB.

Tables 4.3 to 4.5 show RRs for different components of air pollution: PM10, EC, and NO_2 respectively. Tables 4.3a and 4.3b show a significant association between PM10 concentration and hospital admission of IHD or cerebrovascular disease with RR 1.06 (95 % CI: 1.01-1.11) and RR 1.20 (95 % CI: 1.04-1.38) for a 1 μg/m^3 and a 5^{th} to 95^{th} percentile interval increase respectively) before adjustment for potential confounders. After adjustment for covariates in the full model, this association was not significant with RR 1.01 (95 % CI: 0.97-1.06) and RR 1.04 (95 % CI: 0.90-1.21) for a 1 μg/m^3 and a 5^{th} to 95^{th} percentile interval increase in PM10 respectively). The RR seemed highest, although not significant, in the subgroup of elderly subjects with RR 1.04 (95 % CI: 0.96-1.13) and RR 1.13 (95 % CI: 0.87-1.46) for a 1 μg/m^3 and a 5^{th} to 95^{th} percentile interval increase respectively).

Table 4.3a *Hazard ratios for particulate matter (PM10) exposure (for a 1 μg m^{-3} increase in PM10) for ischemic heart disease or cerebrovascular disease (hospital admission for ICD9 410–414 or 430–438) in pre-specified subgroups of the GLOBE study sample.*

Group[a]	**RR** ***unadjusted***	**RR** ***adjusted: age, sex***	**RR** ***Adjusted full model***	**RR** ***adjusted: full model and L_{den}***
GLOBE study sample	1.06 (1.01–1.11)*	1.01(0.97-1.06)	1.01 (0.97–1.06)	1.01 (0.95–1.08)
No history of cardiovascular disease	1.05 (0.99–1.11)†	1.00 (0.95-1.06)	1.00 (0.94-1.06)	1.00 (0.93-1.08)
History of cardiovascular disease	1.03 (0.95–1.11)	1.02 (0.94-1.11)	1.03 (0.94-1.12)	1.00 (0.89-1.12)
Aged 65 and over	1.02 (0.94-1.11)	1.03 (0.95-1.12)	1.04 (0.96-1.13)	1.04 (0.93-1.16)

[a]Relative risks from Cox proportional hazard analysis are shown, for four different models: (1) unadjusted; (2) adjusted for age and sex; (3) full model: adjusted for age, sex, Body Mass Index, smoking, education, exercise, marital status, alcohol use, work situation, financial difficulties; (4) full model with additional adjustment for road traffic noise (L_{den})

† Indication of an association (P < 0.1); * significant relationship (P < 0.05); ** significant relationship (P < 0.01).

In the subgroup with a history of cardiovascular disease, a RR was found of (RR 1.03 [95 % CI: 0.94-1.12]) and RR 1.09 (95 % CI: 0.83-1.43) for a 1 μg/m^3 and a 5^{th} to 95^{th} percentile interval increase in PM10 respectively). After additional adjustment for road traffic noise, this changed to RR 1.00 (95 % CI: 0.89-1.12) and RR 0.99 (95 % CI: 0.70-1.41) for a 1 μg/m^3 and a 5^{th} to 95^{th} percentile interval increase in PM10 respectively).

Table 4.3b *Hazard ratios for particulate matter (PM10) exposure (for a 5th to 95th percentile interval increase of PM10) for ischemic heart disease or cerebrovascular disease (hospital admission for ICD9 410–414 or 430–438) in pre-specified subgroups of the GLOBE study sample.*

Group[a]	RR *unadjusted*	RR *adjusted: age, sex*	RR *adjusted: full model*	RR *adjusted: full model and L_{den}*
GLOBE study sample	1.20 (1.04–1.38)*	1.04 (0.90-1.21)	1.04 (0.90–1.21)	1.04 (0.86–1.26)
No history of cardiovascular disease	1.16 (0.98–1.37)†	1.00 (0.84-1.20)	0.99 (0.83-1.19)	1.01 (0.81-1.26)
History of cardiovascular disease	1.09 (0.85–1.40)	1.06 (0.83-1.37)	1.09 (0.83-1.43)	0.99 (0.70-1.41)
Aged 65 and over	1.08 (0.83–1.39)	1.10 (0.85-1.43)	1.13 (0.87-1.46)	1.12 (0.80-1.57)

[a]Relative risks from Cox proportional hazard analysis are shown, for four different models: (1) unadjusted; (2) adjusted for age and sex; (3) full model: adjusted for age, sex, Body Mass Index, smoking, education, exercise, marital status, alcohol use, work situation, financial difficulties; (4) full model with additional adjustment for road traffic noise (L_{den})

† Indication of an association (P < 0.1); * significant relationship (P < 0.05); ** significant relationship (P < 0.01).

5th to 95th percentile interval of PM10: 3.1 μg/m^3.

Table 4.4a *Hazard ratios for elemental carbon (EC) exposure (for a 1 μg m^{-3} increase in EC) for ischemic heart disease or cerebrovascular disease (hospital admission for ICD9 410–414 or 430–438) in pre-specified subgroups of the GLOBE study sample.*

Group[a]	RR *unadjusted*	RR *adjusted: age, sex*	RR *adjusted: full model*	RR *adjusted: full model and L_{den}*
GLOBE study sample	1.16 (1.04-1.30)**	1.05 (0.93-1.18)	1.04 (0.92-1.18)	1.04 (0.89-1.22)
No history of cardiovascular disease	1.13 (0.99-1.30)†	1.02 (0.88-1.17)	1.00 (0.87-1.16)	1.02 (0.85-1.23)
History of cardiovascular disease	1.05 (0.86-1.28)	1.04 (0.85-1.26)	1.05 (0.85-1.30)	0.96 (0.72-1.28)
Aged 65 and over	1.06 (0.86-1.31)	1.08 (0.88-1.33)	1.10 (0.89-1.35)	1.09 (0.82-1.44)

[a]Relative risks from Cox proportional hazard analysis are shown, for four different models: (1) unadjusted; (2) adjusted for age and sex; (3) full model: adjusted for age, sex, Body Mass Index, smoking, education, exercise, marital status, alcohol use, work situation, financial difficulties; (4) full model with additional adjustment for road traffic noise (L_{den})

† Indication of an association (P < 0.1); * significant relationship (P < 0.05); ** significant relationship (P < 0.01).

Table 4.4b *Hazard ratios for elemental carbon (EC) exposure (for a 5th to 95th percentile interval increase of EC) for ischemic heart disease or cerebrovascular disease (hospital admission for ICD9 410–414 or 430–438) in pre-specified subgroups of the GLOBE study sample.*

Group[a]	RR *unadjusted*	RR *adjusted: age, sex*	RR *adjusted: full model*	RR *adjusted: full model and L_{den}*
GLOBE study sample	1.18 (1.04-1.35)**	1.05 (0.92-1.21)	1.05 (0.91-1.20)	1.05 (0.88-1.25)
No history of cardiovascular disease	1.15 (0.98-1.34)†	1.02 (0.87-1.20)	1.00 (0.85-1.18)	1.02 (0.83-1.26)
History of cardiovascular disease	1.05 (0.84-1.32)	1.04 (0.83-1.30)	1.05 (0.83-1.34)	0.95 (0.69-1.32)
Aged 65 and over	1.07 (0.84-1.35)	1.09 (0.86-1.38)	1.11 (0.88-1.41)	1.10 (0.80-1.50)

[a]Relative risks from Cox proportional hazard analysis are shown, for four different models: (1) unadjusted; (2) adjusted for age and sex; (3) full model: adjusted for age, sex, Body Mass Index, smoking, education, exercise, marital status, alcohol use, work situation, financial difficulties; (4) full model with additional adjustment for road traffic noise (L_{den})

† Indication of an association (P < 0.1); * significant relationship (P < 0.05); ** significant relationship (P < 0.01). 5th to 95th percentile interval of EC: 1.13 μg/m^{-3}.

Tables 4.4a and b show associations found for EC. Comparison of Table 4.3a and Table 4.4a shows that RR estimates per μg/m^3 increase seem higher for EC than for PM10 (RR for EC per μg/m^3 increase: 1.16 (95 % CI: 1.04-1.30) (unadjusted model), 1.04 (95 % CI: 0.92-1.18) (full model) and RR for PM10 per mg/m^3 increase: 1.06 (95 % CI: 1.01-1.11) (unadjusted model), 1.01 (95 % CI: 0.97-1.06) (full model). As shown in Table 4.3b and Table 4.4b, associations found for a 5th to 95th percentile interval increase are comparable in magnitude (RR for EC per 5th to 95th percentile increase: 1.18 (95 % CI: 1.04-1.35) (unadjusted model) and 1.05 (95 % CI: 0.91-1.20) (full model); RR for PM10: 1.20 (95 % CI: 1.04-1.38) (unadjusted model) and 1.04 (0.90-1.21) (full model).

Tables 4.5a and b show associations found for NO_2. With increasing NO_2 concentration, in the unadjusted model, a significantly elevated risk for the incidence of IHD or cerebrovascular disease was found with RR 1.02 (95 % CI: 1.01-1.03) and RR 1.29 (95 % CI: 1.10-1.51) for a 1 μg/m^3 and a 5th to 95th percentile interval increase respectively). However, as for the other air pollution components, these associations were not significant in the full model with RR 1.01 (95 % CI: 1.00-1.02) and 1.12 (0.96-1.32) for a 1 μg/m^3 and a 5th to 95th percentile interval increase respectively). The RR seemed highest, although not significant, in the subgroup of elderly subjects withRR 1.02 (95 % CI: 0.99-1.04) and RR 1.24 (95 % CI: 0.93-1.66) for a 1 μg/m^3 and a 5th to 95th percentile interval increase respectively).

Table 4.5a *Hazard ratios for nitrogen dioxide (NO_2) exposure (for a 1 µg m^{-3} increase in NO_2) for ischemic heart disease or cerebrovascular disease (hospital admission for ICD9 410–414 or 430–438) in pre-specified subgroups of the GLOBE study sample.*

Group[a]	RR *unadjusted*	RR *adjusted: age, sex*	RR *adjusted: full model*	RR *adjusted: full model and L_{den}*
GLOBE study sample	1.02 (1.01-1.03)**	1.01 (1.00-1.02)	1.01 (1.00-1.02)	1.01 (1.00-1.02)
No history of cardiovascular disease	1.02 (1.00-1.03)*	1.01 (0.99-1.02)	1.01 (0.99-1.02)	1.01 (0.99-1.02)
History of cardiovascular disease	1.01 (0.99-1.04)	1.01 (0.99-1.03)	1.01 (0.99-1.03)	1.01 (0.98-1.03)
Aged 65 and over	1.01 (0.99-1.03)	1.01 (0.99-1.04)	1.02 (0.99-1.04)	1.02 (0.99-1.04)

[a]Relative risks from Cox proportional hazard analysis are shown, for four different models: (1) unadjusted; (2) adjusted for age and sex; (3) full model: adjusted for age, sex, Body Bass Index, smoking, education, exercise, marital status, alcohol use, work situation, financial difficulties; (4) full model with additional adjustment for road traffic noise (L_{den})

† Indication of an association (P < 0.1); * significant relationship (P < 0.05); ** significant relationship (P < 0.01).

Table 4.5b *Hazard ratios for nitrogen dioxide (NO_2) exposure (for a 5^{th} to 95^{th} percentile interval increase of NO_2) for ischemic heart disease or cerebrovascular disease (hospital admission for ICD9 410–414 or 430–438) in pre-specified subgroups of the GLOBE study sample.*

Group[a]	RR *unadjusted*	RR *adjusted: age, sex*	RR *adjusted: full model*	RR *adjusted: full model and L_{den}*
GLOBE study sample	1.29 (1.10-1.51)**	1.13 (0.96-1.33)	1.12 (0.96-1.32)	1.13 (0.95-1.34)
No history of cardiovascular disease	1.25 (1.05-1.50)*	1.10 (0.92-1.32)	1.09 (0.91-1.32)	1.12 (0.92-1.36)
History of cardiovascular disease	1.19 (0.85-1.66)	1.15 (0.83-1.61)	1.15 (0.82-1.62)	1.09 (0.75-1.56)
Aged 65 and over	1.16 (0.87-1.55)	1.22 (0.91-1.63)	1.24 (0.93-1.66)	1.24 (0.90-1.69)

[a]Relative risks from Cox proportional hazard analysis are shown, for four different models: (1) unadjusted; (2) adjusted for age and sex; (3) full model: adjusted for age, sex, Body Mass Index, smoking, education, exercise, marital status, alcohol use, work situation, financial difficulties; (4) full model with additional adjustment for road traffic noise (L_{den})

† Indication of an association (P < 0.1); * significant relationship (P < 0.05); ** significant relationship (P < 0.01).
5^{th} to 95^{th} percentile interval: 14.1 µg m^{-3}.

4.4 Discussion and Conclusions

In the present study, we only found significant associations between road traffic noise (L_{den}), various components of air pollution (PM10, EC, and NO_2) and hospital admission for IHD or cerebrovascular disease in the unadjusted models. However, these associations became substantially smaller and non-significant after adjustment for confounders. While the risk estimates seemed highest for NO_2 , when comparing risk estimates for different exposures for a 5^{th} to 95^{th} interval increase, with a RR of 1.12 (0.96-1.32), expressed as RRs per µg/m^3 increase, risk estimates seemed highest for EC with an RR of 1.04 (0.92-1.18) in the full model.

For road traffic noise exposure, RRs seemed highest for the subgroup with a history of cardiovascular disease. For air pollution, RRs seemed highest in the subgroup aged 65 and older. However, associations for subgroups of the study population were not significant.

4.4.1 Noise exposure and cardiovascular disease

During the last decades studies have investigated the association between transportation noise exposure and blood pressure changes and hypertension. In a recent meta analysis, Van Kempen and Babisch (2012) report a small but significant association between road traffic noise and hypertension (OR 1.034; 1.011-1.056) per 5 dB increase in $L_{Aeq,16h}$, based on 24 studies carried out between 1970 and 2010. A limited number of studies have investigated the relationship between IHD, cerebrovascular disease and long-term exposure to transportation noise, with varying results. Early population studies include the Caerphilly (Babisch et al., 1988) and Speedwell (Babisch et al., 1993) studies. In the Caerphilly study, no association was found between road traffic noise and the prevalence of IHD. However, associations were found between noise and a broad range of potential risk factors for IHD. (Babisch et al., 1988) In pooled analyses of the Caerphilly and Speedwell cohorts a marginal risk increase was suggested (RR 1.1 and 1.2 for IHD incidence and prevalence, respectively), for the highest noise category ($L_{eq,\ 6\text{-}22h}$ = 66-70 dB(A)) versus the lowest noise category ($L_{eq,\ 6\text{-}22h}$ = 51-55 dB(A)). These associations however, were not significant. (Babisch et al., 1993) Babisch et al, (2005) reported an association between road traffic noise and the incidence of myocardial infarction (adjusted OR 1.3 [0.88-1.8]), for men exposed to a road traffic noise level exceeding 70 dB(A), compared to those exposed under 60 dB(A), in a case control study

in Berlin. In a subsample of men who lived for at least 10 years at their present address, the OR was higher (OR 1.8 [1.0-3.2]). In a review and meta-analysis Babisch (2008) found no increase in risk below 60 dB(A) (L_{day}) while risk increase was found with increasing noise levels above 60 dB(A). More recently, Selander et al, (2009) reported an association between road traffic noise and myocardial infarction, with an adjusted odds ratio for an exposure above 50 dB(A) of 1.12 (0.95-1.33) in the full population, and 1.38 (1.11-1.71) for a subsample excluding persons with hearing loss, or noise exposure from other sources. Sørensen et al, (2012b) reported a significant association between road traffic noise and incidence of myocardial infarction, with an incidence rate ratio (IRR) of 1.12 (1.02-1.22) per 10 dB (L_{den}) increase in exposure. Gan et al, (2012) reported interquartile range increases of respectively community noise exposure associated with a 6 % (1-11 %) and black carbon with a 4 % (1-8 %) increase in coronary heart disease (CHD) mortality. They conclude that their findings suggest an independent effect of traffic related noise and air pollution on CHD mortality. Huss et al, (2010) reported an adjusted RR of 1.3 (0.96-1.7) for mortality from myocardial infarction, for subjects exposed to aircraft noise ≥60 dB(A) versus <45 dB(A) and 1.5 (1.0-2.2) in a subsample of subjects who had lived at the same place for at least 15 years. However, they found no association between aircraft noise and cerebrovascular disease mortality. Sørensen et al, (2011b) reported an IRR of 1.14 (1.03-1.25) for stroke per 10 dB higher level of road traffic noise (L_{den}), with stronger associations in the elderly (2011). Our study, with risk estimates for a 5^{th} to 95^{th} percentile increase in road traffic noise (L_{den}) of 1.03 (0.88-1.20) (full sample, full model) and 1.19 (0.87-1.64) for the subgroup with a history of cardiovascular disease, falls within the range of reported risk estimates.

4.4.2 Air pollution and cardiovascular health

A number of epidemiological studies have studied the effects of long-term air pollution exposure and cardiovascular morbidity and mortality. Studies have considered different air pollution components and various endpoints. A limited number of studies have also investigated effects of combustion related fractions (EC). In a recent review and meta analyses, Janssen et al. (2011), report a pooled effect estimate of 1.06 (1.04-1.09) for EC and 1.007 (1.004-1.009) for PM2.5 per 1 μg/m^3 increase in concentration, for all-cause mortality.

In the individual studies, generally increased risks were reported with increasing concentration; however, like in this study CI often included 1. Only few studies into long-

term effects on cardiovascular morbidity and mortality have been carried out in Europe. In a large Dutch cohort study, Beelen et al, (2008) found RRs of 1.04 (0.95-1.13) for a 10 $\mu g/m^3$ increase in BS cardiovascular mortality and similar results for PM2.5. In another study, Beelen et al, (2009) found a RR of 1.39 (0.99-1.94) for cerebrovascular mortality and 1.01 (0.83-1.22) for IHD mortality for a 10 $\mu g/m^3$ increase in BS. They concluded that results found in their study were not explained by traffic noise exposure. Our risk estimates with an RR of 1.04 (0.92-1.18) for IHD or cerebrovascular disease for a 1 $\mu g/m^3$ increase in EC concentration and 1.01 (0.97-1.06) for a 1 $\mu g/m^3$ increase in PM10 (full model) fall within the range of previous findings. Most studies on long term exposure to PM10 and mortality were carried out in the US, often reporting somewhat stronger associations (review by Brook et al., 2010). E.g., Laden et al, (2006) found an association between PM2.5 exposure and cardiovascular mortality (RR 1.28 [1.13-1.44]) for a 10 $\mu g/m^3$ increase in concentration.

In our study, although estimated risk estimates for a 1 $\mu g/m^3$ increase seemed higher for EC than for PM10 , risk estimates for a 5^{th} to 95^{th} percentile increase were similar. This is in line with the results of the recent systematic review by Janssen et al (2011).

When comparing air pollution components for a 5^{th} to 95^{th} percentile interval change, RRs seemed highest for NO_2, with an RR of 1.12 (0.96-1.32) in the full model. NO_2 is commonly used as an indicator of combustion related air pollution. Although NO_2 itself is toxic, in toxicological studies, typically effects are only found at levels far exceeding ambient levels (WHO, 2006). Therefore, at current ambient levels it is unclear if NO_2 itself plays a major role, or if (more commonly assumed) NO_2 is an indicator of other toxic components in the air pollution mixture (WHO, 2006). In epidemiological studies, associations between long term exposure to NO_2 and adverse health outcomes have been reported. (e.g., Rosenlund et al., 2008) Rosenlund et al, (2008) reported a RR for incidence in coronary events per 10 $\mu g/m^3$ increase in NO_2 of 1.03 (1.00-1.07), with stronger associations for fatal cases (1.07; 1.02-1.12). Hoek et al, (2002) reported a RR of 1.81 (0.98-3.34) for cardiopulmonary mortality for concentration changes from the 5^{th} to the 95^{th} percentile (approximately 30 $\mu g/m^3$) in a random sample of 5000 people from the full cohort of the Netherlands Cohort study. In the full cohort, however, Beelen et al., (2008) reported a RR of 1.07 (0.94-1.21) for cardiovascular mortality for a 30 $\mu g/m^3$ increase in NO_2 concentration. The risk estimates found in this study fall within the range of previously reported risk estimates.

Studies into short term effects have also reported independent associations between NO_2 and cardiovascular mortality that remained significant after adjustment for ambient

particles or sulfur dioxide (Chen et al., 2012). Similarly, Chiusolo et al, (2011) found statistically significant associations between short-term changes in NO_2 and cardiac mortality, independent of PM10 and O_3 . They state that the role of NO_2 as a surrogate of unmeasured pollutants cannot be ruled out, and suggest that NO_2 may act as a surrogate of ultrafine PM.

4.4.3 Methodological considerations

A strength of our study is that exposure assessment incorporated both road traffic noise and air pollution exposure. As these factors are both identified as possible pathogenic traffic related stressors, it is valuable that in this study we were able to study the effects of both exposures to road traffic noise and air pollution. In addition, we were able to pay specific attention to the combustion related fraction of PM10. Until date, only a limited amount of epidemiological studies have considered black carbon particles, such as EC (reviewed by Janssen et al., 2011). Second, the prospective design of this large population study provides a powerful basis for studying long-term effects as compared with cross-sectional studies.

In this study, a large number of potential confounders were available. Nevertheless, the possibility of residual confounding due to unavailable variables cannot be fully excluded. Even after adjustment for confounders, there may still be some residual confounding that may to some extent explain the associations found. However, we minimized any potential residual confounding by being able to adjust for a large range of potential risk factors in the model, including demographic, socio-economic, and life-style characteristics. Information on the history of disease was available from a question in the questionnaire, which referred to the previous 5 years. No information was available on disease history further back in time.

As outdoor air pollution is a mixture of a large variety of components that are often related as many of these components share the same sources (e.g., traffic), identification of effects of single components remains complicated. The possibility that one component acts as a surrogate for (a mixture of) other pollutants, cannot be ruled out.

While there was substantial spatial variation in road traffic noise (L_{den}) and NO_2, the spatial variation in PM10 and EC in terms of $\mu g/m^3$ was relatively small. This may have limited ability to detect associations between air pollution and cardiovascular events. However, since the study area (the Eindhoven region) is quite a large urban area, the

long-term spatial pattern in exposure may be assumed to be reasonably representative for a within city contrast.

Exposure levels were estimated at the home address. Therefore, there may still be some misclassification of air pollution exposure. No information was available on indoor or occupational exposure or on commuting or on time-activity patterns of the respondents. However, people tend to spend the largest percentage of their time at home.

The effects of high noise exposure may be partly masked by selection mechanisms (e.g., noise sensitive subjects moving away from high exposure areas), better sound insulation measures to the home of most exposed dwellings, choice of bedroom location or changed window opening behavior in reaction to exposure. Some previous studies have shown stronger associations, when information on exposure modifying factors (e.g., bedroom position, window opening behavior, insulation) (e.g., Babisch et al., 1999; Bluhm et al., 2007; Lercher et al., 2011), or effect modifying factors (e.g., hearing loss) (Selander et al., 2009) could be taken into account. However, in this study no data were available to take these factors into account.

Furthermore, there are indications that effects on cardiovascular morbidity mainly start to occur at very high exposure levels (exceeding 60 dB). (Babisch, 2008) In an average city, only a small percentage of the population is exposed to such high levels, which may have limited the ability to detect associations for noise.

In summary, in this study no significant association between road traffic noise (L_{den}), various components of air pollution (PM10, EC, and NO_2) and hospital admission for IHD or cerebrovascular disease was found after adjustment for confounders. When comparing risk estimates for different exposures for a 5^{th} to 95^{th} interval increase, NO_2 seemed to have the highest risk estimate for events while, when expressed per $\mu g/m^3$ increase in concentration, risk estimates seemed highest for EC. For noise, risks estimates seemed highest for the subgroup with a history of cardiovascular disease. For air pollution, risks estimates seemed highest for the subgroup aged 65 and older.

References

Allen RW, Davies H, Cohen MA, Mallach G, Kaufman JD, Adar SD. The spatial relationship between traffic-generated air pollution and noise in 2 US cities. Environ Res. 2009;109:334-42.

Babisch W, Gallacher JE, Elwood PC, Ising H. Traffic noise and cardiovascular risk. The Caerphilly study, first phase. Outdoor noise levels and risk factors. Arch Environ Health. 1988;43:407-14.

Babisch W, Ising H, Elwood PC, Sharp DS, Bainton D. Traffic noise and cardiovascular risk: The Caerphilly and Speedwell studies, second phase. Risk estimation, prevalence, and incidence of ischemic heart disease. Arch Environ Health. 1993;48:406-13.

Babisch W, Ising H, Gallacher JE, Sweetnam PM, Elwood PC. Traffic noise and cardiovascular risk: The Caerphilly and Speedwell studies, third phase - 10-year follow up. Arch Environ Health. 1999;54:210-6.

Babisch W, Fromme H, Beyer A, Ising H. Increased catecholamine levels in urine in subjects exposed to road traffic noise: The role of stress hormones in noise research. Environ Int. 2001;26:475-81.

Babisch W. The noise/stress concept, risk assessment and research needs. Noise Health. 2002;4:1-11.

Babisch W, Beule B, Schust M, Kersten N, Ising H. Traffic noise and risk of myocardial infarction. Epidemiology. 2005;16:33-40.

Babisch W. Road traffic noise and cardiovascular risk. Noise Health. 2008;10:27-33.

Barregard L, Bonde E, Ohrström E. Risk of hypertension from exposure to road traffic noise in a population-based sample. Occup Environ Med. 2009;66:410-5.

Beelen R, Hoek G, van den Brandt PA, Goldbohm RA, Fischer P, Schouten LJ, *et al*. Long-term effects of traffic-related air pollution on mortality in a Dutch cohort (NLCS-AIR study). Environ Health Perspect. 2008;116:196-202.

Beelen R, Hoek G, Houthuijs D, van den Brandt PA, Goldbohm RA, Fischer P, *et al*. The joint association of air pollution and noise from road traffic with cardiovascular mortality in a cohort study. Occup Environ Med. 2009;66:243-50.

Beelen R, Voogt M, Duyzer J, Zandveld P, Hoek G. Comparison of the performances of land use regression modelling and dispersion modelling in estimating small-scale variations in long-term air pollution concentrations in a Dutch urban area. Atmos Environ. 2010;44:4614-21.

Belojeviæ GA, Jakovljeviæ BD, Stojanov VJ, Slepceviæ VZ, Paunoviæ KZ. Nighttime road-traffic noise and arterial hypertension in an urban population. Hypertens Res. 2008;31:775-81.

Bluhm LG, Berglind N, Nordling E, Rosenlund M. Road traffic noise and hypertension. Occup Environ Med. 2007;64:122-6.

Bodin T, Albin M, Ardö J, Stroh E, Ostergren PO, Björk J. Road traffic noise and hypertension:

Results from a cross-sectional public health survey in southern Sweden. Environ Health. 2009;8:38.

Borst HC, Miedema HM. Comparison of noise impact indicators, calculated on the basis of noise maps of DENL. Acta Acust. 2005;91:378-85.

Brook RD, Rajagopalan S. Particulate matter air pollution and atherosclerosis. Curr Atheroscler Rep. 2010;12:291-300.

Brook RD, Rajagopalan S, Pope CA 3 rd , Brook JR, Bhatnagar A, Diez-Roux AV, *et al*. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation. 2010;121:2331-78.

Can A, Rademaker M, Van Renterghem T, Mishra V, Van Poppel M, Touhafi A, *et al*. Correlation analysis of noise and ultrafine particle counts in a street canyon. Sci Total Environ. 2011;409:564-72.

Chen LH, Knutsen SF, Shavlik D, Beeson WL, Petersen F, Ghamsary M, *et al*. The association between fatal coronary heart disease and ambient particulate air pollution: Are females at greater risk? Environ Health Perspect. 2005;113:1723-9.

Chen R, Samoli E, Wong CM, Huang W, Wang Z, Chen B, *et al*. Associations between short-term exposure to nitrogen dioxide and mortality in 17 Chinese cities: The China Air Pollution and Health Effects Study (CAPES). Environ Int. 2012;45:32-8.

Chiusolo M, Cadum E, Stafoggia M, Galassi C, Berti G, Faustini A, *et al*. Short term effects of nitrogen dioxide on mortality and susceptibility factors in ten Italian cities: The epiair study. Environ Health Perspect. 2011;119:1233-8.

Davies HW, Vlaanderen JJ, Henderson SB, Brauer M. Correlation between co-exposures to noise and air pollution from traffic sources. Occup Environ Med. 2009;66:347-50.

Dratva J, Phuleria HC, Foraster M, Gaspoz JM, Keidel D, Künzli N, *et al*. Transportation noise and blood pressure in a population-based sample of adults. Environ Health Perspect 2012;120:50-5.

Floud S, Vigna-Taglianti F, Hansell A, Blangiardo M, Houthuijs D, Breugelmans O, *et al*. Medication use in relation to noise from aircraft and road traffic in six European countries: Results of the HYENA study. Occup Environ Med. 2011;68:518-24.

Fuks K, Moebus S, Hertel S, Viehmann A, Nonnemacher M, Dragano N, *et al*. Long-term urban particulate air pollution, traffic noise, and arterial blood pressure. Environ Health Perspect. 2011;119:1706-11.

Gan WQ, Davies HW, Koehoorn M, Brauer M. Association of long-term exposure to community noise and traffic-related air pollution with coronary heart disease mortality. Am J Epidemiol. 2012;175:898-906.

Hoek G, Brunekreef B, Goldbohm S, Fischer P, van den Brandt PA. Association between mortality and indicators of traffic-related air pollution in the Netherlands: A cohort study. Lancet. 2002;360:1203-9.

Hoffmann B, Moebus S, Möhlenkamp S, Stang A, Lehmann N, Dragano N, *et al*. Residential

exposure to traffic is associated with coronary atherosclerosis. Circulation. 2007;116:489-96.

Huss A, Spoerri A, Egger M, Röösli M, Swiss National Cohort Study Group. Aircraft noise, air pollution, and mortality from myocardial infarction. Epidemiology. 2010;21:829-36.

Ising H, Babisch W, Günther T. Work noise as a risk factor in myocardial infarction. J Clin Basic Cardiol. 1999;2:64-8.

Janssen NA, Hoek G, Simic-Lawson M, Fischer P, van Bree L, ten Brink H, *et al*. Black carbon as an additional indicator of the adverse health effects of airborne particles compared with PM10 and PM2.5. Environ Health Perspect. 2011;119:1691-9.

van Kempen E, Babisch W. The quantitative relationship between road traffic noise and hypertension: A meta-analysis. J Hypertens. 2012;30:1075-86.

de Kluizenaar Y, Gansevoort RT, Miedema HM, de Jong PE. Hypertension and road traffic noise exposure. J Occup Environ Med. 2007;49:484-92.

Laden F, Schwartz J, Speizer FE, Dockery DW. Reduction in fine particulate air pollution and mortality: Extended follow-up of the Harvard six cities study. Am J Respir Crit Care Med. 2006;173:667-72.

Van Lenthe FJ, Gevers E, Joung IM, Bosma H, Mackenbach JP. Material and behavioral factors in the explanation of educational differences in incidence of acute myocardial infarction: The globe study. Ann Epidemiol. 2002;12:535-42.
Lercher P, Botteldooren D, Widmann U, Uhrner U, Kammeringer E. Cardiovascular effects of environmental noise: Research in Austria. Noise Health. 2011;13:234-50.

Mackenbach JP, van de Mheen H, Stronks K. A prospective cohort study investigating the explanation of socio-economic inequalities in health in The Netherlands. Soc Sci Med. 1994;38:299-308.

Miedema HM, Oudshoorn CG. Annoyance from transportation noise: Relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect. 2001;109:409-16.

Miedema HM, Vos H. Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behav Sleep Med. 2007;5:1-20.

Miller KA, Siscovick DS, Sheppard L, Shepherd K, Sullivan JH, Anderson GL, *et al*. Long-term exposure to air pollution and incidence of cardiovascular events in women. N Engl J Med. 2007;356:447-58.

Naess Ø, Nafstad P, Aamodt G, Claussen B, Rosland P. Relation between concentration of air pollution and cause-specific mortality: Four-year exposures to nitrogen dioxide and particulate matter pollutants in 470 neighborhoods in Oslo, Norway. Am J Epidemiol. 2007;165:435-43.

Ostro B, Feng WY, Broadwin R, Green S, Lipsett M. The effects of components of fine particulate air pollution on mortality in California: Results from CALFINE. Environ Health Perspect. 2007;115:13-9.

Peng RD, Bell ML, Geyh AS, McDermott A, Zeger SL, Samet JM, *et al*. Emergency admissions for cardiovascular and respiratory diseases and the chemical composition of fine particle air pollution.

Environ Health Perspect. 2009;117:957-63.

Puett RC, Hart JE, Yanosky JD, Paciorek C, Schwartz J, Suh H, *et al*. Chronic fine and coarse particulate exposure, mortality, and coronary heart disease in the Nurses' Health Study. Environ Health Perspect. 2009;117:1697-701.

Rosenlund M, Picciotto S, Forastiere F, Stafoggia M, Perucci CA. Traffic-related air pollution in relation to incidence and prognosis of coronary heart disease. Epidemiology. 2008;19:121-8.

Schaap M, Denier van der Gon HA. On the variability of black smoke and carbonaceous aerosols in the Netherlands. Atmos Environ. 2006;41:5908-20.

Schauer JJ, Lough GC, Shafer MM, Christensen WF, Arndt MF, DeMinter JT, *et al*. Characterization of metals emitted from motor vehicles. Res Rep Health Eff Inst. 2006;133: 1-76.

Selander J, Nilsson ME, Bluhm G, Rosenlund M, Lindqvist M, Nise G, *et al*. Long-term exposure to road traffic noise and myocardial infarction. Epidemiology. 2009;20:272-9.

Sørensen M, Hvidberg M, Andersen ZJ, Nordsborg RB, Lillelund KG, Jakobsen J, *et al*. Road traffic noise and stroke: A prospective cohort study. Eur Heart J. 2011;32:737-44.

Sørensen M, Hvidberg M, Hoffmann B, Andersen ZJ, Nordsborg RB, Lillelund KG, *et al*. Exposure to road traffic and railway noise and associations with blood pressure and self-reported hypertension: A cohort study. Environ Health. 2011;10:92.

Sørensen M, Andersen ZJ, Nordsborg RB, Jensen SS, Lillelund KG, Beelen R, *et al*. Road traffic noise and incident myocardial infarction: A prospective cohort study. PLoS One. 2012;7:e39283.

Sørensen M, Hoffmann B, Hvidberg M, Ketzel M, Jensen SS, Andersen ZJ, *et al*. Long-term exposure to traffic-related air pollution associated with blood pressure and self-reported hypertension in a Danish cohort. Environ Health Perspect. 2012;120:418-24.

VROM. Meet-en rekenvoorschrift geluidhinder. (Prescribed measurement and calculation methods for noise annoyance), Staatscourant 2006;249:84.

VROM. Meet-en rekenvoorschrift bevoegdheden luchtkwaliteit. Staatscourant 2006;215:20.

WHO. Air Quality Guidelines: Particulate Matter, Ozone, Nitrogen Dioxide and Sulphur Dioxide. Global Update 2005. Copenhagen, Denmark: World Health Organization; 2006.

WHO. Burden of Disease from Environmental Noise. Quantification of Healthy Life Years Lost in Europe. Copenhagen, Denmark: The WHO European Centre for Environment and Health, Bonn Office, WHO Regional Office for Europe: World Health Organization; 2011.

WHO, Janssen NA, Gerlofs-Nijland ME, Lanki T, Salonen RO, Cassee F, *et al*. Health Effects of Black Carbon. Bonn: WHO Regional Office for Europe, The WHO European Centre for Environment and Health; 2012.

Chapter 5A

Urban road traffic noise and annoyance: the effect of a quiet façade

Yvonne de Kluizenaar
Erik M. Salomons
Sabine A. Janssen
Frank J. van Lenthe
Henk Vos
Han Zhou
Henk M. E. Miedema
Johan P. Mackenbach

Adapted from J. Acoust. Soc. Am. 2011; 130 (4): 1936–1942

Abstract

Road traffic noise in urban areas is a major source of annoyance. A quiet façade has been hypothesized to beneficially affect annoyance. However, only a limited number of studies investigated this hypothesis, and further quantification is needed. This study investigates the effect of a relatively quiet façade on the annoyance response. Logistic regression was performed in a large population based study (GLOBE, N ~ 18,000), to study the association between road traffic noise exposure at the most exposed dwelling façade (L_{den}) and annoyance in: (1) the subgroup with a relatively quiet façade (large difference in road traffic noise level between most and least exposed façade (Q > 10 dB); (2) the subgroup without a relatively quiet façade (Q < 10 dB). Questionnaire data were linked to individual exposure assessment based on detailed spatial data (GIS) and standard modeling techniques. Annoyance was less likely ($OR_{Q>10}$ < $OR_{Q<10}$) in the subgroup with relatively quiet façade compared to the subgroup without relatively quiet façade. The difference in response between groups, seemed to increase with increasing Q and L_{den}. Results indicate that residents may benefit from a quiet façade to the dwelling.

5A.1 Introduction

This study investigates the effect of a quiet façade at the dwelling on the noise response of inhabitants. Traffic noise in European cities is a major source of annoyance and sleep disturbance, omnipresent, and hardly avoidable (e.g., de Kluizenaar et al., 2009; Miedema and Oudshoorn, 2001; Miedema and Vos, 2007; Pearsons et al., 1995). Exposure to high levels of road traffic noise may in the long term induce further adverse health effects, including cardiovascular effects (e.g., Babisch et al., 2005; Babisch, 2008; de Kluizenaar et al., 2007; Passchier-Vermeer and Passchier, 2000). Environmental noise has been recognized as a serious health problem. In the Guidelines for Community Noise, the World Health Organization (WHO) estimated about 40% of the population in the European Union countries to be exposed to road traffic noise with a daytime equivalent sound pressure level exceeding 55 dB (WHO, 1999). Considering the continuing growth of road traffic and the large number of people exposed, the need for effective noise reduction policy has become increasingly pronounced.

Invigorated by the accumulating amount of evidence of the potential harmful effects of environmental noise, in the Sixth Environmental Action Programme (2002) the EU set itself the objective of substantially reducing the number of people affected by noise exposure. This has resulted in the Directive 2002/49/EC on the Assessment and Management of Environmental Noise (END), which aims to define a common approach within Europe to prevent or reduce the harmful effects of environmental noise. The member states are required to make strategic noise maps, create or protect quiet zones, and to develop action plans in cooperation with the local authorities. Developing effective policy to protect citizens from the adverse effects of road traffic noise in urban areas however, is challenging and often not straightforward. Although techniques have been developed that have reduced noise emission for partial aspects, the vehicle fleet as a whole has not become much quieter since the 1970s. Source related measures, such as more stringent rules for road traffic vehicle emissions, remain therefore of utmost importance, and form an important part of European policy. In addition, following the END, local authorities have the responsibility to develop action plans to reduce environmental noise exposure. However, existing local measures such as the application of silent asphalt, the installation of noise screens, and regulation of the (local) traffic flow, may not always result in the desired levels of reduction, may be costly, or may in some cases not even be applicable. Consequently, for the local authorities, this sometimes seems to leave little room for maneuver. A wider span of practically applicable and effective alternatives would thus be desirable to complement the existing policy ‘toolkit’. In urban areas, an optimized approach – utilizing all different available policy options in combination – is required to create an acceptable noise environment.

This implies the need for quantification of the effectiveness of practical measures that may be applied.

Annoyance is the most widely acknowledged effect of environmental noise exposure, and is considered to be the most widespread. For annoyance of transportation noise, exposure-effect relationships have been presented (Miedema and Oudshoorn, 2001). In addition to the noise level at the most exposed façade of the dwelling, other aspects have been hypothesized to affect the annoyance response at a certain exposure level, including a quiet façade, living in the vicinity of quiet areas, and insulation (Miedema and Borst, 2006; Miedema and Borst, 2007). However, to date only a limited amount of research is available to quantify the impact of these aspects.

Creating quiet façades and quiet urban areas may reduce the harmful effects of noise by offering an 'escape' from the noise to the inhabitants, for example by the option to reside or sleep at a quiet side of the dwelling, or by the presence of a quiet garden (or balcony) at the back side of the dwelling. Consequently, inhabitants of a dwelling with a relatively quiet façade may be expected to be less annoyed (on average) as compared to inhabitants with the same traffic noise exposure at the most exposed façade but without a quiet façade. Previous studies have indicated a potential benificial effect of a quiet façade (Öhrström et al., 2006; Gidlöf-Gunnarsson and Öhrström, 2007). However, to date limited information is available, and studies on the basis of large datasets are now needed to further investigate this association. As far as we know, this study is the first to investigate the effect of a quiet façade on the relationship between road traffic noise exposure and annoyance response in such a large, population based sample
(N ≈ 18,000). An additional advantage of this large representative random sample of subjects from a larger urban area, is that different dwelling types within the housing stock and different source orientations can be assumed to be represented accordingly. We used objective measures for noise exposure, and odds ratios are studied with adjustment for potential confounders.

5A.2 Methods

5A.2.1 Study population

The GLOBE study is a prospective cohort study carried out in The Netherlands, with a primary aim of explaining socioeconomic inequalities in health. GLOBE is the Dutch acronym for Health and Living Conditions of the Population of Eindhoven and surroundings. Baseline data were collected in 1991. Details of the study protocol have

been described elsewhere (Mackenbach et al., 1994), and will only be briefly summarised here.

In 1991, an a-select sample (stratified by age, degree of urbanization, and socioeconomic position) of 27,070 non-institutionalized subjects (aged 15 to 74 years) was drawn from 18 municipal population registers in the south-eastern part of The Netherlands and asked to participate in the study. With a response rate of 70.1%, baseline information was collected in 1991 from 18,973 individuals using a postal questionnaire. The area of study included the city of Eindhoven, which was the fifth largest city of The Netherlands in 1991.

5A.2.2 Noise annoyance response and covariates

The data collection comprised a broad range of potential confounders including sociodemographic variables (age, gender, marital status, and education), lifestyle factors (smoking, alcohol use, physical activity, and BMI), and living conditions (employment status, financial problems). Age was entered in the analyses as a continuous variable, while gender, BMI, physical activity, marital status, employment status, financial problems, alcohol use, and education, were entered as categorical variables. BMI was categorised into four groups (underweight [BMI < 20], normal weight range [BMI 20–25], overweight [BMI 25–30], obese [BMI >30]). Physical activity was available in four categories (none, little, moderate, and much physical activity). Marital status was categorised into four groups (married or living together, unmarried, divorced, and widow/widower). Employment status was categorised in three categories, including 'unemployed'. Three categories of financial problems were distinguished (no difficulty, some difficulty, and large difficulty). Alcohol use was categorised into three groups (moderate, abstainer, and excessive). The highest attained level of education was distinguished into four different categories (primary education, lower professional and intermediate general education, intermediate professional and higher general education, and higher professional education and university). Missings in potential confounding variables (the percentage of missings for all confounding variables was below 5.6 %) were imputed, replacing the missing values with the most common category. The indicator for environmental noise annoyance, which is further referred to as the annoyance response, was available from the following question in the questionnaire: “This question concerns the dwelling and surrounding environment in which you live: In the past year, were you often confronted with annoying levels of sound [in Dutch: lawaai] from traffic, street noises, aircraft, businesses, etc. (Y/N)?” The response format is: “Yes”, “No”.

5A.2.3 Noise exposure

The road traffic noise exposure of the subjects was calculated at the most- and the least exposed façade of the home address with the Dutch standard method SRM2 in accordance with requirements of the EU Environmental Noise Directive (END). Road traffic noise may be assumed to be the dominant source in urban areas. For the analyses we used the EU standard noise metric L_{den}. L_{den} (day-evening-night level) is defined as the A-weighted 'average' sound level over 24 hours in which sound levels during the evening and the night are increased by 5 dB and 10 dB respectively (International Standards Organization, 2002) over a year. Noise levels were assessed at the façades of a dwelling with the highest- and the lowest overall exposure respectively (i.e., most- and least exposed façade). SRM2 is the Netherlands' standard method for noise modelling, in compliance with the END (VROM, 2006a). SRM2 is implemented in Urbis (Borst and Miedema, 2005), that was used here for the exposure calculations. Noise calculations were carried out in two steps calculating first the emission and then the transmission. The emission calculations take into account traffic characteristics, including traffic intensities, traffic composition (percentages light duty, medium duty, and heavy duty vehicles), speed, road height, and road surface type. The transmission calculations take into account the distance between source (road) and dwelling façade, air attenuation, effects of (yearly) meteorological conditions, ground attenuation, object screening (diffraction), and reflection of objects opposite the dwelling with one reflection per sound path. Noise exposure was calculated at the height of the centre of the dwelling façade of the exposed subject. For the most exposed façade, very low noise exposure levels (below 45 dB) were recoded as 45 dB, as this can be considered to be a lower limit of the ambient noise in urban areas. For the least exposed façade, levels below 40 dB were recoded as 40 dB, as this can be considered a lower limit of the ambient noise level at the quiet side in urban areas. Road traffic noise levels at both the most and the least exposed façade could be calculated for most respondents (N = 17,650).

Input data for the noise emission calculations was a detailed digital map describing the geographic location of roads and the traffic characteristics for each road segment (including traffic intensities for each vehicle category, speed, and road surface type), provided by the local authorities of Eindhoven for the current situation (2004). Traffic data were attached as attributes to the road segments for a dense network of roads, including highways, arterial roads, main streets, and principal residential streets.

Basis for the noise transmission calculations were digital maps with precise information on geographic location of buildings and ground characteristics (Topographic Service data [TOP10]) provided by the Netherlands Ministry of Housing, Spatial Planning and the Environment (VROM/DGR). Building height was derived from the Actual Height

Information Netherlands (AHN), a 5 m x 5 m grid with height information based on laser altimetry. The geographic location of noise screens with their height was provided by the local authorities of Eindhoven. The geographical location of dwellings within the building contours (Topographic Service data [TOP10]) was identified with the use of address coordinates.

5A.2.4 Statistical analysis

Logistic regression was performed to investigate the association between day-evening-night residential road traffic noise exposure (L_{den}) and the annoyance response. As a measure of strength of the association, estimated odds ratios (OR) are presented, where the odds ratio represents the ratio of the odds in favor of annoyance among the exposed to the odds in favor of annoyance among the 'unexposed' (reference group: noise exposure most exposed façade ≤45 dB). Odds ratios are presented together with their corresponding 95% confidence intervals (CI).

For each dwelling the difference Q between the most- and least exposed dwelling façade is calculated by

$$Q_i = L_{den} - L_{den,\min}$$

with

L_{den}: level (L_{den}) at the most exposed façade,

$L_{den,min}$: level (L_{den}) at the least exposed façade.

The subjects are divided into subgroups depending on L_{den} and Q. We consider overlapping intervals of L_{den}. For the level difference Q we consider two subgroups and the full population:

Group 0: Full population (All);

Group 1: Q <10;

Group 2: Q >10.

Logistic regression was carried out for the full population (Group 0) as well as for the two subgroups (Group 1 and Group 2). In the model, factors were included that could potentially confound the relationship between traffic noise exposure and the annoyance response. These variables are: age, sex, BMI, physical activity, marital status, employment status, financial problems, alcohol use, and self-reported level of education. A P value of at most 0.05 was considered to indicate significance of the association. All analyses were performed with SPSS Inc. (PASW statistics version 18.0.0).

5A.3 Results

5A.3.1 Population Characteristics

Table 5A.1 shows the distribution of subjects of the GLOBE study sample over the road traffic noise exposure categories (L_{den}), assessed at the most exposed façade of the dwellings at the home address. There is a clear increase in annoyance response with increasing noise exposure, with the subjects in the highest road traffic noise exposure category most often reporting annoyance. The table further shows that the average age is higher and subjects are on average less often married or living together at higher noise levels than at lower noise levels.

5A.3.2 Noise exposure

Table 5A.1 shows that the variation in road traffic noise exposure in the study population of the Eindhoven region is substantial. The difference in exposure between the lowest exposed 5 % and the highest exposed 5% of dwellings exceeds 20 dB (L_{den}), ranging from about 45 dB (urban background) to more than 65 dB (L_{den}), in the vicinity of roads.

Table 5A.1 *Characteristics of the GLOBE cohort by road traffic noise (L_{den}) [dB] exposure category at the most exposed façade (unadjusted).*

L_{den} [dB]	< 45	45–50	50–55	55–60	> 60
N	5077	4102	2820	2447	3204
Age (*years*)	46.8	47.0	47.8	48.4	49.2
Sex: Male *(%)*	48.9	49.1	46.6	49.2	48.0
BMI (QI > 25) *(%)*	35.6	37.2	37.9	38.3	38.2
Physical activity: much *(%)*	33.3	33.2	33.9	33.6	31.1
Marital (married/live together) *(%)*	76.0	75.7	74.9	73.1	68.0
Work situation: unemployed *(%)*	10.8	10.0	10.2	9.1	10.7
Financial: much difficulty *(%)*	4.7	4.6	3.9	3.4	3.8
Alcohol use: excessive *(%)*	8.4	8.3	7.3	7.7	8.6
Education low *(%)*	20.8	21.5	19.7	20.7	22.9
Annoying levels of sound (Y) *(%)*	7.9	9.3	12.7	17.3	31.5

Variables are described by means, and percentages in case of dichotomous variables.
Abbreviations are: BMI, Body Mass Index; L_{den}, road traffic noise level (dB).

Figure 5A.1 illustrates some typical geographical building orientations towards the roads, resulting in varying differences between most and least exposed façade (*Q*). Dwellings for which *Q* is smaller than 10, are marked with a black outline. As the figure shows, these include dwellings exposed from more than one direction (e.g., near cross roads, indicated with nr. 1 in the figure), and dwelling blocks oriented perpendicular to the road (nr. 2). In contrast, dwelling blocks oriented parallel to the road source (nr. 3) or built in a U-shaped formation (nr. 4) creating a noise-shielded side, are characterised by a higher *Q*.

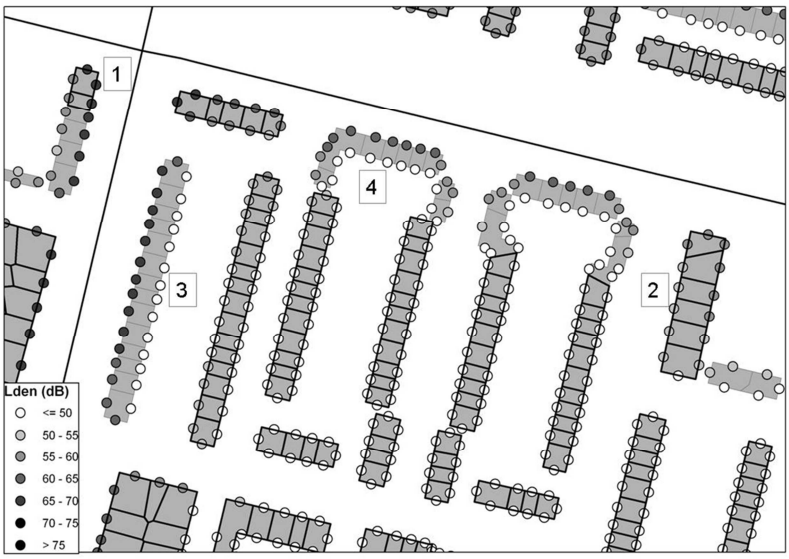

Figure 5.A.1 *Illustration of some typical geographical orientations of blocks of dwelling towards the roads.*

Table 5A.2 shows the mean differences between most and least exposed façade (*Q*) calculated for the different noise categories for: the full population (Group 0, *All*); the subgroup without the advantage of a quiet side to the dwelling (Group 1; *Q* <10); the subgroup with the advantage of a quiet side (Group 2; *Q* >10).

The mean level difference Q_{av} for the total population was estimated by the following calculation: $Q_{av} = \Sigma_i(N_i\ Q_{i,0})/\ \Sigma_i\ (N_i) = 7.3$ dB, with N_i from Table 5A.1. This value is rather low as a result of the large percentage (about 50%) of the population in the lowest two noise categories (including the reference group: $L_{den} \leq 45$ dB). The estimated mean level difference for the total population excluding the reference group equals 8.7 dB.

Table 5A.2 *Mean differences (Q) between most exposed facade (L_{den}) and least exposed façade ($L_{den,min}$) and median noise levels (L_{den}) for noise exposure categories, for the full population (Group 0, All), the subgroup without a quiet side (Group 1; Q <10) and the subgroup with a quiet side (Group 2; Q >10).*

Category (L_{den})	Median $L_{den,0}$	Q_0	Median $L_{den,1}$	Q_1	Median $L_{den,2}$	Q_2
<45	45	*3.8**	45	*3.8**	-	-
45-50	47.3	3.8	47.3	3.8	-	-
45-52.5	48.1	4.3	48.0	4.1	51.6	11.1
50-55	52.4	6.7	52.1	5.2	53.1	11.9
52.5-57.5	54.8	8.6	54.4	5.5	55.5	13.0
55-60	57.5	10.7	57.1	5.8	57.8	14.1
57.5-62.5	59.9	12.7	59.3	5.9	60.1	15.2
>60	63.7	15.1	63.6	5.5	63.8	17.3
>62.5	65.3	15.8	65.0	5.5	65.4	18.1

* Q for dwellings situated in areas within urban background noise level , Q is unknown and has been assumed equal to the average Q for the closest category (L_{den} 45–50).

The mean differences between most and least exposed façade show a clear relationship with the (median) noise levels at the most exposed façade. The functions that describe this relationship are different for the three groups. Figure 5A.2 shows these relationships, described by polynomials of degree 3 that were fitted to the functions $Q_i(L_{den})$ (i = 0, 1, 2). In the analysis of the quiet-side effect presented in the remainder of Section III, we investigated the difference in annoyance response between subjects living in dwellings with Q > 10 and Q < 10.

5A.3.3 The effect of a quiet side

Figure 5A.3 shows the percentage of respondents with a positive annoyance response (Y/N) by L_{den}, in the subset of the population without a quiet side to the dwelling (Group 1: Q <10) and the subset of the population with a quiet side to the dwelling (Group 2: Q >10). This figure presents the unadjusted percentages of positive response, and should be interpreted with caution, as covariates related with Q may confound the association.

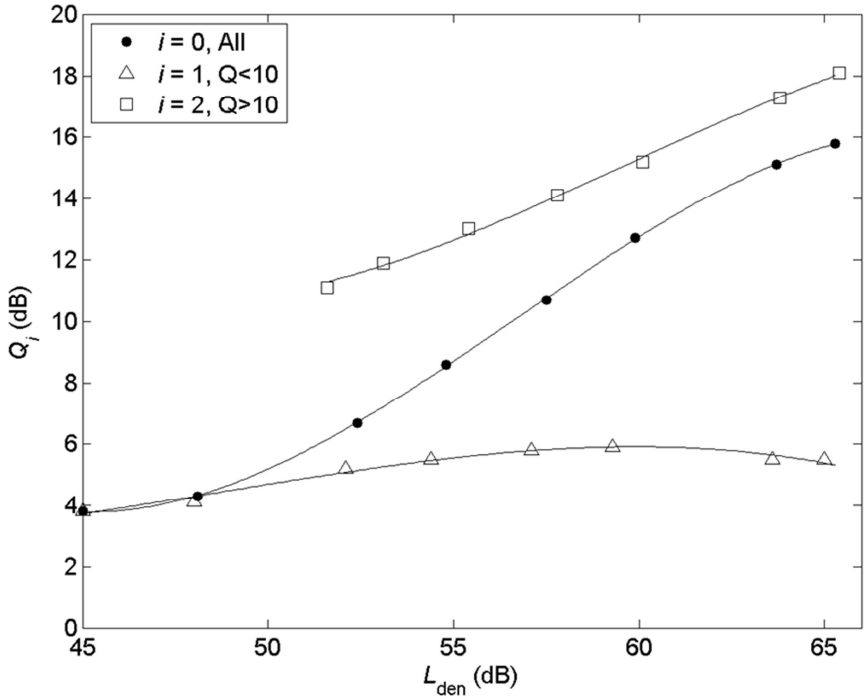

Figure 5.A.2 *Q_i as a function of L_{den} (i=0, 1, 2), and 3rd order polynomials.*

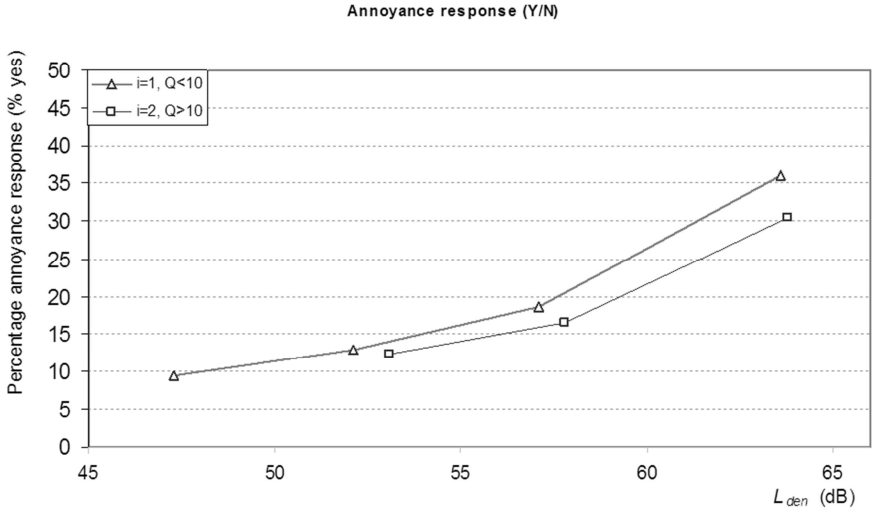

Figure 5.A.3 *Percentage of respondents with a positive annoyance response (Y/N) by L_{den}, in the subset of the population without a quiet side to the dwelling (Group 1: Q <10) and the subset of the population with a quiet side to the dwelling (Group 2: Q >10).*

Table 5A.3 shows the odds ratios for the annoyance response in different noise categories after adjustment for covariates for the 2 groups. First we calculated the odds ratios for the following 5 dB noise categories: <45 (reference category), 45-50, 50-55, 55-60, > 60 dB. Second, we additionally calculated the odds ratios for the following noise categories: <45 (reference category), 45-52.5, 52.5-57.5, 57.5-62.5, >62.5 dB. We calculated the associations for the additional (overlapping) noise categories in order to refine the estimated shape of the response function. The table shows that at a given noise level at the most exposed façade, annoyance is more likely in the group without a quiet façade (Group 1; *Q* <10) (higher odds ratios) than in the group with a quiet façade (Group 2; *Q* >10).

Table 5A.3 *Odds ratios for road traffic noise exposure (L_{den}) [dB], for the annoyance response in the GLOBE study sample after adjustment for covariates[a)] for: The subset of the population without a quiet side to the dwelling (Group 1; Q<10); the subset of the population with a quiet side to the dwelling (Group 2; Q>10).*

Category (L_{den})	Median $L_{den,1}$	OR_1	Median $L_{den,2}$	OR_2
<45	45	1.00	45	1.00
45-50	47.3	1.19 (1.03–1.39)*	-	-
45-52.5	48.0	1.26 (1.09–1.44)**	51.6	1.33 (0.84–2.10)
50-55	52.1	1.74 (1.47–2.05)**	53.1	1.63 (1.25–2.13)**
52.5-57.5	54.4	2.23 (1.87–2.66)**	55.4	2.05 (1.67–2.52)**
55-60	57.1	2.75 (2.27–3.34)**	57.8	2.38 (1.99–2.84)**
57.5-62.5	59.3	3.83 (3.09–4.74)**	60.1	2.96 (2.52–3.48)**
>60	63.6	6.93 (5.65–8.50)**	63.8	5.30 (4.63–6.07)**
>62.5	65.0	8.00 (6.30–10.16)**	65.4	6.54 (5.64–7.58)**

* Significant relationship (P < 0.05); ** Significant relationship (P < 0.01).

a) Odds ratios from logistic regression are shown, adjusted for age, sex, Body Mass Index, exercise, marital status, work situation, financial difficulties, alcohol use, education.

The odds ratio for the two groups with and without a quiet side to the dwelling is presented in Figure 5A.4. Odds ratios are plotted using the median for each noise category. Odds ratios are lower in the group with a quiet façade.

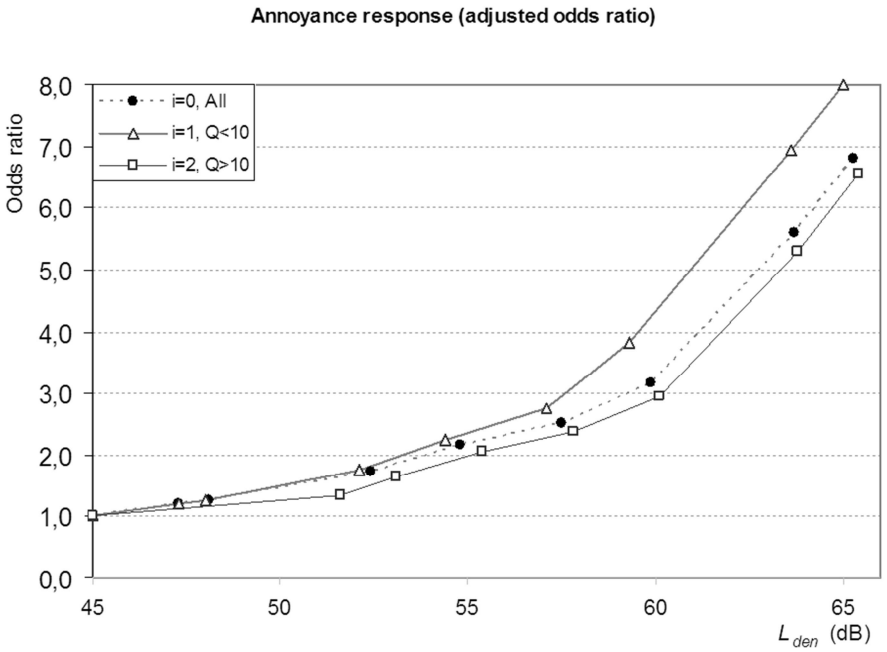

Figure 5.A.4 *Odds ratio as a function of road traffic noise exposure at the most exposed facade (L_{den}) after adjustment for covariates for: the full population (Group 0; All); the subset of the population without a quiet side to the dwelling (Group 1: Q <10); the subset of the population with a quiet side to the dwelling (Group 2: Q >10).*

To derive a quantitative estimate of the quiet-side effect, we took the following steps: First we tested if the strength of the association (odds ratio) within a given noise category was significantly dependent on quiet side (as defined by Q > 10 dB [Y/N]). This was done by including the interaction between noise category and quiet side in the model. This interaction term was significant at higher noise levels for two categories (> 60 and 57.5 – 62.5 dB).

Second, to estimate the size of the potential beneficial effect, we assessed the difference between the curves in noise level at which the two groups (1 and 2) showed equal likelyhood of annoyance response (equal odds ratios). Thus, the potential benefit (in dB) was assessed by deriving the difference in L_{den} along horizontal lines, i.e., at equal odds ratio (equal annoyance response). Values of ΔL were determined as horizontal distances between the response functions for groups 1 and 2 in Figure 5A.4, for two values of OR: the OR values of the two noise categories where the quiet-side effect (difference in odds ratios between groups 1 and 2) was found to be significant:

i) OR = 3.177, corresponding to L_{den} = 59.9 dB (median $L_{den,0}$ of interval 57.5-62.5 dB);
ii) OR = 5.584, corresponding to L_{den} = 63.7 dB (median $L_{den,0}$ of interval >60 dB).

Thus, the difference in quiet side effect between the two groups was estimated at approximately 2.5 dB. For the category of respondents with a noise exposure >60 dB, the average Q was 5.5 in group 1 (Q < 10), and 17.3 in group 2 (Q > 10). For the category of respondents with a noise exposure between 57.5 and 62.5 dB, the average Q was 5.9 in group 1 (Q <10), and 15.2 in group 2 (Q >10). Thus, the average difference in Q between the two groups, for which the above effect (in dB) was estimated, was approximately 10 dB (5.5-5.9 to 15.2-17.3).

5A.4 Discussion and Conclusions

This study investigated the effect of a quiet façade at the dwelling on the noise response of inhabitants. We tested the hypothesis that a relatively quiet side at the home may affect the noise annoyance response. Annoyance was less likely (lower odds ratios) for the subgroup with relatively quiet façade (Q >10 dB) as compared to the subgroup without relatively quiet façade (Q <10 dB). Thus, a quiet façade was observed to affect the annoyance response, in addition to the noise level at the most exposed façade, suggesting that, as hypothesized, residents may benefit from a quiet façade. The difference in response between groups, seemed to increase with increasing difference (Q) between exposure at the most and least exposed façade and with increasing L_{den} at the most exposed façade.

An effect of having a quiet side on self-reported annoyance has been reported previously (Gidlöf-Gunnarsson and Öhrström, 2010; Gidlöf-Gunnarsson and Öhrström, 2007; Öhrström et al., 2006). Öhrström et al. (2006) investigated whether having a quiet side of one's dwelling reduced noise annoyance in selected residential areas (four study sites, similar in dwelling type: flat blocks). A quiet side (as defined by $L_{Aeq,\ 24h} \leq 45$ dB) reduced annoyance, corresponding to a reduction of sound level of approximately 5 dB at the most exposed side. Gidlöf-Gunnarsson and Öhrström, (2007) added to this finding by showing that in addition 'better' availability of nearby green areas may also reduce the annoyance response, and Gidlöf-Gunnarsson and Öhrström (2010) showed that physical environmental quality of the quiet side itself (degree of naturalness and utilization of the courtyard) may also modify the annoyance response. Our study adds to previous findings by showing a quiet side effect in a large random (population based) sample. Our results indicate an effect of a *relatively* quiet side. In EU's Environmental Noise Directive (END) a definition in this line is used: "A quiet façade is defined as a façade where L_{den} 20 dB lower than L_{den} at the most exposed façade ($Q \geq 20$ dB)." In an average city however, only a small percentage of dwellings may meet this criterion: for the city of Amsterdam and

the Eindhoven region, The Netherlands, an average *Q* of around 10 dB was calculated: Salomons et al. (2009) calculated a Q_{av} of 12.4 dB for Amsterdam, while for the Eindhoven region the average *Q* was slightly lower than 10 dB.

We used a difference between most and least façade (*Q*), in line with the definition used in the END, and taking into account the size of Q_{av} estimated at around 10 dB for Dutch urban situation, as an approximation of an urban average situation. In this way, we could take into account that a benefit from a relatively quiet façade is expected. Also in high exposure situations where the urban background level at the least exposed side may not be reached.

Some limitations need to be acknowledged. First, the cohort study was originally not designed as a noise annoyance study, and data on noise annoyance were available for self-reported annoying levels of sound by environmental noise on a two point scale (Y/N) only. Despite this, our analysis shows a clear quiet-side effect in the noise-annoyance response. These findings now need to be confirmed and refined in other population studies. It should be noted that this is an observational study, where a quiet side was shown to be associated with the annoyance response. In theory, it cannot be ruled out that another related factor was responsible for the observed effect. However, a causal relationship may be assumed, given that the endpoint is specifically noise related, while the quiet side influences the noise exposure. Furthermore, we tried to minimized this chance by taking into account a wide range of potential confounders, including age, sex, BMI, exercise, marital status, work situation, financial difficulties, alcohol use, and education.

While road traffic noise may be assumed to be the dominant source in urban areas, the possibility for inhabitants to 'escape' from the noise to a quiet side of the dwelling is dependent also on the noise from sources other than road traffic at the back side of the dwelling. However, in the analysis this may be compensated in part by the large population sample (N ~ 18,000). Another possible limitation is that road traffic noise data for the year 2004 were used for exposure assessment, because no historic data were available on traffic intensity in 1991. However, although traffic intensities have increased over the years, the road network is assumed to be rather stable, with only small (if any) but comparable changes in noise exposure across the population. For example, a recent study showed that road traffic intensities for a ten year difference in time (1986 and 1996) in The Netherlands were highly correlated (correlation coefficient 0.9) (Beelen et al., 2009). Other important geographical aspects such as the orientation of dwellings and the distance to the roads were likely to be stable as well.

Noise exposure in this study was calculated with the Netherlands' standard calculation method for road traffic noise modeling. This method is comparable to other European

engineering methods for road traffic noise mapping. These methods may be further optimized for more accurate exposure assessment at the least exposed façade. Recently, Salomons et al. (2009) proposed an engineering model which aims at refining assessment of exposure at the quiet side. So far, however, this method has not (yet) been broader adopted for noise mapping.

A strength of this study is that it was carried out in a large random sample drawn from the general population, of a major urban region (the region of Eindhoven, which was the fifth largest city of The Netherlands at the start of the cohort study). Thus, a representative sample of buildings within the study area was obtained, together with the existing variety in exposure conditions (façade levels and geographical orientations of dwellings towards the surrounding roads). The large sample size increases the power of the statistical analysis, while the population based design of the study increases the possibility to extrapolate the results to the general population, as compared to studies with smaller or non-random samples. The wide range of both exposure levels and differences between most and least exposed façade (*Q*), together with the large sample size, enabled us to investigate the quiet-side effect for different exposure conditions. Still, when generalizing the effect estimates for the population in the region of Eindhoven to other cities, some aspects need consideration. Results of this study have to be confirmed in different populations. Potentially relevant differences with other cities may include composition and lay-out of the building stock, traffic composition, exposure, and population characteristics. Finally, we were able to minimize confounding by adjusting for a large range of covariates in the model. To our knowledge, this effect has not been studied (and quantified) in such a large random sample of the population previously.

The present results suggest that the expected annoyance may be substantially reduced, when in an early stage of the planning process the availability of a quiet side is warranted. In cities with busy traffic, access of the inhabitants to quietness is important to enhance restoration needed to recover from daily stress. This is of primary importance within their direct living environment (the home). As exposure to road traffic noise may adversely affect well-being and health in humans, it is important to investigate practical approaches towards exposure and impact reduction. One such approach may be to create quiet façades as noise refuges, either in new urban areas, or by modifying existing urban areas, for example by choosing specific orientations of houses with respect to roads, or by modifying traffic flows. While developing of action plans as part of environmental noise policy, special urgency may be assigned to dwellings which not only have high noise levels at the most exposed façade, but in addition also do not have a quiet side. In the development of new urban areas and urban renewal initiatives, measures geared towards creating new (or protecting existing) quiet facades may be

adopted in an early stage of the spatial planning process to protect and improve the quality of the noise environment.

References

Babisch W, Beule B, Schust M, Kersten N, Ising H. Traffic noise and risk of myocardial infarction. Epidemiology. 2005;16:33–40.

Babisch W. Road traffic noise and cardiovascular risk. Noise Health. 2008;10(38):27–33.

Borst HC, Miedema HME. Comparison of noise impact indicators, calculated on the basis of noise maps of DENL. Acta Acust. 2005;91:378–385.

Gidlöf-Gunnarsson A, Öhrström E. Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. Landscape Urban Plan. 2007;83:115–126.

Gidlöf-Gunnarsson A, Öhrström E. Attractive “quiet” courtyards: a potential modifier of urban residents responses tot road traffic noise? Int J Environ Res Public Health 2010;7:3359–3375.

Kluizenaar Y de, Janssen SA, Van Lenthe FJ, Miedema HME, Mackenbach JP. Long-term road traffic noise exposure is associated with an increase in morning tiredness. J Acoust Soc Am. 2009;126(2):626–633.

Kluizenaar, Y. de, Gansevoort RT, Miedema HME, Jong PE de. Hypertension and road traffic noise exposure. J Occup Environ Med. 2007;49(5):484–492.

Mackenbach JP, Mheen H. van de, Stronks K. A prospective cohort study investigating the explanation of socioeconomic inequalities in health in The Netherlands. Soc Sci Med. 1994;38:299–308.

Miedema HME, Oudshoorn CGM. (2001). Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect. 2001;109:409–416.

Miedema HME, Borst HC. Rating environmental noise on the basis of noise maps. Proceedings of Euronoise 2006, Tampere, Finland.

Miedema HME, Borst HC. Rating environmental noise on the basis of noise maps within the framework of the EU Environmental Noise Directive. Proceedings of Internoise 2007, Istanbul, Turkey.

Miedema HME, Vos H. Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behav Sleep Med. 2007;5(1):1–20.

Pearsons KS, Barber DS, Tabachnick BG, Fidell S. (1995). Predicting noise-induced sleep disturbance. J Acoust Soc Am. 1995;97:331–338.

Öhrström E, Skanberg A, Svensson H, Gidlöf-Gunnarsson A. Effects of road traffic noise and the benefit of access to quietness. J Sound Vib. 2006;295:40–59.

Passchier-Vermeer W, Passchier WF. Noise exposure and public health. Environ Health Perspect. 2000;108,123–131.

Salomons EM, Polinder H, Lohman WJA, Zhou H, Borst HC, Miedema HME. Engineering modeling of traffic noise in shielded areas in cities. J Acoust Soc. Am. 2009;126 2340-2349.

VROM. (2006). Meet- en rekenvoorschrift geluidhinder 2006 (Prescribed measurement and calculation methods for noise annoyance 2006). Staatscourant 21 december 2006[a]: 249, 84.

WHO. Berglund, B., Lindvall, T., Schwela, D. (1999). Guidelines for Community Noise. Geneva: Word Health Organization.

Chapter 5B

Road traffic noise and annoyance: a quantification of the effect of quiet side exposure at dwellings

Yvonne de Kluizenaar
Sabine A. Janssen
Henk Vos
Erik M. Salomons
Han Zhou
Frits van den Berg

Adapted from Int. J. Environ. Res. Public Health 2013; 10: 2258-2270

Abstract

Previous studies indicate that residents may benefit from a “quiet side” in their dwellings. The influence of the level of road traffic noise exposure at the least exposed side on road traffic noise annoyance was studied in Amsterdam, The Netherlands. Road traffic noise exposure was assessed at the most and least exposed façade ($L_{den,most}$ and $L_{den,least}$ respectively) of dwellings for subjects in a population based survey (N = 1,967). It was investigated if and to what extent *relative quietness* at the least exposed façade affected the level of road traffic noise annoyance by comparing two groups: (1) the subgroup with a relatively quiet façade; (2) the subgroup without a relatively quiet façade (large *versus* small difference in exposure between most and least exposed façade; DIF ≥ 10 dB and DIF < 10 dB respectively). In addition, it was investigated if and to what extent $L_{den,least}$ affected the level of road traffic noise annoyance. Results indicate a significantly lower road traffic noise annoyance score at a given $L_{den,most}$, in the subgroup with DIF ≥ 10 dB *versus* DIF < 10 dB. Furthermore, results suggest an effect of $L_{den,least}$ independent of $L_{den,most}$. The estimated size of the effect expressed in an equivalent change in $L_{den,most}$ approximated 5 dB for both the difference between the two subgroups (DIF ≥ 10 dB and DIF < 10 dB), and for a 10 dB change in $L_{den,least}$.

5B.1 Introduction

Exposure to environmental noise has been associated with a broad range of health effects. Of these effects, annoyance is the most widely recognized and is considered the most prevalent. In a recent study, the WHO concluded that sleep disturbance and annoyance form the main burden of disease from environmental noise in Europe (WHO, 2011). Road traffic is an important cause of noise annoyance in urban areas. For traffic noise annoyance, exposure-response relationships have been established based on pooled analyses of a large international database (Miedema and Oudshoorn, 2001). In an EU position paper, these relationships have been recommended to be used for estimating the expected prevalence of traffic noise annoyance (EC, 2002a). The expected prevalence of annoyance is predicted from levels of exposure at the most exposed façade of dwellings. However, locally the actual prevalence of noise annoyance may substantially differ from predicted values (see e.g., Miedema et al., 1998). This difference may be explained by a broad range of (area specific) characteristics of both the population and the physical environment.

One of these characteristics is the exposure at the least exposed side of dwellings. People living in dwellings with a (relatively) quiet least exposed side may be expected to be better off than average. Similarly, inhabitants of dwellings with relatively high noise exposure at multiple sides may be expected to be worse off than average. It has been previously hypothesized that access to a quiet side may reduce the adverse effects of noise by offering an "escape" from the noise to the inhabitants, e.g., by providing the option to spend time or sleep at the quiet side of the dwelling (Miedema and Borst, 2006; Miedema and Borst, 2007).

Previous studies indeed indicate that having access to a (relatively) quiet side is associated with a comparatively lower annoyance (Öhrström et al., 2006; de Kluizenaar et al., 2011; Van Renterghem et al., 2012). Different approaches to investigate the influence of exposure at the least exposed side have been followed. For example, Öhrström et al. defined a quiet side as an exposure level at the least exposed façade below 45 dB $L_{Aeq,24h}$, while other studies have looked at the influence of a relatively quiet façade, expressed as an indicator for difference between the exposure at the most and

the least exposed side (Öhrström et al., 2006). To date, however, only a limited number of studies is available. More studies are needed to further corroborate the hypothesized effect, and to enable the comparison of results between studies in different populations. Furthermore, there is a need for further quantification of the influence of exposure at the least exposed side. In this study, the influence of the level of road traffic noise exposure at the least exposed side on annoyance was studied in a population based survey in Amsterdam, The Netherlands. Road traffic noise annoyance was available on an 11 point scale for a large urban population. The effect of exposure at the least exposed side was investigated in two ways. First, it was investigated if and to what extent *relative quietness* at the least exposed façade affected the road traffic noise annoyance level. Second, it was investigated if and to what extent the road traffic noise level at the least exposed side ($L_{den,least,}$ continuous) affected the level of road traffic noise annoyance, in addition to the level at the most exposed side ($L_{den,most,continuous}$).

5B.2 Methods

Road traffic noise exposure at both the most and the least exposed façade of dwellings ($L_{den,most}$ and $L_{den,least}$, respectively), was estimated by model calculations for all addresses in the city of Amsterdam. Noise exposure was linked to questionnaire data on self-reported traffic noise annoyance and potential confounding factors of subjects in a population based survey. In this way a substantially sized sample with both noise exposure and response data was obtained. This provided the opportunity to investigate the hypothesized association between exposure at the least exposed side of the dwelling on the annoyance response of the inhabitants.

5B.2.1 Study Population

Survey data were collected in 2008 by the Public Health Service (GGD) of the Municipality of Amsterdam (Amsterdam Health Monitor 2008) (Dijkshoorn et al., 2009). The following procedure was used: First, a random sample of 13,600 inhabitants of Amsterdam was drawn from the municipal population register. From this initial sample,

subjects who had moved out of the study area or had died were excluded. Secondly, the sample was stratified by age and by district, to ensure comparable representation of all age groups and all urban districts (city boroughs) of Amsterdam. Two different versions of the questionnaire were developed: one version was dedicated to the 16 to 54 years age group, and one version for the older age group (aged 55 years and older). The annoyance question was available only in the questionnaire for the age group of 16 to 54 years olds. This sub sample consisted of 6,800 subjects, who were invited to participate. Addresses were available only for respondents who had indicated that their data could be used for further studies. The response rate was approximately 50%. Thus, road traffic noise exposure at the dwelling façades could be estimated for 1,967 subjects.

Survey data were collected by a postal questionnaire or by an internet questionnaire, or (if requested) with the aid of an interviewer. The main purpose of the survey was to gauge the health status of the Amsterdam adult population, including demographic, socioeconomic, psychosocial, and environmental determinants. The survey included questions on self-reported noise annoyance from a number of sources (apart from road traffic noise including e.g., noise from neighbors and humming noise [e.g., from fans]), and a broad range of potential confounders including socio-demographic variables (e.g., age, gender, and education level). Data on education were available in four categories: low (primary education), medium low (lower professional and intermediate general education), medium high (intermediate professional and higher general education), and high education (higher professional education and university).

Data on road traffic noise annoyance were available from the following questions in the questionnaire: “Thinking of the last 12 months, when you are at home, which number on a scale from 0 to 10 best represents to what extent you are being annoyed or disturbed by noise from the following sources”, followed by: (a) traffic on roads with a maximum speed limit greater than 50 km/h, and (b) traffic on roads with a maximum speed limit of 50 km/h. From these two road traffic noise annoyance questions, an annoyance scale was constructed by taking for each respondent the maximum score of both items. It was also possible to indicate that either type of traffic noise was not audible.

5B.2.2 Noise Exposure

Exposure to road traffic noise was determined by model calculations for all dwellings (addresses in the population registry) in the city of Amsterdam. For each dwelling, exposure levels were calculated at the most and least exposed façade ($L_{den,most}$ and $L_{den,least}$, respectively). Here, L_{den} is the day-evening-night level, which is a "weighted average" of the levels L_{day} for the day period (7:00–19:00 h), $L_{evening}$ for the evening period (19:00–23:00 h), and L_{night} for the night period (23:00–7:00 h), and includes "penalties" of 5 and 10 dB for the evening and night periods, respectively. The model calculations were performed with the Dutch standard calculation method for road traffic noise (SRM2) (VROM, 2006). This method is a standard engineering method, which is also used for strategic noise mapping in the framework of the Environmental Noise Directive 2002/49/EC (END) (EC, 2002b). Input for the model calculations includes: geometrical data of buildings and noise barriers, geometrical data of roads (location and surface type of road segments), traffic data for all road segments (vehicle intensities, traffic composition [incl. light vehicles {passenger cars}, medium-heavy vehicles, and heavy vehicles], and driving speed), and geometrical data for land surface types. The data were provided by the municipality of Amsterdam, for the year 2011. Road traffic data were available for the urban roads with substantial traffic intensities in Amsterdam (typically with a traffic intensity above about 1,000 vehicles per 24 h). Noise levels were calculated depending on the height of the dwelling.

For the most exposed façade, noise levels below 45 dB were recoded as 45 dB. The level of 45 dB was assumed an approximate representation of ambient noise in urban areas. This value has previously been used as a cut off value for the most exposed façade, e.g., in the development of the exposure response curves for annoyance (Miedema et al., 2001; Miedema et al., 1998). For the least exposed façade, levels below 40 dB were recoded as 40 dB, which was assumed an approximate representation of ambient noise at the quiet side in urban areas.

5B.2.3 Statistical Analyses

Linear regression analyses were performed to investigate the relationship between road traffic noise exposure at the most exposed façade, and at the least exposed façade, and the annoyance score (scale 0 to 10). Exposure at the least exposed façade was entered in the model two ways: First, the effect of a relatively quiet façade was investigated (difference between most and least exposed façade (DIF < 10 dB *versus* DIF ≥ 10 dB)). Second, the influence of the road traffic noise level at the least exposed façade ($L_{den,\ least}$, as a continuous variable) was investigated. Linear regression analyses were carried out for 3 models: (1) unadjusted model; (2) adjusted model (adjustment for age, gender, and education); (3) full model: as (2) with additional adjustment for annoyance from noise by neighbors and humming sounds (e.g., fans), as these sources possibly disrupt quietness at the least exposed façade. All analyses were carried out with the statistical software package IBM SPSS statistics version 20.0.0.

5B.3 Results

5B.3.1 Characteristics of the Study Population

Table 5B.1 shows the characteristics of the Amsterdam study population. The average age of the study population is approximately 36 years. Relatively more women than men participated in the study, and the percentage of subjects with high education level is comparatively high with slightly over 50%. The average reported road traffic noise annoyance score (scale 0 to 10) in the Amsterdam study population is approximately 2. The average annoyance from neighbor noise exceeds this average with a mean score of approximately 3. Figure 5B.1 shows the mean road traffic noise annoyance score, for categories of $L_{den,most}$ with confidence intervals, for the Amsterdam study population.

Table 5B.1 *Characteristics of the Amsterdam study population*

Variable	
Age (average, SD)	35.8 (10.4)
Men (%)	38.7
Women (%)	61.3
Education low (%)	6.9
Education medium low (%)	17.3
Education medium high (%)	25.2
Education high (%)	50.6
Annoyance road traffic noise scale 0 to 10 (average, SD)	2.2 (2.7)
Annoyance noise neighbors scale 0 to 10 (average, SD)	2.9 (2.9)
Annoyance noise humming sound (e.g., fans) scale 0 to 10 (average, SD)	1.3 (2.3)
$L_{den,most}$ (average, SD)	52.3 (8.0)
$L_{den,least}$ (average, SD)	41.7 (3.7)
Relatively quiet façade (DIF ≥ 10 dB; %)	40.5

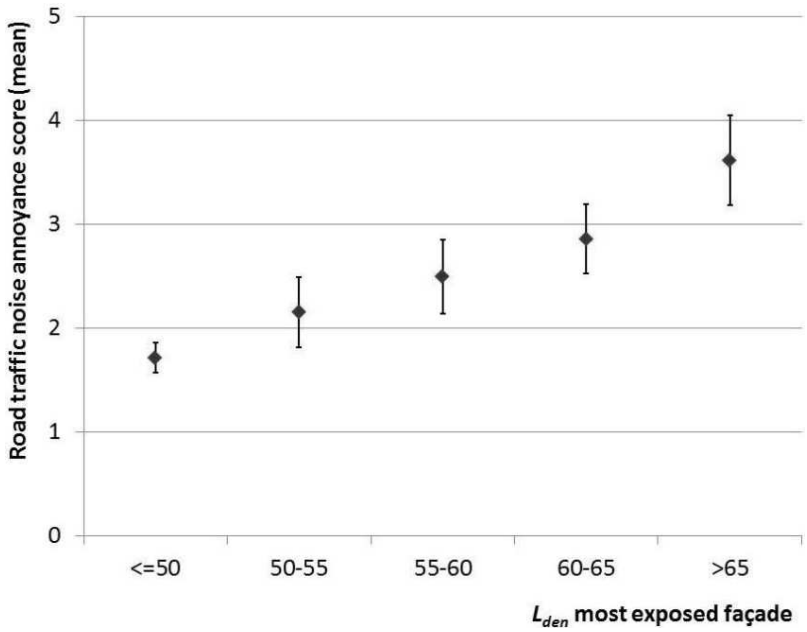

Figure 5B.1 *Mean road traffic noise annoyance score (scale 0 to 10), with 95% confidence intervals for the Amsterdam study population*

5B.3.2 Relatively Quiet Façade and Annoyance

Figure 5B.2 presents the mean annoyance score for the subgroup with a relatively low difference between most and least exposed façade (DIF < 10 dB) and the subgroup with a relatively high difference between most and least exposed façade (DIF ≥ 10 dB), by most exposed façade road traffic noise level ($L_{den,most}$). The figure suggests the mean annoyance scores are lower for the subgroup with a relatively quiet façade, although not consistently for all categories of $L_{den,most}$.

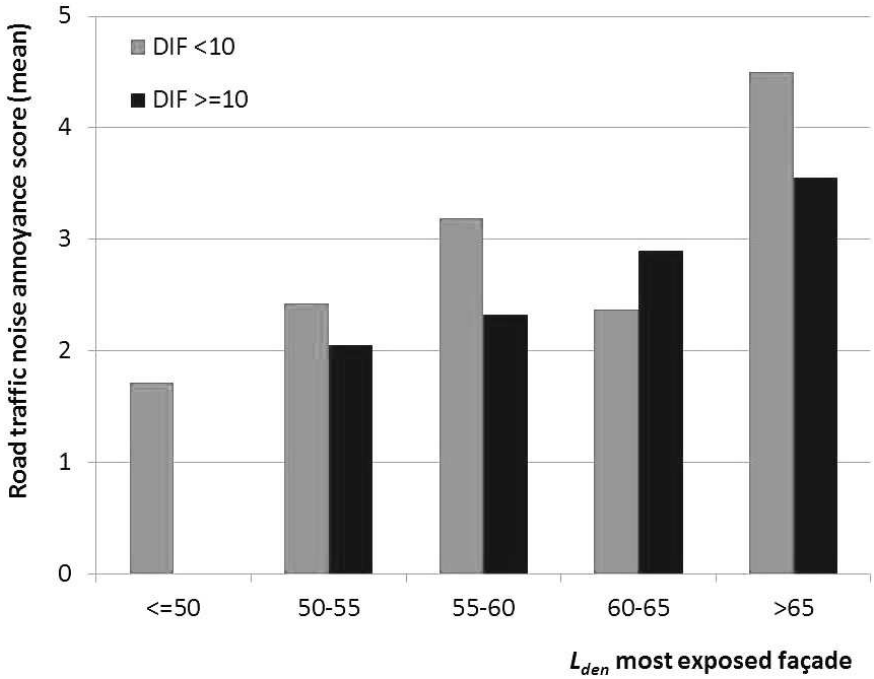

Figure 5B.2 *Mean annoyance score (scale 0 to 10) in the Amsterdam study population for two categories of difference between most and least exposed façade (DIF < 10 dB versus DIF ≥ 10 dB), using 5 dB intervals of $L_{den,most}$.*

Table 5B.2 provides an overview of the results from the linear regression analyses. In the analyses, the annoyance score is predicted from the exposure at the most exposed façade ($L_{den,most}$; dB; continuous) and the availability of relative quietness at the least

exposed façade (difference between $L_{den,most}$ and $L_{den,least}$ in two categories (DIF < 10 dB *versus* DIF ≥ 10 dB)), with additional adjustment for covariates in the two extended models. Table 5B.2 shows that there was a significant association between road traffic noise annoyance and the availability of relative quietness at the least exposed façade, with significantly lower annoyance in a situation with a relatively high difference as compared to a relatively low difference in exposure at the most and least exposed façade. The table shows that the parameter B estimates remain significant and similar in magnitude between the three models, indicating that the effect did not diminish after additional adjustment. Adjusted R Squared of Model 1, 2 and 3 are 0.055, 0.055 and 0.214 respectively. The adjusted R Squared of these same models, but without relative quietness, are slightly lower, with 0.053, 0.053 and 0.212 respectively. The interaction between $L_{den,most}$ and relative quietness was tested. However, this was found to be not significant (results not shown).

Table 5B.2 *Parameter estimates for the contribution of $L_{den,most}$ (dB, continuous) and the difference between $L_{den,most}$ and $L_{den,least}$ (DIF ≥ 10 dB* versus *DIF < 10) in the linear regression model for annoyance score.*

	$B_{Model\ 1}$ (SE)	**$B_{Model\ 2}$ (SE)**	**$B_{Model\ 3}$ (SE)**
$L_{den,most}$	0.101 (0.013) ***	0.100 (0.013) ***	0.099 (0.012) ***
DIF ≥ 10	−0.463 (0.205) *	−0.448 (0.207) *	−0.481 (0.190) *

Model 1: Unadjusted model; Model 2: Adjusted for age, gender, education; Model 3: Full model: Adjusted for age, gender, education, annoyance from neighbor noise and humming noise (e.g., fans). Statistical significance is indicated as usual: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. The numbers B (SE) are the unstandardized regression coefficients, with their standard error (in brackets).

In Figure 5B.3 regression lines are shown for the two subgroups of most and least exposed façade exposure difference (DIF < 10 dB *versus* DIF ≥ 10 dB), for the full model. Results are visualized for the assumption of equal gender distribution, average age, most prevalent education level, and average annoyance score from neighbor noise and humming noise (e.g., fans). The parameter B estimate for $L_{den,most}$ determines the slope of

the regression line, while the parameter B estimate for the difference determines the additional change in annoyance score related to this difference. The horizontal shift in the regression lines, which can be read from the figure by looking at equal annoyance scores, provides an estimate of the difference in "effective noise level" ($L_{den,most}$) between these two groups. The figure shows that the horizontal shift in the regression lines approximates 5 dB, $L_{den,most}$.

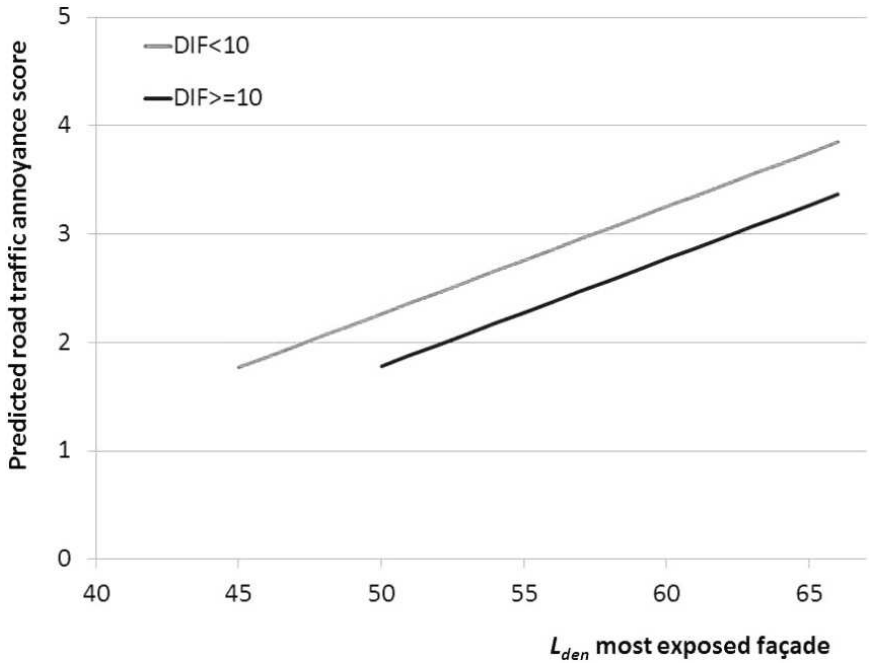

Figure 5B.3 *Road traffic noise annoyance score predicted from $L_{den,most}$ (dB, continuous) and difference between $L_{den,most}$ and $L_{den,least}$ in two categories (DIF < 10 dB* versus *DIF ≥ 10 dB). Results from linear regression analyses.*

5B.3.3 Exposure at the Least Exposed Façade and Annoyance

Table 5B.3 shows the results from linear regression analyses where the annoyance score is predicted from the exposure at the most exposed façade ($L_{den,most}$; dB; continuous) and the least exposed façade ($L_{den,least}$; dB; continuous). A significant association was found between $L_{den,least}$, and annoyance score in the full model. This model adjusted for age, gender, education, and annoyance from neighbor noise and humming noise (e.g., fans), independently of $L_{den,most}$. Adjusted R Squared of Model 1, 2 and 3 are 0.054, 0.054 and 0.213 respectively. In addition, the interaction between $L_{den,most}$ and $L_{den,least}$ was tested. However, this was found to be not significant (results not shown).

In Figure 5B.4, the regression lines are visualized for various levels of $L_{den,least}$, for the full model. The results indicate that for the predicted annoyance score a reduction of 1 dB at the least exposed façade corresponds to a reduction of approximately 0.5 dB at the most exposed façade (*i.e.*, a 5 dB horizontal shift ($L_{den,most}$) in regression lines corresponds to a 10 dB change in $L_{den,least}$ (e.g., from $L_{den,least}$ 45 dB to $L_{den,least}$ 55 dB)).

Table 5B.3 *Parameter estimates for $L_{den,most}$ (dB, continuous) and $L_{den,least}$ (dB, continuous) in the linear regression model for annoyance score*

	$B_{Model\ 1}$ (SE)	$B_{Model\ 2}$ (SE)	$B_{Model\ 3}$ (SE)
$L_{den,most}$	0.073 (0.008) ***	0.073 (0.008) ***	0.069 (0.007) ***
$L_{den,least}$	0.026 (0.017)	0.025 (0.018)	0.035 (0.016) *

Model 1: Unadjusted model; Model 2: Adjusted for age, gender, education; Model 3: Adjusted for age, gender, education, annoyance from neighbor noise and humming noise (e.g., fans). Statistical significance is indicated as usual: $^{+}$ $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. The numbers B (SE) are the unstandardized regression coefficients, with their standard error (in brackets).

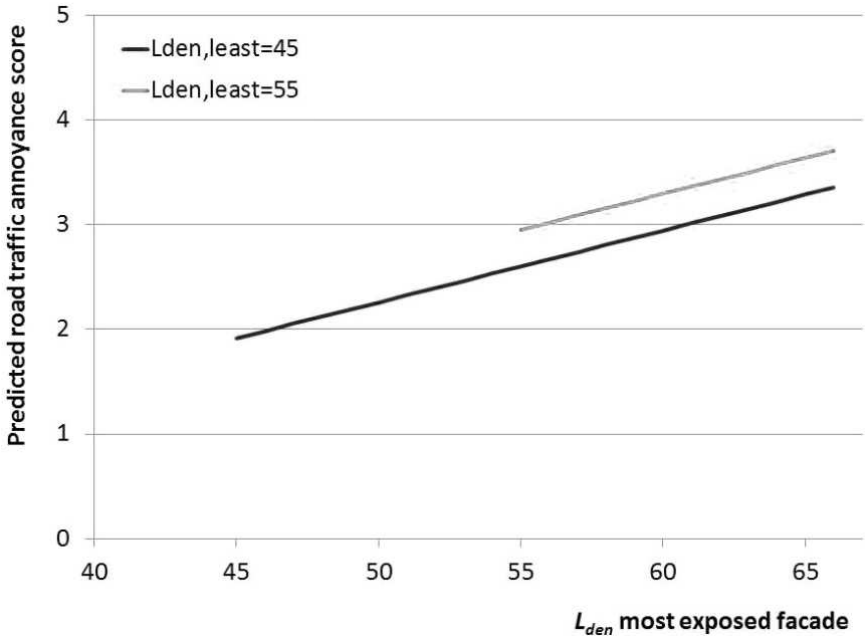

Figure 5B.4 *Road traffic noise annoyance score predicted from $L_{den,most}$ (dB, continuous) and $L_{den,least}$ (dB, continuous). Results from linear regression analyses.*

5B.4 Discussion and Conclusions

The results of this study indicate that there is an association between road traffic noise annoyance and both the availability of *relative* quietness at the least exposed side of dwelling, and the actual exposure level at the least exposed façade itself ($L_{den,least}$), independent of $L_{den,most}$. The road traffic noise annoyance score (at a given exposure level at the most exposed façade) was lower in the group with *relative* quietness at the least exposed façade, expressed as a an exposure difference between most and least exposed façade (DIF ≥ 10 dB). Similarly, results suggested lower annoyance with decreasing noise level at the least exposed façade ($L_{den,least}$). An association between $L_{den,least}$ and annoyance, independent of $L_{den,most}$, indicates not only that *lower* exposures at the least exposed façade may be better for the inhabitants, it also implies that *higher* exposures at the least exposed façade may *increase* adverse effects. In addition, it should be noted that even at *low* values of $L_{den,least}$, adverse effects are still to be expected when $L_{den,most}$ is

high. Similarly, the results on *relative* quietness only indicate a difference in expected road traffic noise annoyance score between the groups with a DIF < 10 dB compared to DIF ≥ 10 dB. However, also at a DIF ≥ 10 dB, at high façade levels (e.g., $L_{den,most}$ = 71 dB, $L_{den,least}$ = 60 dB), exposures are still undesirably high, and on the bases of existing exposure response curves (see e.g. WHO, 2011), still adverse health effects are to be expected (even though people might be (slightly) better off than in a situation with an exposure of e.g., 71 dB on multiple sides). Nevertheless, these results provide further support for the hypothesis that inhabitants exposed to road traffic noise may benefit from a quiet side to the dwelling.

These results are in line with previous studies. Öhrström *et al.* previously investigated the potential benefit of a quiet side to the dwelling amongst 956 individuals aged 18–75 years, within the Soundscape Support to Health research programme (Öhrström et al., 2006). They studied the relationship between having access to a quiet side of the dwelling (defined as a façade with an $L_{Aeq,24h}$ ≤ 45 dB) and a number of adverse noise effects, including annoyance. Results indicated that having access to a quiet side corresponded to a decrease in disturbances by an average of 30–50%. This decrease was estimated to correspond to a reduction in noise level at the most-exposed side of about 5 dB ($L_{Aeq,24h}$). Likewise, de Kluizenaar et al., (2011) studied the association between road traffic noise and the environmental noise annoyance response within two groups: the subgroup with a relatively quiet façade (difference in road traffic noise level between the most and least exposed façade > 10 dB L_{den}), and the subgroup without a relatively quiet façade (difference < 10 dB) (de Kluizenaar et al., 2011). Results suggested annoyance to be less likely in the group with a relatively quiet façade. The recent study of Van Renthergem and Botteldooren provides additional support for a beneficial effect of the presence of a quiet façade at a dwelling (Van Renterghem et al., 2012). This study showed that the absence of a quiet façade (expressed as a difference in road traffic noise level between the most and least exposed façade < 10 dB) leads to a substantial increase of self-reported noise annoyance.

Further and indirect evidence for the potential benefit of a quiet side came from studies that investigated the difference in noise response between respondents having a bedroom facing the traffic source, or facing the noise shielded side. In a study on road

traffic noise annoyance and sleep disturbance in a stratified random sample of 1,000 respondents, Bluhm et al. (2004) reported a lower prevalence of both self-reported road traffic noise annoyance and sleep disturbance for respondents with their bedroom facing a "quiet side" (defined as: not facing the street). Amundsen et al. (2011) estimated the benefit of having the bedroom facing the noise-shielded side of the dwelling on noise annoyance to correspond to a 6 dB noise reduction. In other words, the difference in annoyance between "having the bedroom on the least-exposed façade" *versus* "having the bedroom on the most-exposed façade" was estimated to correspond to an exposure difference of 6 dB in outdoor noise level ($L_{Aeq,24h}$) at the most exposed façade. In line with these findings Gidlöf-Gunnarsson et al., based on field study data obtained for 1,695 respondents, reported a twice as high prevalence of general noise annoyance among residents in dwellings with a balcony/patio oriented towards the railway, and about 1.5 times higher for residents with their bedroom facing the railway (Gidlöf-Gunnarsson et al., 2012). Furthermore, Lercher et al. (2011) reported on the ALPNAP-study, where they found a clear trend of reduced risk of hypertension for participants with their bedroom facing a quiet yard. In addition, Selander et al. (2009) found that risk estimates for myocardial infarction were particularly elevated for participants annoyed by noise mostly in their bedroom. The above results indicate a possible mechanistic pathway through disturbance of sleep, and/or the importance of exposure at the least exposed side (assuming that on average, particularly at higher exposure levels, people tend to sleep at the quiet side if they have the option).

In addition to access to a quiet side as such, the visual and functional quality of the quiet side has been suggested to have an influence. In a previous study, Gidlöf-Gunnarsson and Öhrström studied the influence of the physical environmental quality (degree of naturalness and utilization) of "quiet" outdoor courtyards (defined as $L_{Aeq,24h} \leq 48$ dB, façade reflex included) in a sample of 385 residents (Gidlöf-Gunnarsson et al., 2010). They found that access to a "high quality" quiet court yard was associated with less noise annoyance among the residents. Furthermore, the results of an earlier study by the same researchers have suggested that "better" availability to nearby green areas may decrease the risk of annoyance (Gidlöf-Gunnarsson et al., 2007). Thus, all of the above factors may affect the perceived quality of the least exposed side, and potentially may (positively or negatively) affect its benefit. In the "Quiet Places Project" in Amsterdam,

Booij and van den Berg (2012) also reported the potential importance of the presence of vegetation and other pleasant stimuli, in addition to relative quietness of a place, based on a survey among 809 respondents.

Some limitations should be noted. Since this is an observational study with a cross sectional design, the possibility that a related factor other than road traffic noise was in fact responsible for the observed effect, in theory cannot be fully ruled out. However, as the investigated effect is specifically road traffic noise related, and the least exposed side exposure influences the overall road traffic noise exposure, a causal relationship is plausible. Secondly, while road traffic noise may be assumed to be the dominant source of environmental noise in urban areas, the possibility for inhabitants to "escape" from the noise to a quiet side of the dwelling will also depend on the noise from other sources, which may harm the relative quietness at the back side of a dwelling. Indeed, previous research has shown that noise generated by installations (e.g., fans) at the quiet side of dwellings can cause substantial annoyance and thereby "spoil" the quiet (Persson Waye et al., 2003). Similarly, noise from neighbors may affect the "quietness" at the least exposed side. In view of both issues raised above, we tried in this study to minimize the risk of confounding by adjustment for a number of potential confounders, including education (as an indicator of socio-economic status), age, and gender, as well as the influence of noise from other sources: neighbors and installations (humming noise e.g., fans). However, it should be noted that other potentially important modifying factors, about which unfortunately no information was available, may influence the effect of the quiet side exposure, such as orientation of the bedroom towards the noise source, noise sensitivity, and the visual quality and accessibility of the quiet side.

The study population consisted of a sample of the total Amsterdam city population. Still, the possibility that the generalizability of results to the Amsterdam city population may to some extent have been influenced by selective response cannot be ruled out. Furthermore, it is not known to what extent the inhabitants of the city of Amsterdam may be representative to the general population in The Netherlands or in Europe. Therefore, it would be valuable to investigate the influence of noise exposure at the least exposed side to confirm results in future studies, also in other cities.

In this study, road traffic noise exposure was calculated with The Netherlands' standard calculation method for road traffic noise, SRM2, a method that is comparable to other European engineering methods for road traffic noise modeling. These methods may be further optimized for refined exposure assessment at the noise shielded side of buildings (Salomons et al., 2009). So far however, no such method has (yet) been adopted for noise mapping. Should this limitation have affected the effect estimate, it may be assumed that the actual association is slightly stronger than found. However, this would need to be confirmed in future studies. Furthermore, road traffic data was available for the urban roads with substantial traffic intensities in Amsterdam (including roads typically with a traffic intensity above about 1,000 vehicles per 24 h). In future studies the exposure assessment may be further refined if traffic intensity data will become available also for the smallest roads in the network. Currently, however, this is typically not available at that level of detail. Nevertheless, our results show a clear association between quiet side indicators and the noise annoyance. In this study both detailed information on road traffic noise annoyance as well as objectively assessed road traffic noise exposure levels were available for a large sample of residents (N = 1,967). Road traffic noise annoyance was available on a scale from 0 to 10 (11 point scale), in line with the international recommendation (Fields et al., 2001). The large sample size, together with this detailed information for each resident, may be expected to have increased the power of the analysis.

In large urban areas, access of residents to quietness is important to allow and support restoration needed to recover from the impact of stress caused by daily activities. This is likely to be of particular importance in the immediate living environment, the home. This study provides further support for the hypothesized benefit of quietness at the least exposed façade. Because of the adverse effects of noise exposure on health (WHO, 2011), it is important to avail of practical applicable measures to reduce the impact of exposure for urban residents as much as possible. In urban planning processes, first of all, this needs to be addressed by striving towards low exposure at dwellings in general, starting with the most exposed façade, which still appears to have a higher impact on annoyance. One approach to further improve the noise environment may be the creation of quiet facades to offer an "escape" to the noise for the inhabitants. In existing

situations with high exposure levels, particular attention may need to be paid to dwellings with high exposure at multiple sides.

References

Amundsen AH, Klaeboe R, Aasvang GM. The Norwegian façade insulation study: The efficacy of façade insulation in reducing noise annoyance due to road traffic. J Acoust Soc Am. 2011;129:1381–1389.

Bluhm G, Nordling E, Berglind N. Road traffic noise and annoyance—An increasing environmental health problem. Noise Health. 2004;6:43–49.

Booi H, van den Berg F. Quiet areas and the need for quietness in Amsterdam. Int J Environ Res Public Health. 2012;9:1030–1050.

Dijkshoorn H, Fakiri FE, Janssen A, Ujcic-Voortman J, Verhagen C. Opzet en Evaluatie Dataverzameling Amsterdamse Gezondheidsmonitor 2008 (Design and Evaluation of Datacollection Amsterdam Health Monitor 2008); GGD Amsterdam (Public Health service Amsterdam): Amsterdam, The Netherlands, 2009.

European Commission. Position Paper on Dose Response Relationships between Transportation Noise and Annoyance. EU's Future Noise Policy, WG2-Dose/Effect; Office of Official Publications of the European Communities: Luxembourg, Luxembourg, 2002a.

European Commission, DG Environment. Directive 2002/49/EC of the European Parliament and of the Council. Brussels: EU/DG Environment, 2002b. Available online: http://ec.europa.eu/environment/noise/ (accessed on 27 May 2013).

Fields JM, de Jong RG, Gjestland T, Flindell IH, Job RFS, Kurraf S, Lercher P, Vallet M, Yano T, Guski R, Felscher Suhr U, Schumer R. Standarized general purpose noise reaction questions for community noise surveys: Research and a recommendation. J Sound Vib. 2001;242:641–679.

Gidlöf-Gunnarsson A, Ögren M, Jerson T, Öhrström E. Railway noise annoyance and the importance of number of trains, ground vibration, and building situational factors. Noise Health. 2012;14:190–201.

Gidlöf-Gunnarsson A, Öhrström E. Attractive “quiet” courtyards: A potential modifier of urban residents responses tot road traffic noise? Int J Environ Res Public Health. 2010;7:3359–3375.

Gidlöf-Gunnarsson A, Öhrström E. Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. Landscape Urban Plan. 2007;83:115–126.

Kluizenaar Y de, Salomons E, Janssen SA, van Lenthe F, Vos H, Zhou H, Miedema H, Mackenbach J. Urban road traffic noise and annoyance: The effect of a quiet façade. J Acoust Soc Am. 2011;130:1936–1942.

Lercher P, Botteldooren D, Widmann U, Uhrner U, Kammeringer E. Cardiovascular effects of environmental noise: Research in Austria. Noise Health. 2011;3:234–250.

Miedema HME, Oudshoorn CGM. Annoyance from transportation noise: Relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect. 2001;109:409–416.

Miedema HME, Borst HC. Rating Environmental Noise on the Basis of Noise Maps. In Proceedings of Euronoise 2006, Tampere, Finland, 30 May–1 June 2006.

Miedema HME, Borst HC. Rating Environmental Noise on the Basis of Noise Maps within the Framework of the EU Environmental Noise Directive. In Proceedings of Internoise 2007, Istanbul, Turkey, 28–31 August 2007.

Miedema HME, Vos H. Exposure-response relationships for transportation noise. J Acoust Soc Am. 1998;104:3432–3445.

Öhrström E, Skånberg A, Svensson H, Gidlöf-Gunnarsson A. Effects of road traffic noise and the benefit of access to quietness. J Sound Vib. 2006;295:40–59.

Persson Waye K, Bengtsson J, Agge A, Björkman M. A descriptive cross-sectional study of annoyance from low frequency noise installations in an urban environment. Noise Health. 2003;5:35–46.

Renterghem T van, Botteldooren D. Focused study on the quiet side effect in dwellings highly exposed to road traffic noise. Int J Environ Res Public Health. 2012;9:4292–4310.

Selander J, Nilsson ME, Bluhm G, Rosenlund M, Lindqvist M, Nise G, Pershagen G. Long-term exposure to road traffic noise and myocardial infarction. Epidemiology. 2009;20:272–279.

Salomons EM, Polinder H, Lohman WJA, Zhou H, Borst HC, Miedema HME. Engineering modeling of traffic noise in shielded areas in cities. J Acoust Soc Am. 2009;126:2340–2349.

VROM: Meet-en rekenvoorschrift geluidhinder 2006 (Prescribed measurement and calculation methods for noise annoyance 2006). Staatscourant 1942, 249, 84.

WHO. Burden of Disease from Environmental Noise—Quantification of Healthy Life Years Lost in Europe; Fritschi, L., Brown, L., Kim, R., Schwela, D., Kephalopoulos, S., Eds.; WHO Regional Office for Europe: Copenhagen, Denmark, 2011.

Chapter 6

General discussion

6.1 Introduction

In recent years it has become more broadly recognized that exposure to road traffic noise is an important and persistent environmental health problem, adversely affecting a substantial part of the population in urbanized areas. The most prevalent effects of road traffic noise, annoyance and sleep disturbance, not only in itself have a considerable impact on general well-being, but may also in the long term lead to further adverse health effects. Indeed, environmental noise exposure has been linked to long term health effects in epidemiological studies, including cardiovascular disease (Babisch, 2008; WHO, 2011; Basner et al., 2013).

Advances in Geographic Information Systems (GIS) techniques and exposure modelling, together with the availability of data from large ongoing cohort studies, have provided new opportunities for research into the effects of road traffic related exposure. In recent years an increasing amount of epidemiological studies has become available, providing further support for an association between long term traffic noise exposure and several health endpoints, including cardiovascular morbidity (e.g., reviews by Babisch, 2008; Van Kempen and Babisch, 2012; Babisch, 2014). The majority of studies into adverse effects of traffic related exposures however, have focused on air pollution. The number of large epidemiological studies into the long term effects of road traffic noise, is comparatively limited. These studies are strongly needed, both to further explore the hypothesized mechanism, and to allow the establishment and further refinement of exposure response relationships for cardiovascular endpoints.

Results of previous studies into the long term effects of road traffic noise, in particular the older studies, may to some extent have been distorted by limitations in study population (e.g., small sample size, non-random selection of the sample), exposure assessment (e.g., subjectively assessed exposure), effect measure (e.g., subjectively assessed health status), or in adjustment for confounding. With respect to confounding, combined exposure to road traffic noise and air pollution is one important issue that needs further investigation, gaining increasing interest in recent years. However, the number of studies taking into account both exposures, is still small (Review by Tetreault et al., 2013).

Reducing the adverse effects of road traffic noise is challenging, since the spectrum of measures suitable for local application in residential areas is modest. In addition to exposure at the most exposed façade, exposure at the least exposed façade can affect personal exposure, and thereby the health effects. Reducing exposure at the least

exposed façade may be one useful way to reduce adverse effects of exposure. Insight into the effect of noise exposure at the least exposed façade is needed, to be able to evaluate effectiveness of measures geared towards reducing exposure at the least exposed façade.

The studies described in this thesis were initiated to gain more knowledge about the long term effects of road traffic noise. These studies complement existing knowledge by adding a number of large epidemiological studies on the association between long term road traffic noise exposure and adverse health effects, for a range of key health endpoints within the causal pathway: sleep, hypertension and cardiovascular events. Furthermore, a broad range of potential confounders was taken into account to adjust for confounding, including air pollution, in the studies where cardiovascular endpoints were studied. In addition, the effect of exposure at the least exposed façade of the dwelling was investigated, contributing towards a more complete characterization of personal exposure, and increasing insight in the importance of exposure at the least exposed side.

In this chapter the main findings are summarized, and the interpretation of these findings is discussed. Furthermore, methodological considerations are discussed and recommendations are provided for future research.

6.2 Main findings

The results of the studies described in the preceding chapters strengthen and add to previous insights in a number of ways as briefly discussed below, by Chapter.

6.2.1 Road traffic noise and sleep

In Chapter 2, the association was investigated between long-term road traffic noise exposure at the home during the night, and two indicators of sleep problems: getting up tired and not well rested in the morning (morning tiredness), and the use of sleep or tranquilizing medication (medication use). Cross sectional analyses was performed in the GLOBE study, a large population based cohort including over 18 000 respondents. Road traffic noise exposure was significantly associated with morning tiredness. Even though the prevalence of medication use was higher at higher noise levels, this association was not significant after adjustment for potential confounders. The latter implies that, in this

study, no evidence was found of an effect of road traffic noise on medication use. The results of this study add to previous knowledge, by showing that long-term road traffic noise exposure during night time is associated with self-reported morning tiredness, and supports the hypothesis that night time road traffic noise exposure at home may, through affecting sleep quality, have after-effects the following day. A strong feature of this study is that morning tiredness and noise exposure were assessed independently, and the sleep question did not refer to noise. Thus, the results indicate that road traffic noise exposure plays a role amongst other possible causes of sleep problems, a conclusion that cannot be drawn based on analyses of data from community surveys, with questions explicitly focused on *noise related* sleep disturbance alone.

6.2.2 Road traffic noise and hypertension

In Chapter 3, the association between long-term exposure to road traffic noise and prevalence of hypertension was investigated, taking air pollution into account. Cross sectional analyses was conducted in a large random sample of more than 40 000 inhabitants of Groningen City in which data was available on self reported hypertension, and in the PREVEND cohort of 8 592 subjects, for which more detailed information was available, including blood pressure measurements.

While there was a significant association between exposure to road traffic noise and hypertension in the unadjusted models, no significant association was found between road traffic noise exposure and hypertension after adjustment for potential confounders. Results indicate there may be a moderating effect of age, with strongest and significant associations in the group of subjects aged between 45 and 55. Furthermore, associations seemed to be stronger at higher noise levels. In the city of Groningen sample, in addition to the middle-aged, a significant association was found for subjects exposed to higher noise levels ($L_{den} \geq 55$ dB). This study shows that it is plausible that road traffic noise is associated with hypertension, particularly in the high exposure range. In addition, as these associations did not disappear in the extended models with additional adjustment for air pollution, the outcomes of this study suggest that the association between road traffic noise exposure and hypertension cannot be explained by air pollution. To our knowledge, this was the first study in which the effects of road traffic noise exposure on the prevalence of hypertension were studied in such a large random population based sample, with objective measures for road traffic noise exposure and — in the PREVEND cohort — objectively assessed hypertension (blood pressure measurements).

Furthermore, at the time of this study, to our knowledge, this was the first study into the effects of road traffic noise exposure, taking potential confounding by air pollution into account.

6.2.3 Road traffic noise, air pollution and cardiovascular events

In Chapter 4, the association between road traffic noise exposure and the incidence of hospital admissions for ischemic heart disease events (IHD: ICD9 410–414) or cerebrovascular disease events (CVE: ICD9 430–438) was investigated, taking air pollution into account. Prospective analyses were performed within the large population based GLOBE cohort.

Subjects with a cardiovascular event during follow up, on average, had higher road traffic noise (L_{den}) and air pollution exposure at the home. However, after adjustment for confounders (age, sex, Body Mass Index, smoking, education, exercise, marital status, alcohol use, work situation, financial difficulties), no significantly increased risk of cardiovascular events with increasing exposure levels was shown. It was further investigated if subjects with a history of cardiovascular disease and the elderly may be susceptible groups for road traffic noise or air pollution exposure. No conclusive evidence was found for the hypothesis that these groups may be susceptible groups. However, relative risk estimates for road traffic noise exposure seemed highest in the subgroup with a history of cardiovascular disease, and relative risk estimates for air pollution seemed highest in the subgroup of elderly. This study contributes towards increasing insight in cardiovascular health effects of road traffic noise, taking air pollution into account as a potential confounder. Furthermore, the prospective nature of this study is a strong feature. In a prospective study subjects have not yet developed the outcome of interest at the start of follow up. Large prospective studies is this research area are still extremely rare.

6.2.4 A quiet façade: reducing the adverse effects of noise exposure?

In Chapter 5, the influence of road traffic noise exposure at the least exposed side on noise annoyance was investigated in two large population studies. The first study investigated the effect of a relatively quiet façade on the annoyance response in the large population based GLOBE study in the Eindhoven region, the Netherlands. To

further quantify the effects, and to confirm results in a different urban area, data analyses were also performed in a population based survey in Amsterdam, the Netherlands.

The first study revealed that annoyance was less likely in the subgroup with a relatively quiet façade (difference between road traffic noise level at the most and at the least exposed façade > 10 dB), as compared to the subgroup without a relatively quiet façade. This study, to our knowledge, was the first study to investigate this effect in such a large population based sample (N ~ 18 000). The results, because of the size and random selection of the study sample, may be assumed representative for a larger urban area, with its broad variety of building structure and of potential orientations of individual buildings towards the noise source. However, while being an important step in strengthening the evidence for the hypothesized beneficial effect of a 'quiet side', this study allowed only a small step towards further quantification of effects, because of the less specific and dichotomous nature of the noise annoyance question. In the second study, road traffic noise annoyance was available on an 11 point scale. This allowed more detailed analyses, including additional investigation of the effect of road traffic noise level at the least exposed side ($L_{den,least}$). The estimated effect size expressed in change in $L_{den,most}$ approximated 5 dB, both for the difference between the two subgroups (DIF >= 10 dB and DIF <10 dB), and for a 10 dB change in $L_{den,\ least}$. While exposure at the most exposed façade still appears to be the dominant predictor of road traffic noise annoyance, results indicate that in addition, noise exposure at the least exposed side independently influences this effect. These studies provide further support for the hypothesized benefit of reducing exposure at the least exposed façade. Furthermore, results contribute to the quantification of this effect.

6.3 Methodological considerations

This section discusses methodological limitations that have to be considered when interpreting the results of observational studies in general, and hence, also the studies described in this thesis. Strengths and limitations of the specific studies have been described in detail previously in each of the dedicated chapters (Chapter 2 to Chapter 5), and therefore will not extensively be repeated here.

6.3.1 Study design

As noted in the introduction, investigating the relationships between road traffic noise and health endpoints is challenging. Some of the main reasons are discussed here.

Challenges in studying effects of long term road traffic noise exposure
While there is a strong and *direct* relationship between road traffic noise exposure and road traffic noise annoyance (or road traffic noise induced sleep disturbance), the relationship between long term exposure and *indirect* health effects, such as after-effects of disturbed sleep (in this thesis: e.g., morning tiredness), and clinical health endpoints (in this thesis: e.g., hypertension or cardiovascular events) is typically weaker and therefore more difficult to identify. Moreover, the risk attributable to noise exposure is small as compared to the risk attributable to other, dominant risk factors. Well known prominent risk factors for cardiovascular health effects for example, include e.g., lifestyle related factors (such as physical activity, smoking and Body Mass Index), as well as e.g., demographic factors (such as age). These risk factors usually play a much stronger role than the exposure under study. This combination of a comparatively small exposure attributable risk, together with the presence of dominant risk factors, typically complicates isolating an effect of noise exposure. Therefore, a study design is needed which allows identification of a contribution of environmental exposures to these health effects amongst other risk factors. Such analyses first of all require a large study population, preferably with a prospective design. A prospective study design allows evaluation of the question of temporality: do participants with higher exposure at the start of follow up have an increased risk for the development of the health outcome of interest during the follow-up? The studies described in the previous chapters, were all carried out in large population based studies, two of which were large prospective cohort studies. The prospective nature of a cohort study allows studying the relationship between an exposure and the development of an outcome. Strong features of the studies described here include the large sample size, the population based design, and the prospective nature of the cohort studies.
Secondly, accurate information is needed on the individual noise exposure, preferably objectively assessed. Exposure to road traffic noise at the façade of the dwelling of each respondent was objectively assessed by model calculation. This is an improvement as compared to subjectively assessed indicators of exposure (e.g., by questions referring to the intensity or type of nearby roads), as well as compared to exposure assessment with lower spatial resolution (e.g., at street level, or coarse grid level).

Third, adequate information is needed not only on the health endpoints of interest, but also on the above mentioned other risk factors. Particularly, information is needed on those risk factors that may be associated with the investigated exposure and thereby confound the relationship that is being investigated. In the described studies, data was collected not only on the health outcomes studied, but also on a broad range of potential confounders. Hence, in the analysis we could adjust for these covariates. One potential confounder many previous studies have not been able to adjust for, is air pollution, which was taken into account in the studies into cardiovascular outcomes described in this thesis.

Limitations and strengths of a population based design

A population based design can be less suitable to study rare health outcomes, since the prevalence or incidence of an endpoint under study has to be sufficiently large to provide sufficient power to allow investigation of relationships. Furthermore, in the general population only a proportion of the residents have a high noise exposure level at their home, while the risk for cardiovascular health effects is expected to increase mainly at higher levels (although newer studies do not suggest a threshold for effects) (e.g., Babisch, 2008; Babisch, 2014). This may partly explain why, in the study investigating the association between noise exposure and cardiovascular events, even though risk estimates seemed elevated, these associations were not significant in the adjusted models, while more clear indications were found of an association with hypertension and sleep disturbance (morning tiredness), respectively. However, a very important strong feature of the population based design of the studies described here, is a better generalizability of findings, as further elaborated under 6.2.4.

Observational studies: Association or causality

While observational studies can identify statistical associations, conclusive evidence of causality cannot be obtained. Observed relationships are not always necessarily causal. Factors identified as being associated to the health effect under study, may be indicators for (other) underlying causes. Even in studies with a prospective design, while results may show that exposure *preceded* the disease, this does not necessarily prove that exposure *caused* the disease. However, epidemiological studies are essential and complement laboratory and field studies, as they allow investigation of associations between hypothesized risk factors and long term health effects under 'real life' conditions in the general population, which clearly cannot easily be achieved in any other way. In the epidemiological studies described here, data could be analyzed for large

populations, with broad spectrum of available variables, both in terms of exposures, and in health outcomes, and in potential confounding or modifying factors.
To aid further evaluation of the plausibility of causality, in 1965 Bradford Hill proposed a list of 9 considerations, now commonly referred to as the "Bradford Hill criteria". These criteria included: 1) strength of the association; 2) consistency (is it more frequently observed in different studies using different techniques, in different places, circumstances and time); 3) specificity; 4) temporality; 5) biological gradient (or dose-response curve); 6) plausibility (is there a plausible mechanism between cause and effect), 7) coherence (cause and effect interpretation should not seriously conflict with known facts); 8) experimental evidence (e.g., by investigating the effect of an intervention), and 9) analogy (Bradford Hill, 1965). These criteria were not developed to 'reject' or 'prove' the causality of associations, however they can be helpful to evaluate possible causality. These criteria are further discussed in relation to noise effects in section 6.3 (Interpretation of the findings).

6.3.2 Bias

Bias may arise from systematic error in the assessment of a variable. Information bias may get introduced for example with respect to the health outcome of interest. By illustration, in studies specifically focused on the effects of noise, when participants may be aware of the noise focus of the study, the answers concerning the effect studied (e.g., sleep disturbance) may be biased by the attitude of a respondent towards the noise source. In the studies described here, exposure was retrospectively and objectively assessed, and thus the answers to the questionnaires are not likely to be biased by such influence.

Information bias may also occur when the exposure assessment is subject to error. For road traffic noise and air pollution, systematic misclassification can be introduced for example when low resolution spatial data is used (e.g., long term air pollution exposure based on the neared monitoring station, or road traffic noise exposure derived from a noise map with a large grid cell size). Typically there can be strong gradients near sources, particularly in urban areas where noise transmission or air pollution dispersion can be affected by characteristics of the built environment (e.g., screening by buildings or noise screens etc.). In the studies described here, the risk of such misclassification was minimized by objective assessment of exposure by modelling with high spatial resolution: at the facade of the dwellings.

Finally, it has to be noted that it cannot be excluded that exposure response functions may be affected by self-selection of people, with people who are less bothered by noise comparatively more frequently choosing to live (or stay) in noise exposed areas. In addition, dwellings exposed to very high noise levels may more likely have undergone acoustical insulation measures to reduce noise exposure inside the dwelling. In addition, previous studies have indicated that the choice of the location of the bedroom away from the noise source, may reduce the adverse effects of noise (e.g., Amudsen et al., 2011; Babisch et al., 2012; Gidlof-Gunnarsson et al., 2012). It may be assumed that particularly in high noise exposed areas, people are more likely to choose to sleep at the noise shielded side of the dwelling, if they have this opportunity. Thus, effects of high noise exposure may be partly masked by such selection mechanisms. If this would have affected the results in any way, it may be assumed that the actual associations may be stronger than the ones found.

6.3.3 Confounding

As previously noted, investigating the health effects of long term road traffic noise exposure, requires identification of a potentially small attributable risk amongst other dominant risk factors. This underlines the importance of adequate adjustment for potential confounding. In epidemiological studies in general, one should always be aware that the possibility of residual confounding due to unknown or unmeasured risk factors cannot be fully ruled out. When studying the long term effects of traffic related exposures, the possibility of confounding by spatial correlation between the traffic related exposure of interest and various population characteristics needs specific attention. Traffic exposures may spatially correlate with characteristics, which in turn may be related to the health effect of interest. Exposure has for example previously been found to be somewhat higher in certain age groups, and in low income areas, although not consistently for all different exposures (e.g., Van den Hooven et al., 2012; Kruize et al., 2007). Such correlations may differ between populations (in strength and direction), depending on characteristics of the study area (e.g., size, country).

Previous studies may in some cases have been limited in the ability to adjust for these factors. One prominent potential confounding factor, which has not been taken into account in many previous studies, is air pollution. This may be considered as a (potentially serious) limitation: Not only are long term exposure to road traffic noise and air pollution known to be spatially related (e.g., Allen et al., 2009; Can et al., 2011;

Foraster et al., 2011), but also there is evidence to support a causal relationship with cardiovascular health effects for both exposures (e.g., Brook et al., 2010; Basner et al., 2013). Only in recent years this has become a topic of growing attention. While over the last few years, since the publication of the study on hypertension described in this thesis (de Kluizenaar et al., 2007), a number of epidemiological studies have come available into the effects of combined exposure, the number such studies is still limited (e.g., Beelen et al., 2009; Selander et al., 2009; Review by Tetreault et al., 2013).

In the studies described in this thesis, to minimize the risk of bias by confounding, in the adjusted models a wide range of potential risk factors was taken into account, including demographic, socio-economic and life-style characteristics. The studies on cardiovascular effects additionally adjusted for air pollution in the extended models.

6.3.4. Generalizability

Generalizability is an issue of concern, not only in laboratory or field studies, but also in epidemiological studies. It is always unclear to what extent results found in studies may be generalized to other populations, other places and other conditions. Noise data reported by the EU member states, presented by the European Environment Agency (EEA) and the European Topic Centre on Spatial Information and Analysis (ETC SIA) for example, indicate that the percentage of the population exposed to high road traffic noise levels living in the large urban agglomerations in the Netherlands, is still (relatively) modest, as compared to certain other European large urban agglomerations, including e.g., Paris, Lyon, Barcelona, Prague, Bratislava, Budapest and Warschau (*http://noise.eionet.europa.eu/about.html*). The lower percentage highly exposed, may (in combination with the comparatively small effect of noise exposure between other dominant risk factors) in part explain why some associations were not found significant in the study described in Chapter 4. In general, replication of findings from epidemiological is needed in other populations, cities and/or countries, and conditions. Particularly in studies where the sample is drawn from a small area (e.g., a selection of streets, or a single neighborhood), or from a particular subgroup in the population (e.g., university students), this may limit the ability to generalize findings to the general population. Because the study populations of the studies described here, each consisted of a population based sample of a larger urban area (a region or city: The Eindhoven region, the city of Groningen and Amsterdam), these may be expected to better reflect an 'average' urban population. Furthermore, the broader range of exposure levels

typically observed within urban areas is covered this way. In addition, the different dwelling types and dwelling orientations towards the road source commonly present in an urban area is better represented. Thus, the population based design of the studies described here contributes to better generalizability of findings.

6.4 Interpretation of the findings

6.4.1 Road traffic noise and sleep disturbance

In the recent international effort to estimate the burden of disease by environmental noise exposure, the World Health Organization (WHO) estimated the annual amount of healthy life years lost to exceed one million in Western Europe. The disturbance of sleep was identified as the main contributing factor, followed by annoyance (WHO, 2011). For these estimates the existing exposure response curves (Miedema and Vos, 2007; Miedema and Oudshoorn, 2001) were applied. However, while the relationship between night time transportation noise exposure and self-reported *noise related* sleep disturbance is well established (Miedema and Vos, 2007), less is known on the after effects of night time road traffic noise exposure in the general population.

Results of this thesis add to previous insights by showing a relationship between long term exposure to road traffic noise at the home and morning tiredness ("in general getting up tired and not well rested in the morning"), an 'after-effect' of disturbed sleep. Tiredness in the morning is one of the commonly known consequences of reduced sleep quality during the night (e.g., Porkka-Heiskanen et al., 2013). This association between road traffic noise exposure and morning tiredness (as 'after effect' and as indicator of reduced sleep quality) is an important finding in itself, because of its impact on general well-being. Furthermore, it is an important finding because of its potential adverse health effects in the long term. This will be further discussed in 6.3.2.

6.4.2 Road traffic noise and cardiovascular effects: sleep as a pathway

As discussed in the introduction of this thesis, several pathways have been proposed through which exposure to environmental noise in the long term may lead to adverse cardiovascular health effects, one of which is through the disturbance of sleep. It is increasingly recognized that (chronic) sleep deficit may lead to severe adverse health

effects (e.g., Leineweber et al., 2003; reviews by Cappucio et al., 2010a; Cappuccio et al., 2011: Guo et al., 2013; Meng et al., 2013). The insight that inadequate sleep may cause adverse health effects in the long term, is not new. Support for this hypothesis comes from a large number of both experimental and epidemiological studies. Sleep deficit has been linked with changes in a broad range of cardiovascular risk markers both in experimental and epidemiological studies. Furthermore, epidemiological studies have associated sleep loss to several adverse health outcomes, including hypertension and cardiovascular disease. Current insights will be briefly discussed here.

Sleep and cardiovascular risk factors

An example of experimental studies showing a relationship between sleep restriction and cardiovascular risk factors in healthy volunteers is the study by Spiegel et al. (1999). They showed, in an experimental study in young men, an adverse effect of sleep restriction on metabolic and endocrine function (glucose tolerance, thyrotropin concentration, cortisol and sympathetic nervous system activity, respectively). In recent years, a number of reviews have been published that focused on the adverse physiological effects of reduced sleep (e.g., Faraut et al., 2012; Mullington et al., 2009; Knudson et al., 2007; Meerlo et al., 2008, Porkka-Heiskanen et al., 2013; Van Cauter et al., 2008). Based on a review of controlled sleep restriction laboratory studies, Faraut et al. (2012) reported evidence for adverse effects on systemic immune and inflammatory markers after sleep loss. Mullington et al. (2009), in a review of experimental studies in healthy individuals, reported evidence for sleep loss induced alterations in established cardiovascular risk factors, including changes in autonomic function, endocrine and metabolic changes, blood pressure, inflammatory and coagulatory changes, in directions recognized as increasing cardiovascular risk. Knutson et al. (2007) reported that available laboratory and epidemiological studies provide support for adverse effects of sleep loss on glucose metabolism and hormone levels (leptin and ghrelin) involved in appetite regulation, as well as on energy expenditure. Based on a review of existing animal studies into the effects of *chronic* sleep restriction, Meerlo et al. (2008) concluded that results indicate that effects do not seem to be restricted to short-term effects alone. There are indications that in the long term alterations in brain- and neuroendocrine systems may occur, which may sensitize organisms to stress-related disorders, and increase cardiovascular risk.

Sleep and hypertension

Further support for the hypothesis that chronic sleep deficit may lead to adverse cardiovascular health effects in the long term, comes from epidemiological studies. Cappucio et al. (2007), for example, found that sleep deprivation was associated with a higher risk of hypertension in women, both in cross-sectional as well as prospective analyses of data of the Whitehall II Study, a cohort of British civil servants. In line with this finding, Gottlieb et al. (2006) found that a 'usual sleep duration' shorter than the median of 7 to 8 hours was associated with an increased prevalence of hypertension, in a cross sectional analyses of data from the Sleep Heart Study. In recent years a number of reviews have been published, that support an association between short sleep duration and hypertension (e.g., Knutson, 2010; Calhoun and Harding, 2010; Guo et al., 2013; Meng et al., 2013; Palagini et al., 2013). In a review of observational studies on the relationship between sleep duration (or quality) and 'cardiometabolic' disease risk, Knutson (2010) reported that short sleep duration (typically < 6 h per night) was associated with prevalence of hypertension, and that these results are supported by several (but not all) prospective epidemiological studies.

Counterintuitively, also an association with *longer* sleep duration has been reported (e.g., Gottlieb et al., 2006; review by Knudson et al., 2010). This association however, has been widely discussed and should be interpreted with caution. Several authors note that, to date, no biological mechanism has been identified to explain this association frequently found in observational studies (e.g., reviews by Knutson, 2010; Meng et al., 2013; Guo et al., 2013), and that the possibility of causal bias cannot be excluded (Gottlieb et al., 2006). Associations between sleeping longer and lifestyle factors (including e.g., less physical activity, increased alcohol use), low socio economic status, as well as depression have been reported (Gottlieb et al., 2006; reviews by Knutson, 2010; Meng et al., 2013). Furthermore, Knutson (2010) notes that there are indications from studies in which objectively (wrist actigraphy) measured and self-reported sleep duration were compared, that reporting bias may in part explain this association, with 'long sleepers' only spending more time in bed without actually physiologically sleeping longer. The author speculates that this may be explained by underlying sleep disorder or pathology. Indeed, more recent reviews and meta-analyses, evaluating epidemiological studies into the relationship between sleep duration and hypertension incidence, report a significant association between short sleep duration and hypertension incidence, but less to no evidence for an association with long sleep duration from prospective studies (e.g., Guo et al., 2013; Meng et al., 2013). Meng et al. (2013), in a review and meta-

analysis restricted to prospective studies, even report a tendency towards *decreased* risk of hypertension incidence with longer sleep duration (Meng et al., 2013).

Sleep and cardiovascular disease

Furthermore, an increasing amount of epidemiological studies support the existence of an association between long term sleep deficit and cardiovascular disease, including coronary heart disease and stroke (e.g., Leineweber et al., 2003; Chandola et al., 2010; Kronholm et al., 2011; review by Cappucio et al., 2011) and all-cause mortality (review by Cappucio et al., 2010b). For example Leineweber et al. (2003), found a significant association between poor sleep and recurrent events of coronary heart disease in prospective analysis of the Stockholm Female Coronary Risk Study. They reported a similarly increased risk for 'Not waking up well-rested'. Prospective analyses of data from the Whitehall II cohort, showed an association between short sleep and coronary heart disease. Interestingly, this association was most evident among participants who reported some extent of sleep disturbance (Chandola et al., 2010).

The studies described above from the field of sleep research provide support for the plausibility of disturbed sleep as one potential pathway linking night time noise exposure to hypertension and cardiovascular disease.

6.4.3 Road traffic noise and hypertension

The association between road traffic noise and hypertension was investigated. Results from analysis of data of the PREVEND cohort study presented in this thesis in Chapter 3, indeed provide some support for the hypothesis of an association between long term road traffic noise exposure at the home and hypertension. After adjustment for confounders including air pollution, significant associations between road traffic noise exposure at the home and hypertension were found in the middle-aged, and in the higher exposure range.

In recent years, an increasing amount of studies have been performed that investigated the association between environmental noise and hypertension, for different source types, including road traffic noise (e.g., Bluhm et al., 2007, Barregard et al., 2009; Belojevic et al., 2008; Bendokiene et al., 2012; Bodin et al., 2009; Chang et al., 2011a; Jarup et al., 2008; Sørensen et al., 2011a) and aircraft noise exposure (e.g., Floud et al., 2011 ; Greiser et al., 2007; Jarup et al., 2008). Furthermore, a number of recent studies have focused on the association between occupational noise exposure and hypertension

(Chang et al., 2011b; Chang et al., 2013; Hwang et al., 2012, Stokholm et al., 2013; Tomei et al., 2013; Review by Tomei et al., 2010). In addition, recently one study investigated the association between individual noise exposure (using personal noise dosimeters) and hypertension (Weinmann et al., 2012).

The main results of the above mentioned studies focusing on road traffic noise, are briefly summarized here. The majority of studies, suggested an association between road traffic noise and hypertension, although not all (e.g., Sørensen et al, 2011a). Bluhm et al (2007) found a significant association between road traffic noise and self-reported physician diagnosed hypertension in a sample of 667 respondents of a postal questionnaire. Barregard et al (2009) found a significant association between road traffic noise and self-reported physician diagnosed hypertension in a sample of 1 953 respondents of a postal questionnaire. Belojevic et al (2008) reported a significant association between road traffic noise and arterial hypertension in men, but not in women, in a sample of 2 803 residents of Belgrade. Bendokiene et al (2012) reported an association between road traffic noise exposure in a sample of 3 121 pregnant women, which was significant only in the subgroup of women aged between 30 and 45, at higher noise levels (> 61 dB). Bodin et al (2009), based on analyses of a sample of 24 238 adults of a public health survey from Southern Sweden, reported an association which seemed more pronounced at higher exposure categories as well as in the middle aged. Chang et al (2011a) studied the association between road traffic noise exposure and prevalence of hypertension in a sample of 820 respondents of a face to face survey in selected study areas within the city of Taichung, Taiwan. They reported an association between noise exposure and self-reported physician diagnosed hypertension. Road traffic noise levels in this city by far exceeded levels typically found in European studies. Jarup et al (2008) found an association between road traffic noise exposure during the day and risk of hypertension, which was stronger in men. Furthermore, they reported an association between night time aircraft noise and hypertension, based on blood pressure measurements in a sample of 4 861 persons who had lived near one out of six major European airports 5 year or longer. Sørensen et al (2011a) found an association between systolic blood pressure and road traffic noise levels in men, but no association for diastolic blood pressure nor for self-reported hypertension, based on analyses of a sample of 44 083 participants in a population based cohort.

In 2012, a meta-analysis was performed, in which the results of 24 studies published between 1970 and 2010 were included to derive a quantitative exposure-response relationship. This effort revealed a small but significant odds ratio of 1.034 (95 % CI

1.011–1.056) for a 5 dB increase in road traffic noise level. From this analysis it was not possible to draw conclusions on the existence of a threshold value for this relationship (Van Kempen and Babisch, 2012).

In line with the findings for road traffic noise, several studies focusing on aircraft noise have reported an association between exposure and hypertension, or use of anti-hypertensive medication (e.g., Eriksson et al., 2007; Floud et al., 2011; Greiser et al., 2007; Jarup et al., 2008; Rosenlund et al., 2001; Knipschild, 1977). Similarly, studies into the effects of occupational noise exposure have reported significant associations with hypertension (Hwang et al., 2012; Chang et al., 2013; Tomei et al., 2013; review by Tomei et al., 2010), although not consistently (e.g., Stokholm et al., 2013). In 2002, Van Kempen et al. performed a meta-analysis in which they already showed a significant association of both aircraft noise and occupational noise exposure with hypertension, with relative risks of 1.14 (95 % CI: 1.01–1.29) and 1.26 (1.14–1.39), respectively. In 2009, an updated meta-analysis was published on the association between aircraft noise and hypertension. While providing an estimate based on the meta-analysis, the authors note however, that the resulting estimated exposure-response function should still be viewed as preliminary, because of large methodological differences between studies and lack of continuous noise data presented in available studies (Babisch and Van Kamp, 2009).

A totally different and rather uncommon approach in investigating noise effects, was followed in the study by Weinmann et al (2012), who assessed individual noise exposure (regardless of source) by personal dosimeters. They found an association between night time noise and hypertension. For day time noise, they did not find an association, however, perhaps not surprisingly: The authors note as a limitation of their approach, that personal dosimeters also capture sounds produced by the participants themselves, including for example their own speaking sound. This may have affected results particular for the day time, when people are awake and active.

6.4.4 Road traffic noise and cardiovascular disease events

While significant associations were found between road traffic noise exposure and both morning tiredness and hypertension, in our study, no conclusive evidence was found for an association with ischemic heart disease (IHD) or cerebrovascular disease events. However, in view of the increasing body of evidence from the international literature

supporting an association between road traffic noise and cardiovascular disease, as discussed in this section, it is likely that such effects exist.

In the eighties, nineties and beginning of this century a range of epidemiological studies was published investigating the relationship between road traffic noise and ischemic heart disease events, including myocardial infarction (Babisch et al., 1988; Babisch et al., 1993; Babisch et al., 1994; Babisch et al., 1999; Babisch et al., 2003; Babisch et al., 2005). Results from these studies provided some support for the hypothesis of an association between road traffic noise exposure and IHD events, with significant odds ratios for subgroups (Babisch et al., 2005), but results were inconsistent and evidence was still limited. These early studies were included in a first meta-analysis and quantification of an preliminary exposure-response function. This meta-analysis reported an increase in risk with increasing noise levels above 60 dB(A) (Babisch, 2008). However, confidence intervals were wide and it was noted that this should be considered a preliminary exposure-effect estimate, which would need regular updating as results from new studies would become available. In recent years, a number of epidemiological studies have been performed investigating the relationship between environmental noise exposure, adding to insights from earlier studies (e.g., Selander et al, 2009; Beelen et al., 2009; Eriksson et al, 2012; Sørensen et al., 2012; Selander et al., 2013).

Selander et al (2009) investigated the association between road traffic noise and myocardial infarction in a population based cohort with 3666 participants. They reported a non-significant odds ratio of 1.12 (95 % CI: 0.95–1.33) for road traffic noise level exceeding 50 dBA. After exclusion of persons with hearing loss or exposure from other noise sources, they found a significant odds ratio of 1.38 (95 % CI: 1.11–1.71), after adjustment for confounders including air pollution. Beelen et al (2009) studied the association between air pollution, road traffic noise and cardiovascular mortality in the large ongoing Netherlands Cohort Study on Diet and Cancer (N = 120 852). They reported increased cardiovascular mortality in the highest noise category (> 65 dB(A)), with a relative risk of 1.15 (95 % CI: 0.86–1.53) for IHD and 1.99 (95 % CI: 1.05–3.79) for heart failure mortality respectively. After additional adjustment for both air pollution and traffic intensity on the nearest road, risk estimates decreased. Eriksson et al (2012) analyzed Swedish survey data (N=2498) and reported an association for railway noise with self-reported doctor's diagnosed cardiovascular disease, but not for road traffic noise. Sørensen et al (2012) studied the association between road traffic noise and myocardial infarction in a population based cohort (N = 57053) and reported a significant association with an incidence rate ratio of 1.12 (95 % CI: 1.02–1.22) per 10 dB increase in

noise. Based on analysis of data from this same cohort study, a significant association was reported for stroke incidence (Sørensen et al, 2011b). Selander et al (2013), in analyses of data from a population based case-control study (N = 3050), found an association between road traffic noise and myocardial infarction with an odds ratio of 1.23 (95 % CI: 1.01–1.51). Furthermore, they added to previous findings by showing that exposure to a combination of road traffic noise, occupational noise and job strain increased the risk for myocardial infarction substantially, with an odds ratio of 2.27 (95 % CI: 1.41–3.64).

In 2014, a meta-analysis was performed on the association between road traffic noise and coronary heart disease events. This meta-analysis provided an update of the earlier preliminary quantification of the exposure-response function, with a significant pooled estimate of the relative risk of 1.08 (95 %CI 1.04–1.13) per 10 dB increase in road traffic noise level (Babisch, 2014).

Further support for an association between noise exposure and cardiovascular morbidity came from occupational noise studies (e.g., Davies et al., 2005), aircraft noise studies (e.g., Huss et al., 2010), and a large study (N = 445 868) on total transportation noise (road traffic, railway and aircraft) and coronary heart disease mortality (Gan et al., 2012).

6.4.5 Cardiovascular effect of road traffic noise: Likelihood of causality

As noted in section 6.2, while observational studies can show associations, this does not necessarily prove causality of the association. In general, it is therefore essential to further evaluate this likelihood.

What complicates studying the long term health effects of environmental noise, is that the added risk attributable to exposure is small as compared to other prominent risk factors (including lifestyle related factors such as e.g., Body Mass Index, smoking, physical inactivity). This brings us to the first point: '*Strength*' of the association. Meta-analyses show the effect is in the order of magnitude of percentages: For example, for the relationship between road traffic noise and hypertension the meta-analyses by Van Kempen and Babisch (2012) reports an estimated odds ratio of 1.034 (95 % CI 1.011–1.056) for a 5 dB(A) increase in road traffic noise level, while for the coronary heart disease the meta-analysis by Babisch (2014) reports a significant pooled relative risk estimate of 1.08 (95 % CI: 1.04–1.13) per 10 dB(A) increase. Thus, the observed

association is slight, but as Bradford Hill (1965) notes: 'there are many occasions in medicine when this is in truth so'. However, as the meta-analyses conclude, there is a growing body of evidence to support that the relationship between road traffic noise and both hypertension and coronary heart disease events is consistent (Van Kempen and Babisch, 2012; Babisch, 2014). Thus, it may be concluded that there is an increasing amount of support for the second characteristic of the list: '*Consistency*'. Third on the list is '*Specifity*'. The likelihood of causality increases if associations are found for specific exposures and specific outcomes, with no other likely explanations. This aspect is hard to evaluate in the field of environmental exposures and cardiovascular effects. Cardiovascular disease has a broad range of well-known other risk factors that may contribute to its development. However, aircraft noise studies (e.g., Hansell et al., 2013; Correira et al., 2013; Floud et al., 2013; reviews by Van Kempen et al., 2002; Babisch and Van Kamp, 2009) and occupational noise studies (e.g., review by Tomei et al., 2010) provide some support for this feature. A fourth aspect is '*Temporality*': Does the exposure precede the disease? Such insight may be obtained from prospective studies. The number of large prospective studies in this field is still limited. However a number of recent prospective studies have supported associations between transportation noise exposure (aircraft and road traffic noise, respectively) and cardiovascular outcomes including systolic blood pressure, hypertension, myocardial infarction and stroke (Eriksson et al., 2007; Eriksson et al., 2010; Huss et al, 2010; Sørensen et al., 2011b, Sørensen et al. 2012), between proximity to road traffic and myocardial infarction (Hart et al., 2013), and between occupational noise exposure and hypertension (Chang et al., 2013). However, results were not always consistent. For example, while prospective studies by Eriksson et al. (2007) and Eriksson et al. (2010) reported a significant association between aircraft noise and hypertension, a prospective study by Sørensen et al. (2011a) could not confirm such association for road traffic noise. Huss et all (2010) reported an association between aircraft noise and mortality from myocardial infarction but not for other causes (including stroke), while the large prospective study by Sørensen et al., 2011b reported a significant association between road traffic noise and stroke. There is an increasing amount of evidence for the fifth feature in the list: '*Biological gradient*'. A large amount of studies report a dose-response relationship between transportation noise exposure (mainly aircraft noise and road traffic noise) and cardiovascular endpoints (reviews by Van Kempen et al., 2002; Van Kempen and Babisch, 2012; Babisch and Van Kamp, 2009; Babisch, 2008; Babisch, 2014). The '*Plausibility*' of the relationship between noise exposure and cardiovascular effects is commonly recognized. As described in the introduction of this thesis, there is a number of

hypothesized pathways, through which exposure may in the long term lead to adverse health effects. Proposed biological mechanisms involve stress responses, which induce physiological effects, either directly or indirectly through the disturbance of activities, communication or sleep (Babisch, 2002; Babisch, 2011). The seventh feature: '*Coherence*', implies that the interpretation of data should not seriously conflict with the commonly known facts of the health endpoint under study. Much is known about the physiological reactions to psychological stress, including adverse cardiovascular effects in the long term (e.g., reviews by Brotman et al., 2007; Cohen et al., 2007; Dimsdale, 2008). "*Experiment*': From a large amount of experimental laboratory studies and field studies, there is support for the hypothesis of a causal relationship between noise exposure and physiological effects, including changes in cardiovascular risk markers (reviews by e.g., Babisch, 2002; Babisch, 2003; WHO, 2009; WHO, 2011). One recent example, of an experimental blinded field study is the study by Schmidt et al (2013). In this study, 75 health volunteers were exposed at home to different aircraft noise conditions. The study showed that high noise exposure did not only cause a worse sleep quality, but was also associated with noise induced endothelial dysfunction, increases in morning adrenaline, and pulse transit time (reflecting arterial stiffness) (Schmidt et al., 2013). Intervention studies are still rare. While a number of intervention studies have been performed investigating the effect of changes in noise exposure on noise annoyance, sleep disturbance and general well-being (e.g., Öhrström 2004; Amudsen et al., 2011; review by Laszlo et al., 2012), a recent review by Laszlo et al (2012) could not identify any study into the effects of changes in noise exposure focusing on physiological effects or morbidity. The authors concluded that there is a strong need for intervention studies investigating health endpoints. The last feature in the list of criteria discussed by Bradford Hill (1965) is '*Analogy*'. As elaborated in this chapter, similar results have been reported from epidemiological studies into the effects of road traffic noise, aircraft noise and occupation noise. Furthermore, there is analogy with the literature on the cardiovascular effects of stress.

6.4.6 Road traffic noise and air pollution

As discussed earlier, road traffic noise and prominent air pollution components, including nitrogen oxides (NO_x) and particulate matter, in part share a same source. Consequently, these traffic related exposures show correlations, both spatially (e.g., Allen et al., 2009; Davies et al., 2009; Foraster et al., 2011), and in time (Can et al., 2011; Ross et al., 2011). Cardiovascular health effects have been linked to both air pollution

and noise, however, the amount of studies that take into account both traffic related exposures is still limited. The topic has increasingly gained attention however, in recent years. An increasing amount of studies is becoming available that take both exposures into account (Beelen et al., 2009; Selander et al., 2009; Huss et al., 2010; Sørensen et al., 2011; Fuks et al., 2011; Clark et al., 2012; Dratva et al., 2012; Gan et al., 2012; Sørensen et al., 2012; Bilenko et al., 2013; Floud et al., 2013; Huang et al., 2013; Babisch et al., 2014; Kalsch et al., 2014; Liu et al., 2014), including a first review (Tetreault et al., 2013). More studies are needed to investigate the relative contribution of road traffic noise and air pollution. Current insights do not yet allow conclusions on potential confounding or interaction. There are large methodological differences between studies both in terms of exposure indicators used, and in quality of exposure assessment. Results should be interpreted with caution, particularly in studies where information on the secondary exposure of interest (the 'confounder') is of low(er) quality (Foraster, 2013). However, available studies suggest that confounding between transportation noise and air pollution is limited (Tetreault et al., 2013). Although some studies suggest that there may be some extent of confounding between road traffic noise and traffic related air pollution (e.g., Floud et al., 2013; Babisch et al., 2014; Liu et al., 2014), the majority of studies report that effects of road traffic noise exposure seemed independent of air pollution (e.g., Selander et al., 2009; Huss et al., 2010; Sørensen et al., 2011; Dratva et al., 2012; Gan et al., 2012; Sørensen et al., 2012; Kalsch et al., 2014). However, a recent field study assessed personal exposure to both noise and air pollutants (including $PM_{2.5}$, black carbon (BC) and carbon monoxide (CO)) and heart rate variability (HRV) by continuous monitoring in 40 healthy volunteers. They reported effects of both air pollution and noise. Results suggested effect modification, with stronger effects of air pollution at higher noise levels (Huang et al., 2013).

6.4.7 Exposure at the least exposed side of the dwelling

Results of the studies into the effect of road traffic noise exposure at the least exposed side of the dwelling, as described in Chapter 5, suggest an independent effect of exposure both at the most and at the least exposed side. This indicates the importance of exposure at the noise shielded side of the dwellings for the perception of the noise environment by the inhabitants. Exposure at the most exposed façade however, still appeared to be the dominant predictor of road traffic noise annoyance.

The 'beneficial effect' of having a side to the dwelling with low exposure, allowing inhabitants to 'escape' from the noise, and to choose to reside or sleep at a more quiet side, may depend on several aspects. First, the transmission of noise within the dwelling and the *usability* of the side with lower exposure, may be expected to play a role. For example, if an apartment or dwelling has no usable (or unoccupied) bedroom, obviously for a resident there may no longer be the option to sleep at the lower exposed side. Furthermore, in dwellings where the largest and most convenient bedrooms are situated at the side facing the street, there may be other considerations which will make inhabitants choose to sleep at the most exposed side, irrespective of the noise environment. Results from previous studies provided support for the influence of building situational factors on annoyance. Gidlöf-Gunnarsson et al. (2012), in a study into the effects of railway noise, indicated that annoyance was approximately 1.5 to 2 times higher among inhabitants with their bedroom window or balcony (or patio) facing the railway. Second, the *accessibility* and *quality* of the outdoor space (e.g., balcony or garden) may be of influence. A Swedish study showed that the physical environmental quality of 'quiet' courtyards affected the perceived annoyance, with 'high quality' courtyards associated with lower noise annoyance (Gidlöf-Gunnarsson and Öhrström, 2010). Furthermore, previous studies have indicated that the perceived availability to nearby green areas may affect noise annoyance, both in dwellings with and without a 'quiet side' (Gidlöf-Gunnarsson and Öhrström, 2007). Third, *other sources of disturbance* may intervene with the presumed 'quietness', for example if a parking space is at the least exposed side of dwellings, or stock supply activities for shops, restaurants, or café's, or other small medium enterprises (SMEs), installation noises from air conditioning or ventilation systems. Behavior may modify exposure and effects (e.g., perceived annoyance) in different ways: Previous studies have shown that people tend to more often close their bedroom windows, when situated on a site exposed to high noise levels. However, this was found to be conflicting with the residents' preference (Van Renthergem et al., 2012), which may be expected to be a source of annoyance.

6.5 Implications

With a growing body of evidence from experimental studies, and increasing support from epidemiological studies, to date, it seems no longer the question if there is a relationship between road traffic noise exposure and hypertension and several cardiovascular disease outcomes. Rather, further refinement is needed on the exposure-response relationships (refinement of estimates of magnitude(s) and shape).

Furthermore, the relative contribution of both air pollution and noise, which may be expected to differ between health outcomes, remains to be further clarified. There is more insight needed in the potential modification of effects, by age, gender, and health status, and work related factors such as job strain as well as occupational exposure.

Given the large number of residents involuntarily exposed, the trend of increasing urbanization, and the adverse effects associated with road traffic noise exposure, noise is expected to remain a persistent public health problem.

More attention is needed for noise abatement measures geared towards reducing exposure and effects. The social costs of environmental noise exposure in urban areas in the Netherlands have been estimated to be substantial (Jabben et al., 2007; Review by Den Boer et al., 2008). Cost benefit analysis by RIVM reported that a range of (mainly source oriented) measures can be highly cost effective. For road traffic, low emitting tyres and low emitting road surface, were identified as most cost effective (Jabben et al., 2007). Road traffic noise abatement measures are preferably source orientated. International regulation setting emission limits for vehicular traffic (i.e. emissions from tyre and engine) have the benefit of affecting exposure everywhere, in contrast to locally applied measures, which, while remaining essential and valuable, can only improve a noise environment within a restricted area. Furthermore, measures can be geared towards reducing exposure and effects at the side of the receiver. Smart spatial planning, as well as building design, can support the reduction of exposures as well as the perception of the noise environment, and thereby reduce adverse effects. In addition to the most exposed side of dwellings, exposure at the lower exposed side should be considered. Optimizing the noise environment can aid the reduction of adverse effects of noise. Practical application of these concepts however, should take account of factors that may counteract the effect of a lower exposed side. The accessibility and usability of the ‘quiet side’, as well as its quality, and perceived nearby green areas may modify effects. Furthermore, it should be realized that for the perceived annoyance, exposure at the most exposed façade is still the dominant predictor. For the protection of inhabitants, a lower exposure at one side of the dwelling should not be used to allow concessions with respect to exposure at the most exposed side.

6.6 Future research directions

Numerous recommendations for future research can be given. A selection of prominent ones is listed here.

Replication of results

To date, only a limited amount of large population studies into the after effects of noise induced sleep disturbance are available. The association between road traffic noise and morning tiredness needs to be confirmed in future studies, in different populations, and in different cities or countries. Future studies may strengthen evidence and provide further support for hypothesized causality, by a prospective design, as well as by studies into the effects of *changes* in road traffic noise exposure.

Refinement of exposure response relationships

In recent years substantial progress has been made in the field of cardiovascular effects of noise. Meta-analyses have been published, reporting significant associations between road traffic noise and both hypertension (Van Kempen and Babisch, 2012), and coronary heart disease (Babisch, 2014). However, the number of large population studies is still limited. There is substantial heterogeneity between available studies in methodology. Sources of heterogeneity include differences in age and gender of the population under study, large differences in quality of exposure assessment, and in adjustment for confounders. Large prospective studies are needed to further refine exposure response relationships. Advances in the field of information technology may aid the improvement of traffic data, particularly for the small to medium urban roads. This may aid further refinement of exposure assessment both for road traffic noise and traffic related air pollution, and thereby, when applied in epidemiological studies, aid refinement of exposure-response relationships, as well as disentangling the relative contribution of different exposures. In future studies, specific attention may be paid to taking into account factors that may modify exposure or effects. One such factor includes the orientation of the living room and bedroom towards the source, as results from previous studies have indicated these may affect associations (e.g., Babisch et al., 2014b). Furthermore, future studies which take into account effects of combined stressors, such as the combination of high road traffic noise exposure at the home and job strain, since a high level of job strain may increase the need for restoration when people return home from a working day.

Road traffic noise and air pollution

While currently an increasing amount of studies is coming available taking into account both road traffic noise and air pollution, this amount is still limited. It has been recognized that there is a need for studies, which take into account the 'secondary exposure' with a similarly high quality of exposure assessment for both exposures (Foraster, 2013). Studies with large differences in spatial resolution between air pollution and noise exposures for example, may not provide a clear picture on the relative contribution of exposures and thus may provide biased results. Future studies into short term fluctuations in cardiovascular parameters (e.g., Huang et al., 2013) may provide more insight in the influence of different exposures, while increasing understanding of underlying mechanisms. It should be noted however, that the translation between short term physiological changes and adverse health effects on the long term is difficult to make.

Intervention studies

Intervention studies allow evaluation of the effect of prevention measures. An intervention design, however, is typically not easily applicable to evaluate long term exposure effects. Not only would the time needed for such evaluation be long, but also in many cases the potential study population within a (local) intervention area will be limited in size. Thus, a lack of power may further complicate studying long term cardiovascular health effects in these type of studies. However, intervention studies can be still be extremely valuable to evaluate effects of different abatement measures on adverse effects that may emerge in the short term (e.g., annoyance, sleep disturbance, (physiological) changes in cardiovascular risk factors etc.), while providing further support for the hypothesis of causality. The amount of studies evaluating effects of changes in environmental noise exposure is still limited, particularly for health endpoints. More studies are needed that investigate the impact of noise reduction (or increase) on health (Laszlo et al., 2012).

Effectivity of road traffic noise abatement measures

In addition to quantification of the effects of exposure at the least exposed side, further quantification of the effect of dwelling insulation is needed. With the current trend in improvement of the insulation of buildings, in the transition towards an energy neutral built environment, energy related measures and acoustical insulation may go hand in hand. However, it should be noted that insulation may not reduce effects such as annoyance and sleep disturbance to the extent one might expect based on the potential

to reduce indoor exposures. The quality of the noise environment outside the dwelling (e.g., on the balcony or garden) will affect the perception. Furthermore, it is well known that a substantial proportion of people prefer to sleep with windows opened.

Exposure response relationships for 'new' outcomes

In recent years, studies have become available that indicate an association between noise exposure and a range of 'new' health outcomes, including e.g., stroke, atherosclerosis, diabetes, and obesity (e.g., Sørensen et al., 2011b; Floud et al., 2013; Kalsch et al., 2013; Sorensen et al., 2013; Eriksson et al., 2014). These new outcomes deserve more attention. Findings need to be further confirmed in future studies.

6.7 Conclusion

The different studies presented in this thesis provide support for a relationship between road traffic noise exposure and both reduced sleep quality (with morning tiredness as indicator) and hypertension. No conclusive evidence was found for an effect of ischemic heart disease or cerebrovascular disease events, but in view of the increasing body of evidence from the international literature, it is likely that such effects exist. It was shown that adverse effects may be reduced by reducing exposure not only at the most exposed façade, but also at the least exposed façade. Therefore, exposure at the least exposed façade seems important to consider, both in view of a more complete characterization of personal exposure, as well as in view of spatial planning, design of dwelling lay-out (architecture), and noise abatement measures.

Future studies are needed to further refine exposure-response relationships, to further investigate the relative contribution of road traffic noise and air pollution to effects, their potential interaction, and to further explore underlying mechanisms. It is increasingly becoming recognized that environmental noise exposure, in addition to causing noise annoyance and sleep disturbance, may lead to adverse health effects. Further international, national and municipal efforts are needed to reduce the harmful effects of road traffic noise exposure, where local measures can complement source oriented measures enforced by (inter)national regulation.

References

Allen RW, Davies H, Cohen MA, Mallach G, Kaufman JD, Adar SD, "The spatial relationship between traffic-generated air pollution and noise in 2 US cities", Environmental Research 2009; 109(3): 334–342.

Amundsen AH, Klaeboe R, Aasvang GM. The Norwegian façade insulation study: the efficacy of façade insulation in reducing noise annoyance due to road traffic. Journal of the Acoustical Society of America 2011; 129: 1381–1389.

Babisch W, Gallacher JE, Ising H, Elwood PC. Traffic noise and cardiovascular risk. The Caerphilly study, first phase. Outdoor noise levels and risk factors. Archives of Environmental Health 1988; 43(6): 407–414.

Babisch W, Ising H, Elwood PC, Sharp DS, Bainton D. Traffic noise and cardiovascular risk: the Caerphilly and Speedwell studies, second phase. Risk estimation, prevalence, and incidence of ischemic heart disease. Archives of Environmental Health 1993; 48(6): 406–413.

Babisch W, Ising H, Kruppa B, Wiens D. The incidence of myocardial infarction and its relation to road traffic noise — The Berlin case-control studies. Environment International 1994; 20(4): 469–474.

Babisch W, Ising H, Gallacher JEJ, Sweetnam PM, Elwood PC. Traffic noise and cardiovascular risk: The Caerphilly and Speedwell studies, third phase-10 years follow-up. Archives of Environmental Health 1999; 54(3): 210–216.

Babisch W. The noise/stress concept, risk assessment and research needs. Noise and Health 2002; 4(16): 1–11.

Babisch W, Ising H, Gallacher JE. Health status as a potential effect modifier of the relation between noise annoyance and incidence of ischaemic heart disease. Occupational and Environmental Medicine 2003; 60(10): 739–745.

Babisch W. Stress hormones in the research on cardiovascular effects of noise. Noise and Health 2003; 5(18): 1–11.

Babisch W, Beule B, Schust M, Kersten N, Ising H. Traffic noise and risk of myocardial infarction. Epidemiology 2005; 16(1): 33–40.

Babisch W. Road traffic noise and cardiovascular risk. Noise and Health 2008; 10: 27–33.

Babisch W, van Kamp I. Exposure-response relationship of the association between aircraft noise and the risk of hypertension. Noise and Health 2009;11:149-56.

Babisch W. Cardiovascular effects of noise. Noise and Health 2011; 13: 52:201-204.

Babisch W, Swart W, Houthuijs D, Selander J, Bluhm G, Pershagen G, Dimakopoulou K, Haralabidis AS, Katsouyanni K, Davou E, Sourtzi P, Cadum E, Vigna-Taglianti F, Floud S, Hansell A. Exposure modifiers of the relationships of transportation noise with high blood pressure and noise annoyance. Journal of the Acoustical Society of America 2012; 132 (6): 3788–3808.

Babisch W. Updated exposure-response relationship between road traffic noise and coronary heart diseases: A meta-analysis. Noise and Health 2014; 16(68): 1–9.

Babisch W, Wolf K, Petz M, Heinrich J, Cyrys J, Peters A. Associations between traffic noise, particulate air pollution, hypertension, and isolated systolic hypertension in adults: the KORA study. Environmental Health Perspectives 2014a;122(5):492–498.

Babisch W, Wolke G, Heinrich J, Staff W. Road traffic noise and hypertension – Accounting for the location of rooms. Environmental Research (in press).
http://dx.doi.org/10.1016/j.envres.2014.05.007.

Barregard L, Bonde E, Ohrström E. Risk of hypertension from exposure to road traffic noise in a population-based sample. Occupational and Environmental Medicine 2009; 66(6): 410–415.

Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, Stansfeld S. Auditory and non-auditory effects of noise on health. Lancet 2013; 383(9925):1325–1322.

Beelen R, Hoek G, Houthuijs D, Van den Brandt PA, Goldbohm RA, Fischer P, Schouten LJ, Armstrong B, Brunekreef B. The joint association of air pollution and noise from road traffic with cardiovascular mortality in a cohort study. Occupational and Environmental Medicine 2009; 66(4): 243–250.

Belojević GA, Jakovljević BD, Stojanov VJ, Slepcević VZ, Paunović KZ. Nighttime road-traffic noise and arterial hypertension in an urban population. Hypertension Research 2008; 31(4): 775–781.

Bendokiene I, Grazuleviciene R, Dedele A. Risk of hypertension related to road traffic noise among reproductive-age women. Noise and Health 2011;13(55): 371–377.

Bilenko N, Rossem LV, Brunekreef B, Beelen R, Eeftens M, Hoek G, Houthuijs D, De Jongste JC, Van Kempen E, Koppelman GH, Meliefste K, Oldenwening M, Smit HA, Wijga AH, Gehring U. Traffic-related air pollution and noise and children's blood pressure: results from the PIAMA birth cohort study. European Journal of Preventive Cardiology 2013. DOI: 10.1177/2047487313505821.

Bluhm GL, Berglind N, Nordling E, Rosenlund M. Road traffic noise and hypertension. Occupational and Environmental Medicine 2007; 64(2): 122–126.

Bodin T, Albin M, Ardö J, Stroh E, Ostergren PO, Björk J. Road traffic noise and hypertension: results from a cross-sectional public health survey in southern Sweden. Environmental Health 2014; 3(1): 37.

Bradford Hill, A. The environment and disease, association or causation? Proceedings of the Royal Society of Medicine 1965; 58: 295–300.

Brook RD, Rajagopalan S, Pope CA, Brook JR, Bhatnagar A, Diez-Roux AV, Holguin F, Hong Y, Luepker RV, Mittleman MA, Peters A, Siscovick D, Smith SC, Whitsel L, Kaufman JD and on behalf of the American Heart Association Council on Epidemiology and Prevention, Council on the Kidney in Cardiovascular Disease, and Council on Nutrition, Physical Activity and Metabolism. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation 2010; 121: 2331–2378.

Brotman DJ, Golden SH, Wittstein IS. The cardiovascular toll of stress. The Lancet 2007; 370: 1089–1100.

Can A, Rademaker M, Van Renterghem T, Mishra V, Van Poppel M, Touhafi A, Theunis J, De Baets B, Botteldooren D. Correlation analysis of noise and ultrafine particle counts in a street canyon. Science Total Environ 2011; 409; 564–572.

Cappuccio FP, Stranges S, Kandala NB, Miller MA, Taggart FM, Kumari M, Ferrie JE, Shipley MJ, Brunner EJ, Marmot MG. Gender-specific associations of short sleep duration with prevalent and incident hypertension: the Whitehall II Study. Hypertension 2007; 50(4): 693–700.

Cappuccio FP, D'Elia L, Strazzullo P, Miller MA. Quantity and quality of sleep and incidence of type 2 diabetes: a systematic review and meta-analysis. Diabetes Care 2010a; 33(2): 414–420.

Cappuccio FP, D'Elia L, Strazzullo P, Miller MA. Sleep duration and all-cause mortality: A systematic review and meta-analysis of prospective studies. Sleep 2010b; 33(5): 585–592.

Cappuccio FP, Cooper D, D'Elia L, Strazzullo P, Miller MA. Sleep duration predicts cardiovascular outcomes: a systematic review and meta-analysis of prospective studies. European Heart Journal 2011; 32: 1484–1492.

Calhoun DA and Harding SM. Sleep and hypertension. Chest 2010; 138: 434–443.

Chandola T, Ferrie JE, Perski A, Akbaraly T, Marmot MG. The effect of short sleep duration on coronary heart disease risk is greatest among those with sleep disturbance: A prospective study from the Whitehall II Cohort. Sleep 2010; 33(6): 739–744.

Chang TY, Liu CS, Bao BY, Li SF, Chen TI, Lin YJ. Characterization of road traffic noise exposure and prevalence of hypertension in central Taiwan. Science of the Total Environment 2011a; 409: 1053–1057.

Chang TY, Liu CS, Huang KH, Chen RY, Lai JS, Bao BY. High-frequency hearing loss, occupational noise exposure and hypertension: a cross-sectional study in male workers. Environmental Health 2011b;10–35.

Chang TY, Hwang BF, Liu CS, Chen RY, Wang VS, Bao BY, Lai JS. Occupational noise exposure and incident hypertension in men: a prospective cohort study. American Journal of Epidemiology 2013;177:818–825.

Clark C, Crombie R, Head J, Van Kamp I, Van Kempen E, Stansfeld SA. Does Traffic-related Air Pollution Explain Associations of Aircraft and Road Traffic Noise Exposure on Children's Health and Cognition? A Secondary Analysis of the United Kingdom Sample From the RANCH Project. American Journal of Epidemiology 2012; 176(4):327–337.

Cohen S, Janicki_Deverts D, Miller GE. Psychological stress and disease. JAMA 2007; 298(14): 1685–1687.

Correia AW, Peters JL, Levy JI, Melly S, Dominici F. Residential exposure to aircraft noise and hospital admissions for cardiovascular diseases: multi-airport retrospective study. BMJ. 2013;347:f5561.

Davies HW, Teschke K, Kennedy SM, Hodgson MR, Hertzman C, Demers PA. Occupational exposure to noise and mortality from acute myocardial infarction. Epidemiology 2005;16(1): 25–32.

Davies HW, Vlaanderen JJ, Henderson SB, Brauer M. Correlation between co-exposures to noise and air pollution from traffic sources. Occupational and Environmental Medicine 2009; 66:347–350.

Den Boer LC, Van de Vreede GJ, De Jong F, De Bruyn SM. Beleving en MKBA in het geluidsbeleid — Een verkenning naar beleving en kosten-batenanalyse bij de aanpak van geluidshinder. Delft, CE, 2008. Publicatienummer 08.7674.36.

Dimsdale JE. Psychological stress and cardiovascular disease. Journal of the American College of Cardiology 2008; 51(13): 1237–1246.

Dratva J, Phuleria HC, Foraster M, Gaspoz JM, Keidel D, Kunzli N, Liu LJS, Pons M, Zemp E, Gerbase MW, Schindler C. Transportation noise and blood pressure in a population-based sample of adults. Environmental Health Perspectives 2012;120:50–55.

Eriksson C, Rosenlund M, Pershagen G, Hilding A, Ostenson CG, Bluhm G. Aircraft noise and incidence of hypertension. Epidemiology 2007;18(6):716–721.

Eriksson C, Nilsson ME, Willers SM, Gidhagen L, Bellander T, Pershagen G. Traffic noise and cardiovascular health in Sweden: The roadside study. Noise and Health 2012;14 (59):140-147.

Eriksson C, Hilding A, Pyko A, Bluhm G, Pershagen G, Ostenson CG. Long-Term Aircraft Noise Exposure and Body Mass Index, Waist Circumference, and Type 2 Diabetes: A Prospective Study. Environmental Health Perspectives 2014 (in press).

Faraut B, Boudjeltia KZ, Vanhamme L, Kerkhofs M. Immune, inflammatory and cardiovascular consequences of sleep restriction and recovery. Sleep Medicine Reviews 2012; 16(2):137–149.

Floud S, Vigna-Taglianti F, Hansell AL, Blangiardo M, Houthuijs D, Breugelmans O, Cadum E, Babisch W, Selander J, Pershagen G, Antoniotti MC, Pisani S, Dimakopoulou K, Haralabidis AS, Velonakis M, Jarup L, HYENA Study Team. Medication use in relation to noise from aircraft and road traffic in six European countries: results of the HYENA study. Occupational and Environmental Medicine 2011; 68(7): 518–524.

Floud S, Blangiardo M, Clark C, De Hoogh K, Babisch W, Houthuijs D, Swart W, Pershagen G, Katsouyanni K, Velonakis M, Vigna-Taglianti F, Cadum E and Hansell AL. Exposure to aircraft and road traffic noise and associations with heart disease and stroke in six European countries: a cross-sectional study. Environmental Health 2013;12:89.

Foraster M, Deltell A, Basagana X, Medina-Ramon M, Aguilera I, Bouso L, Grau M, Phuleria HC, Rivera M, Slama R, Sunyer J, Targa J, Künzli N. Local determinants of road traffic noise levels versus determinants of air pollution levels in a Mediterranean city. Environmental Research 2011; 111, 177–183.

Foraster M. Is it traffic-related air pollution or road traffic noise, or both? Key questions not yet settled! International Journal of Public Health 2013; 58:647-648.

Fuks K, Moebus S, Hertel S, Viehmann A, Nonnemacher M, Dragano N, Mohlenkamp S, Jakobs H, Kessler C, Erbel R, Hoffmann B, on behalf of the Heinz Nixdorf Recall Study Investigative Group. Long-term urban particulate air pollution, traffic noise, and arterial blood pressure. Environmental Health Perspectives 2011;119:1706-1711.

Gan WQ, Davies HW, Koehoorn M, Brauer M. Association of long-term exposure to community noise and traffic-related air pollution with coronary heart disease mortality. American Journal of Epidemiology 2012; 175: 898-906.

Gidlöf-Gunnarsson A and Öhrström E. Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. Landscape and Urban Planning 83 (2007) 115–126.

Gidlöf-Gunnarsson A, Ögren M, Jerson T, Öhrström E. Railway noise annoyance and the importance of number of trains, ground vibration, and building situational factors. Noise and Health 2012; 14 (59): 190–201.

Gidlöf-Gunnarsson A and Öhrström E. Attractive "Quiet" Courtyards: A Potential Modifier of Urban Residents' Responses to Road Traffic Noise? International Journal of Environmental Research and Public Health 2010; 7: 3359–3375.

Gottlieb DJ, Redline S, Nieto FJ, Baldwin CM, Newman AB, Resnick HE, Punjabi NM. Association of usual sleep duration with hypertension: the Sleep Heart Health Study. Sleep 2006; 29(8):1009–1014.

Greiser E, Greiser C, Janhsen K. Night-time aircraft noise increases prevalence of prescriptions of antihypertensive and cardiovascular drugs irrespective of social class—the Cologne-Bonn Airport study. Journal of Public Health 2007; 15(5): 327–337.

Guo X, Zheng L, Wang J, Zhang X, Zhang X, Li J, Sun Y. Epidemiological evidence for the link between sleep duration and high blood pressure: a systematic review and meta-analysis. Sleep Medicine 2013;14(4): 324–332.

Hänninen O and Knol A (editors). EBoDe working group. European perspectives on environmental burden of disease: Estimates for nine stressors in six European countries. Finland: National Institute for Health and Welfare; 2011.

Hansell AL, Blangiardo M, Fortunato L, Floud S, de Hoogh K, Fecht D, Fecht D, Ghosh RE, Laszlo HE, Pearson C, Beale L, Beevers S, Gulliver J, Best N, Richardson S, Elliot P. Aircraft noise and cardiovascular disease near Heathrow airport in London: small area study. BMJ 2013; 347: f5432.

Huss A, Spoerrt A, Egger M, Röösli M, for the Swiss National Cohort Study Group. Aircraft noise, air pollution, and mortality from myocardial infarction. Epidemiology 2010; 21(6) 829–836.

Huang J, Deng F, Wu S, Lu H, Hao Y, Guo X. The impacts of short-term exposure to noise and traffic-related air pollution on heart rate variability in young healthy adults. Journal of Exposure Science and Environmental Epidemiology 2013; 23: 559–564.

Hwang BF, Chang TY, Cheng KY, Liu CS. Gene-environment interaction between angiotensinogen and chronic exposure to occupational noise contribute to hypertension. Occupational and Environmental Medicine 2012; 69: 236–242.

Jabben J, Potma, C, Lutter S. Baten van geluidmaatregelen. Een inventarisatie voor weg- en railverkeer in Nederland. RIVM report 680300002. 2007.

Jarup L, Babisch W, Houthuijs D, Pershagen G, Katsouyanni K, Cadum E, Dudley ML, Savigny P, Seiffert I, Swart W, Breugelmans O, Bluhm G, Selander J, Haralabidis A, Dimakopoulou K, Sourtzi P, Velonakis M, Vigna-Taglianti F; the HYENA study team. Hypertension and exposure to noise near airports: the HYENA Study. Environmental Health Perspectives 2008; 116(3): 329–333.

Kalsch H, Hennig F, Moebus S, Mohlenkamp S, Dragano N, Jakobs H, Memmesheimer M, Erbel R, Jockel KH, Hoffmann B, on behalf of the Heinz Nixdorf Recall Study Investigative Group. Are air pollution and traffic noise independently associated with atherosclerosis: the Heinz Nixdorf Recall Study. European Heart Journal 2014; 35: 853–860.

Knipschild P. V. Medical effects of aircraft noise: community cardiovascular survey. International Archives of Occupational and Environmental Health 1977; 40(3):185–190.

Knutson KL, Spiegel K, Penev P, Van Cauter E. The metabolic consequences of sleep deprivation. Sleep Medicine Reviews 2007;11(3):163–178.

Knutson KL. Sleep duration and cardiometabolic risk: a review of the epidemiologic evidence. Best Practice and Research Clinical Endocrinology and Metabolism 2010; 24(5): 731–743.

Kronholm E, Laatikainen T, Peltonen M, Sippola R, Partonen T. Self-reported sleep duration, all-cause mortality, cardiovascular mortality and morbidity in Finland. Sleep Medicine 2011; 12: 215–221.

Kruize H, Driessen PPJ, Glasbergen P, Van Egmond KND. Environmental Equity and the Role of Public Policy: Experiences in the Rijnmond Region. Environmental Management 2007; 40: 578–595.

Laszlo HE, McRobie ES, Stansfeld SA, Hansell AL. Annoyance and other reaction measures to changes in noise exposure — A review. Science of the Total Environment 2012; 435–436; 551–562.

Leineweber C, Kecklund G, Janszky I, Akerstedt T, Orth-Gomér K. Poor sleep increases the prospective risk for recurrent events in middle-aged women with coronary disease. The Stockholm Female Coronary Risk Study. Journal of Psychosomatic Research 2003; 54: 121–127.

Liu C, Fuertes E, Tiesler CM, Birk M, Babisch W, Bauer CP, Koletzko S, Von Berg A, Hoffmann B, Heinrich J, GINIplus and LISAplus Study Groups. The associations between traffic-related air pollution and noise with blood pressure in children: Results from the GINIplus and LISAplus studies. International Journal of Hygiene and Environmental Health 2014; 217: 499–505.

Meerlo P, Sgoifo A, Suchecki D. Restricted and disrupted sleep: Effects on autonomic function, neuroendocrine stress systems and stress responsivity. Sleep Medicine Reviews 2008; 12: 197–210.

Meng L, Zheng Y, Hui R. The relationship of sleep duration and insomnia to risk of hypertension incidence: a meta-analysis of prospective cohort studies. Hypertension Research 2013; 36(11): 985–995.

Miedema HME and Vos H. Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behavioral sleep medicine 2007; 5(1): 1–20.

Mullington JM, Haack M, Toth M, Serrador JM, Meier-Ewert HK. Cardiovascular, inflammatory, and metabolic consequences of sleep deprivation. Progress in Cardiovascular Disease 2009; 51(4): 294–302.

Öhrström E. Longitudinal surveys on effects of changes in road traffic noise—annoyance, activity disturbances, and psycho-social well-being. Journal of the Acoustical Society of America 2004; 115 (2): 719–729.

Palagini L, Bruno RM, Gemignani A, Baglioni C, Ghiadoni L, Riemann D. Sleep loss and hypertension: a systematic review. Current Pharmaceutical Design 2013; 19(13): 2409–2419.

Porkka-Heiskanen T, Zitting KM, Wigren HK. Sleep, its regulation and possible mechanisms of sleep disturbances. Acta Physiologica (Oxford, Emgland) 2013; 208(4): 311–328.

Rosenlund M, Berglind N, Pershagen G, Järup L, Bluhm G. Increased prevalence of hypertension in a population exposed to aircraft noise. Occupational and Environmental Medicine 2001; 58: 769–773.

Ross Z, Kheirbek I, Clougherty JE, Ito K, Matte T, Markowitz S, Eisl H. Noise, air pollutants and traffic: Continuous measurement and correlation at a high-traffic location in New York City. Environment Research 2011; 111(8): 1054–1063.

Schmidt FP, Basner M, Kröger G, Weck S, Schnorbus B, Muttray A, Sariyar M, Binder H, Gori T, Warnholz A, Münzel T. Effect of nighttime aircraft noise exposure on endothelial function and stress hormone release in healthy adults. European Heart Journal 2013; 34: 3508-3514.

Selander J, Nilsson M, Bluhm G, Rosenlund M, Lindqvist M, Nise G, Pershagen G. Long-term exposure to road traffic noise and myocardial infarction. Epidemiology 2009; 20(2): 265–271.

Selander J, Bluhm G, Nilsson M, Hallqvist J, Theorell T, Willix P, Pershagen G. Joint effects of job strain and road-traffic and occupational noise on myocardial infarction. Scandinavian Journal Work Environment and Health 2013; 39(2): 195–203.

Sørensen M, Hvidberg M, Hoffmann B, Andersen ZJ, Nordsborg RB, Lillelund KG, Jakobsen J, Tjønneland A, Overvad K, Raaschou-Nielsen O. Exposure to road traffic and railway noise and associations with blood pressure and self-reported hypertension: a cohort study. Environmental Health 2011a;10: 92.

Sørensen M, Hvidberg M, Andersen ZJ, Nordsborg RB, Lillelund KG, Jakobsen J, Tjønneland A, Overvad K, Raaschou-Nielsen O. Road traffic noise and stroke: a prospective cohort study. European Heart Journal 2011b; 32(6): 737–744.

Sørensen M, Andersen ZJ, Nordsborg RB, Jensen SS, Lillelund KG, Beelen R, Schmidt EB, Tjønneland A, Overvad K, Raaschou-Nielsen O. Road traffic noise and incident myocardial infarction: A prospective cohort study. PLoS ONE 2012; 7(6): 1–7.

Sørensen M, Andersen ZJ, Nordsborg RB, Becker T, Tjønneland A, Overvad K, Raasschou Nielsen O. Long-term exposure to road traffic noise and incident diabetes: a cohort study. Environmental Health Perspectives 2013;121:217-22.

Spiegel K, Leproult R, Van Cauter E. Impact of sleep debt on metabolic and endocrine function. Lancet 1999; 354(9188):1435–1439.

Stokholm ZA, Bonde JP, Christensen KL, Hansen AM, Kolstad HA. Occupational noise exposure and the risk of hypertension. Epidemiology 2013; 24:135–142.

Tetreault LF, Perron S, Smargiassi A. Cardiovascular health, traffic-related air pollution and noise: are associations mutually confounded? A systematic review. International Journal of Public Health 2013; 58: 649–666.

Tomei G, Fioravanti M, Cerratti D, Sancini A, Tomao E, Rosati MV, Vacca D, Palitti T, Di Famiani M, Giubilati R, De Sio S, Tomei F. Occupational exposure to noise and the cardiovascular system: a meta-analysis. Science of the Total Environment 2010; 408(4): 681–689.

Tomei G, Sancini A, Tomei F, Vitarelli A, Andreozzi G, Rinaldi G, Di Giorgio V, Samperi I, Fiaschetti M, Tasciotti Z, Cetica C, Capozella A, Ciarocca, Caciari T. Prevalence of systemic arterial hypertension, electrocardiogram abnormalities, and noise-induced hearing loss in agricultural workers. Archives of Environmental and Occupational Health 2013; 68(4):196–203.

Van Cauter E1, Spiegel K, Tasali E, Leproult R. Metabolic consequences of sleep and sleep loss. Sleep Medicine 2008; 9(S1):S23–28.

Van den Hooven EH, Pierik FH, Van Ratingen SW, Zandveld PYJ, Meijer EW, Hofman A, Miedema HME, Jaddoe VWV and de Kluizenaar Y. Air pollution exposure estimation using dispersion modelling and continuous monitoring data in a prospective birth cohort study in the Netherlands. Environmental Health 2012; 11(9), 11pp.

Van Kempen EE, Kruize H, Boshuizen HC, Ameling CB, Staatsen BA, de Hollander AE. The association between noise exposure and blood pressure and ischemic heart disease: a meta-analysis. Environmental Health Perspectives 2002; 110(3): 307–317.

Van Kempen E and Babisch W. The quantitative relationship between road traffic noise and hypertension: a meta-analysis. Journal of Hypertension 2012, 30:1075–1086.

Van Rentherghem T and Botteldooren D. Focused Study on the Quiet Side Effect in Dwellings Highly Exposed to Road Traffic Noise. International Journal of Environmental Research and Public Health 2012; 9(12): 4292–4310.

Weinmann T, Ehrenstein V, Von Kries R, Nowak D, Radon K. Subjective and objective personal noise exposure and hypertension: an epidemiologic approach. International Archives of Occupational and Environmental Health 2012; 85: 363–371.

WHO. Night noise guidelines for Europe. World Health Organization Regional Office for Europe. WHO, Copenhagen, Denmark, 2009.

WHO. World Health Organization Regional Office for Europe and JRC European Commission: Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. WHO, Copenhagen, Denmark, 2011.

Chapter 7

Summary / Samenvatting

Summary

Exposure to road traffic noise is a widespread environmental health problem, adversely affecting a large proportion of residents in our highly urbanized living environment. The most prevalent effects of road traffic noise exposure include self-reported noise annoyance and sleep disturbance. In a recent effort by WHO to quantify the environmental noise related healthy life years lost in Europe, noise related sleep disturbance was estimated to contribute most strongly to the total burden of disease. In addition to annoyance and sleep disturbance, which in itself have a considerable impact on well-being, there is a growing body of evidence supporting the hypothesis that long term exposure to road traffic noise is associated with further health effects, including hypertension and cardiovascular disease.

Invigorated by possibilities that have come available by advances in exposure modelling and Geographical Information System (GIS) technology, over the last 10 years an increasing amount of epidemiological studies studying the effects of environmental exposures has appeared. A large proportion of these studies has focussed on effects of air pollution. The number of large population studies studying long term effects of road traffic noise is however still limited. A topic that has gained increasing interest in recent years is combined exposure to road traffic noise and air pollution. These exposures are to some extent related, both spatially and temporally, as they share the same source. As both these exposures have been associated with adverse cardiovascular outcomes, these may potentially act as confounders. To date, only few epidemiological studies into effects of road traffic noise are available, that have taken air pollution into account.

Reducing road traffic noise exposure in urban areas, and thereby its adverse effects, is challenging, often not straightforward and may require a smart combination of measures. There are indications that having a lower exposed side to a dwelling may reduce adverse effects of noise, by providing an ‘escape’ from the noise to the residents, for example by providing the choice to sleep or reside at the quieter side of the dwelling. Furthermore, taking into account exposure at the least exposed side may contribute to a more complete characterization of individual exposure.

In this thesis the results of studies into the relationship between long term exposure to road traffic noise in the living environment and adverse effects are described. The following specific central research questions were formulated:

1. What is the association between long term night time road traffic noise exposure (L_{night}) and self-reported sleep problems, including the after effect (medication use, morning tiredness)?
2a. What is the association between road traffic noise and the prevalence of hypertension, taking air pollution into account?
2b. What is the association between road traffic noise and the incidence of cardiovascular events, taking air pollution into account?
3. Does a relatively quiet façade reduce adverse effects of exposure: How does exposure at the least exposed side of dwellings affect annoyance?

The first part of the thesis is focused on the first research question, contributing to further exploring the hypothesized mechanism for adverse effects of traffic noise. While the relationship between road traffic noise exposure and self-reported noise induced sleep disturbance is well established, less is known on the after effects of night time noise exposure. **Chapter 2** presents the results of a study in which the association between long term night-time road traffic noise exposure at home and self-reported indicators of sleep problems, including morning tiredness and the use of sleep or tranquilizing medication, was investigated in a large population study in the Eindhoven region (GLOBE). While the prevalence of medication use was higher in the higher exposed, no conclusive evidence was found of an association between road traffic noise and medication use. A significant association between long term night time road traffic noise exposure and morning tiredness was observed. This finding adds to previous knowledge and supports the hypothesis that night time noise exposure at the home may, through adversely affecting sleep quality, have after effects the following day. Morning tiredness and road traffic noise exposure were independently assessed. The question on morning tiredness did not refer to noise. Thus, these results indicate that road traffic noise plays a role amongst other factors causing sleep problems, a conclusion that cannot be drawn based on studies into self-reported noise related sleep disturbance alone.

The second part of this thesis focuses on the second research question. Two studies are described in which the association between road traffic noise and cardiovascular health effects are investigated, taking air pollution into account. In **Chapter 3**, the association between long term exposure to road traffic noise and the prevalence of hypertension was investigated in a large population study: a large random sample of more than 40000 inhabitants of Groningen City and the PREVEND cohort. Air pollution was taken into account in the extended models. The results indicated a moderating effect of age, with

strongest and significant associations in the 45 to 55 year age group. Furthermore, associations seemed stronger and significant at higher noise levels (L_{den} >= 55 dB). These associations did not disappear after additional adjustment for air pollution. The results of this study support that it is plausible that road traffic noise is associated with hypertension, particularly in the higher exposure range. Furthermore, these results indicate that the association between road traffic noise and hypertension cannot be explained by air pollution.

In **Chapter 4** the results of a study into the association between road traffic noise and the incidence of hospital admissions for ischemic heart disease events (ICD9 410-414) or cerebrovascular events (ICD9 430-438) are described. Again, air pollution was taken into account in the extended models. While subjects with a cardiovascular event during follow up on average had higher road traffic noise and air pollution at the home, no significant associations were found in the adjusted models. Relative risk estimates for road traffic noise exposure seemed highest in the subgroup with a history of cardiovascular disease, while for air pollution they seemed highest in the elderly. However, no conclusive evidence was found.

The third part of this thesis is focused on the third research question, and comprises a description of the results of two large population studies. **Chapter 5** first presents the results of a large population study in the Eindhoven region (GLOBE), in which the relationship between road traffic noise at the least exposed façade and noise annoyance was investigated. In this first study the effect of a relatively quiet façade was investigated. In the second study, a population study in Amsterdam, the effects of road traffic noise exposure at the least exposed façade were further quantified. The results provide support for the hypothesis of a potential benefit of having a relatively quiet façade to the dwelling. These studies contribute to increasing insight into the potential impact of reducing noise exposure at the least exposed façade as a measure to decrease the adverse effects of noise, and contributes towards a more complete characterization of personal exposure.

Finally, in **Chapter 6**, the general discussion, the results of the studies presented in this thesis are discussed in a broader perspective of previous research and methodological aspects related to this type of epidemiological studies are discussed. Furthermore, recommendations for future research are provided.

Chapter 7

Samenvatting

Blootstelling aan wegverkeersgeluid is een alomtegenwoordig milieugezondheids-probleem. In onze hedendaagse, sterk verstedelijkte leefomgeving heeft een groot deel van de bevolking te maken met substantiële blootstelling aan verkeersgeluid in de woonomgeving en van de negatieve effecten daarvan. Onder de meest voorkomende effecten van wegverkeergeluid vallen geluidshinder en slaapverstoring. In een recente inspanning van de WHO om de ziektelast in Europa ten gevolge van omgevingsgeluid te kwantificeren, kwam slaapverstoring naar voren als het effect met de grootste gezondheidsimpact, uitgedrukt in verloren gezonde levensjaren. Naast geluidshinder en slaapverstoring, effecten die op zichzelf al een aanzienlijke impact hebben op het welbevinden, komt uit een toenemend aantal wetenschappelijke studies de aanwijzing dat blootstelling aan geluid op de lange termijn mogelijk het risico op ernstige aandoeningen vergroot, waaronder hart- en vaatziekten.

Mede door de nieuwe mogelijkheden die zijn ontstaan door recente ontwikkelingen in blootstellingsmodellering en Geografische Informatie Systeem (GIS) technologie, is in het afgelopen decennium een groeiend aantal epidemiologische studies beschikbaar gekomen waarin de effecten van verschillende milieublootstellingen zijn onderzocht. Een aanzienlijk aandeel hierin vormen studies die zich richten op de effecten van luchtverontreiniging. Het aantal grote populatiestudies die de effecten van lange termijn blootstelling aan wegverkeersgeluid bestuderen, is daarentegen beperkt. In het bijzonder de zogenaamde prospectieve studies zijn nog zeldzaam. Een onderwerp dat de afgelopen jaren steeds meer onder de aandacht is gekomen, is gecombineerde blootstelling aan wegverkeersgeluid en luchtverontreiniging. Deze blootstellingen zijn in zekere mate gerelateerd, zowel ruimtelijk als temporeel, doordat zij eenzelfde bron delen. Tegelijkertijd zijn er aanwijzingen voor een oorzakelijk verband tussen hart- en vaatziekten en deze beide blootstellingen. Hierdoor bestaat in studies waarin geen rekening wordt gehouden met deze beide blootstellingen het risico van zogenaamde ‘confounding’. Tot op heden is slechts in een beperkt aantal epidemiologische studies waarin de effecten van wegverkeersgeluid op hart en vaatziekten zijn onderzocht, rekening gehouden met luchtverontreiniging (en vice versa).

Het reduceren van blootstelling aan wegverkeersgeluid in de stedelijke leefomgeving (en daarmee de negatieve effecten ervan) vormt een grote uitdaging en is vaak niet eenvoudig. Een slimme combinatie van maatregelen, zowel aan de bron als aan de kant van de ontvangers, kan bijdragen aan het reduceren van blootstelling en daarmee van

effecten als geluidhinder. Er zijn aanwijzingen dat een lagere blootstelling aan de 'geluidluwe' kant van de woning bijdraagt tot betere woonomstandigheden door vermindering van effecten van geluid. Een laag (of lager) blootgestelde zijde aan een woning, biedt de bewoners de mogelijkheid aan de continue aanwezigheid van verkeersgeluid te 'ontsnappen', bijvoorbeeld door te kiezen om tijd door te brengen, of te slapen aan de stillere kant. Het beschouwen van zowel blootstelling aan de meest belaste zijde en minst belaste zijde van woningen draagt bij aan een completere karakterisering van individuele blootstelling aan geluid.

Dit proefschrift richt zich op de langetermijneffecten van blootstelling aan wegverkeersgeluid in de woonomgeving. Resultaten van een aantal grote populatiestudies worden beschreven. De volgende specifieke centrale onderzoeks-vragen werden geformuleerd:

1. Wat is het verband tussen lange termijn blootstelling aan wegverkeersgeluid gedurende de nacht (L_{night}) en zelf-gerapporteerde slaapproblemen, waaronder de na-effecten: medicijngebruik en ochtendvermoeidheid?

2a. Wat is het verband tussen wegverkeersgeluid en het voorkomen van hoge bloeddruk, rekening houdend met blootstelling aan luchtverontreiniging?

2b. Wat is het verband tussen wegverkeersgeluid en de incidentie van cardiovasculaire events, rekening houdend met blootstelling aan luchtverontreiniging?

3. Helpt een relatief stille zijde aan de woning de negatieve effecten van blootstelling te verminderen: Hoe beïnvloedt blootstelling aan de minst belaste zijde van de woning de ervaren geluidhinder?

Het eerste deel van dit proefschrift richt zich op de eerste onderzoeksvraag, en draagt daarmee bij aan het verder verkennen van het veronderstelde mechanisme waarmee geluidblootstelling op de lange termijn tot gezondheidseffecten leidt. Terwijl de relatie tussen wegverkeersgeluid en zelf-gerapporteerde wegverkeer gerelateerde slaapverstoring veelvuldig is beschreven en een kwantitatieve relatie is vastgelegd die breed wordt toegepast om de verwachte slaapverstoring te voorspellen, is veel minder bekend over de 'na-effecten' van blootstelling gedurende de nacht. In **hoofdstuk 2** worden de resultaten gepresenteerd van een studie waarin het verband tussen langetermijnblootstelling aan wegverkeersgeluid thuis gedurende de nacht en zelf-gerapporteerde indicatoren van slaapproblemen, waaronder ochtendvermoeidheid en gebruik van slaapmiddelen of rustgevende middelen, zijn onderzocht in een grote

populatiestudie in de regio Eindhoven (GLOBE). Hoewel het medicijngebruik hoger was bij hogere geluidblootstelling, kon het bestaan van een verband tussen geluidblootstelling en medicijngebruik niet voldoende worden aangetoond. Er werd een significant verband gevonden tussen langetermijnblootstelling aan wegverkeersgeluid gedurende de nacht en ochtendvermoeidheid. Deze bevinding draagt bij aan de huidige kennis en ondersteunt de hypothese dat nachtelijke blootstelling aan verkeerslawaai, via een nadelige invloed op de kwaliteit van de slaap, leidt tot na-effecten de volgende dag. In deze studie werden ochtendvermoeidheid en blootstelling aan wegverkeersgeluid onafhankelijk van elkaar bepaald. In de vraag naar ochtendvermoeidheid werd niet verwezen naar wegverkeersgeluid. Deze resultaten geven aanwijzingen dat geluidblootstelling een rol speelt, naast andere al bekende risicofactoren voor slaapproblemen. Een conclusie die niet getrokken kan worden op basis van studies naar zelf-gerapporteerde slaapverstoring door verkeersgeluid alleen.

Het tweede deel van dit proefschrift richt zich op de tweede onderzoeksvraag. Er zijn achtereenvolgens twee studies beschreven, waarin het verband tussen langetermijnblootstelling aan wegverkeersgeluid en cardiovasculaire effecten wordt onderzocht, rekening houdend met blootstelling aan luchtverontreiniging. In **hoofdstuk 3**, is in een grote populatiestudie het verband onderzocht tussen langdurige blootstelling aan wegverkeersgeluid en de prevalentie van hypertensie. Analyses werden uitgevoerd met data van een grote steekproef van meer dan 40.000 inwoners van de stad Groningen en de PREVEND cohort. In deze analyses is rekening gehouden met blootstelling aan luchtverontreiniging. Er werden aanwijzingen gevonden voor leeftijdsafhankelijkheid van het effect, met de sterkste en significante in de groep van 45- tot 55-jarigen. Daarnaast werd een sterker en significant verband gevonden bij hogere geluidsniveaus (L_{den} >= 55 dB). Dit verband verdween niet na aanvullende correctie voor luchtverontreiniging. De resultaten van dit onderzoek ondersteunen de aannemelijkheid van een verband tussen wegverkeersgeluid en hypertensie, vooral in het hogere blootstellingsbereik. Daarnaast laten deze resultaten zien dat het verband tussen wegverkeersgeluid en hypertensie niet kan worden verklaard door luchtverontreiniging.

In **hoofdstuk 4** worden de resultaten van een studie naar het verband tussen blootstelling aan wegverkeersgeluid en de incidentie van ziekenhuisopnames voor ischemische hartaandoeningen (ICD9 410-414) of cerebrovasculaire events (ICD9 430-438) beschreven. Ook in deze studie werd rekening gehouden met blootstelling aan luchtverontreiniging. Hoewel de blootstelling aan wegverkeersgeluid en

luchtverontreiniging gemiddeld hoger was in de groep van respondenten met een cardiovasculaire gebeurtenis tijdens de follow-up periode, werden geen significante verbanden gevonden in de modellen na correctie voor potentiële 'confounders'. Het geschatte relatieve risico van blootstelling aan wegverkeersgeluid leek het hoogst in de subgroep met een voorgeschiedenis van hart- en vaatziekten, terwijl voor luchtvervuiling het geschatte relatieve risico het hoogst leek in de subgroep van ouderen. Echter, voor geen van deze verbanden werd overtuigend bewijs gevonden.

Het derde deel van dit proefschrift richt zich op de derde en laatste onderzoeksvraag, en bestaat uit een beschrijving van de resultaten van twee grote populatiestudies. **Hoofdstuk 5** presenteert eerst de resultaten van een groot bevolkingsonderzoek in de regio Eindhoven (GLOBE), waarin de relatie tussen wegverkeersgeluid aan de minst belaste gevel en geluidshinder werd onderzocht. In deze eerste studie werd het effect van een relatief stille gevel onderzocht. In de tweede studie, een populatiestudie in Amsterdam, werden de effecten van blootstelling aan wegverkeersgeluid aan de minst belaste gevel nader gekwantificeerd. De resultaten ondersteunen de hypothese van een gunstig effect van het hebben van een relatief stille gevel aan de woning. Deze studies dragen bij aan het vergroten van inzicht in de verwachte effecten van het verlagen van de blootstelling aan geluid aan de minst belaste zijde van de woning als maatregel om de nadelige effecten van geluid te verminderen, en draagt bij aan een meer volledige karakterisering van persoonlijke blootstelling.

In **hoofdstuk 6**, de algemene discussie, worden de resultaten van dit proefschrift in een breder perspectief besproken, worden relevante methodologische aspecten, gerelateerd aan dit type epidemiologisch onderzoek, bediscussieerd en worden aanbevelingen gedaan voor verder onderzoek.

Chapter 8

About the author

List of Publications

PhD Portfolio

Dankwoord

Chapter 8

About the author

Yvonne de Kluizenaar was born on the 17th of May 1974, in Eindhoven, The Netherlands. She is the daughter of Erik and Hetty de Kluizenaar. In 1992, she graduated from Gymnasium-β at the Eindhovens Protestants Lyceum, in Eindhoven. Subsequently, she started her study in Environmental Science (in Dutch: Milieuhygiene) with specialization in Air Quality at Wageningen University, Wageningen, the Netherlands. In 1997, she graduated from university and started working as a researcher at University College Dublin, Dublin, Ireland, in the field of air quality.

Since 2000, she is working as a research scientist at TNO in the field of environment and health. Effects of combined exposures, including environmental noise and air pollution, form a key research interest. At TNO, she has been involved in a broad range of national and European research and advisory projects, both as a researcher and as project manager. National projects were performed for the local and national government, including the former Dutch Ministry of Housing, Spatial Planning and the Environment (in Dutch: Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu; VROM) and the Ministry of Health Welfare and Sport (in Dutch: Ministerie van Volksgezondheid, Welzijn en Sport; VWS). Simultaneously with her full time position at TNO, she worked on her PhD research in collaboration with University Medical Center Groningen (UMCG), Groningen, the Netherlands and ErasmusMC, Rotterdam, the Netherlands. She presented her research as invited speaker at large international conferences, and has been involved in the organization of scientific research sessions at international conferences, as session chair. She is currently chair of International Committee of Biological Effects of Noise (ICBEN), Team 3: non auditory effects of noise.

List of Publications

De Kluizenaar Y, Gansevoort RT, Miedema HME, De Jong PE. Hypertension and Road Traffic Noise Exposure. Journal of Occupational and Environmental Medicine, 2007; 49(5): 484–492.

De Kluizenaar Y, Janssen SA, Van Lenthe FJ, Miedema HME and Mackenbach JP. Long-term road traffic noise exposure is associated with an increase in morning tiredness. Journal of the Acoustical Society of America, 2009; 126 (2): 626–633.

De Kluizenaar Y, Salomons EM, Janssen SA, Van Lenthe FJ, Vos H, Zhou H, Miedema HME and Mackenbach JP. Urban road traffic noise and annoyance: The effect of a quiet façade. Journal Acoustical Society America, 2011; 130 (4): 1936–1942.

De Kluizenaar Y, Van Lenthe FJ, Visschedijk AJH, Zandveld PYJ, Miedema HME, Mackenbach JP. Road traffic noise, air pollution components and cardiovascular events. Noise and Health 2013; 15(67): 388–397.

De Kluizenaar Y, Janssen SA, Vos H, Salomons EM, Zhou H, Van den Berg F. Road Traffic Noise and Annoyance: A Quantification of the Effect of Quiet Side Exposure at Dwellings Int. J. Environ. Res. Public Health 2013; 10(6): 2258–2270.

Van den Hooven EH, **de Kluizenaar Y**, Pierik FH, Hofman A, Van Ratingen SW, Zandveld PYJ, Mackenbach JP, Steegers EAP, Miedema HME, Jaddoe VWV. Air Pollution, Blood Pressure, and the Risk of Hypertensive Complications During Pregnancy The Generation R Study. Hypertension 2011; 57: 406–412.

Van den Hooven EH, Pierik FH, **de Kluizenaar Y**, Willemsen SP, Hofman A, Van Ratingen SW, Zandveld PYJ, Mackenbach JP, Steegers EAP, Miedema HME, Jaddoe VWV. Air Pollution Exposure During Pregnancy, Ultrasound Measures of Fetal Growth, and Adverse Birth Outcomes: A Prospective Cohort Study. Environmental Health Perspectives 2012; 120(1): 150–156.

Van den Hooven EH, **de Kluizenaar Y**, Pierik FH, Hofman A, Van Ratingen SW, Zandveld PYJ, Lindemans J, Russcher H, Steegers EAP, Miedema HME, Jaddoe VWV. Chronic Air

Pollution Exposure during Pregnancy and Maternal and Fetal C-Reactive Protein Levels: The Generation R Study. Environmental Health Perspectives 2012; 120(5): 746–751.

Van den Hooven EH, Jaddoe VWV, **de Kluizenaar Y**, Hofman A, Mackenbach JP, Steegers EAP, Miedema HME, Pierik FH. Residential traffic exposure and pregnancy-related outcomes in mother and child: A prospective birth cohort study. Environmental Health 2009; 8(59).

Van den Hooven EH, Pierik FH, van Ratingen SW, Zandveld PYJ, Meijer EW, Hofman A, Miedema HME, Jaddoe VWV, **de Kluizenaar Y**. Air pollution exposure estimation using dispersion modelling and continuous monitoring data in the Generation R Study. Environmental Health 2012; 11(9).

Van den Hooven EH, Pierik FH, **de Kluizenaar Y**, Hofman A, van Ratingen SW, Zandveld PYJ, Russcher H, Lindemans J, Miedema HME, Steegers EAP, Jaddoe VWV. Air pollution exposure and markers of placental growth and function. The Generation R Study. Environmental Health Perspectives 2012;120(12):1753–1759.

Sonnenschein-van der Voort AM, **de Kluizenaar Y**, Jaddoe VWV, Gabriele C, Raat H, Moll HA, Hofman A, Pierik FH, Miedema HME, De Jongste JC and Duijts L. Air pollution, fetal and infant tobacco smoke exposure, and wheezing in preschool children: a population-based prospective birth cohort. Environmental Health 2012; 11 (91).

Hohmann C, Grabenhenrich L, **de Kluizenaar Y**, Tischer C, Heinrich J, Chen CM, Thijs C, Nieuwenhuijsen M, Keil T. Health effects of chronic noise exposure in pregnancy and childhood: a systematic review initiated by ENRIECO. International Journal of Hygiene and Environmental Health 2013; 216(3): 217–229.

Levie D, **de Kluizenaar Y**, Hoes-van Oeffelen ECM, Hofstetter H, Janssen SA, Spiekman ME, Koene FGH. Determinants of ventilation behavior in naturally ventilated dwellings: Identification and quantification of relationships. Building and Environment 82 (2014) 388–399.

Submitted

Basner M, Brink M, **de Kluizenaar Y**, Hong J, Janssen SA, Klaeboe R, Leroux T, Liebl A, Matsui T, Sliwinska-Kowalska M, Sörqvist P. ICBEN Review of Research on the Biological Effects of Noise 2011–2014.

PhD Portfolio

Name PhD student:	Yvonne de Kluizenaar
Erasmus MC Department:	Public Health
Research School:	Netherlands Institute of Health Sciences

1. PhD training

	Year	Workload (Hours/ECTS)
General courses		
– Certified project management associate IPMA level D	2009	1.4
– Communication skills. In Dutch: 'Effectief beïnvloeden'	2011	0.6
Specific courses		
– Cohort studies: Design, Analysis and Interpretation, 16 – 20 August, 2004, Rotterdam, The Netherlands. (Erasmus Summer Programme)	2004	0.7
Attended seminars, symposia, meetings and workshops (selection)		
Research meetings at TNO	2000-now	
– PREVEND research meetings	2006-2007	0.1
– CALM Conference, 'Research and Strategies for Less Noise in Europe', 2 October 2007, Brussels, Belgium	2007	0.5
– Workshop on Environment & Health: Air Quality Research Needs and Opportunities in the EU 7th Framework Programme, 15 – 16 January 2007, Brussels, Belgium	2007	0.6
– Workshop meetings, ENNAH-European Research Network on Noise and Health	2009-2011	2.0
– Project meetings QSIDE - The positive effects of quiet facades and quiet urban areas on traffic noise annoyance and sleep disturbance	2010-2013	1.4
– Project meetings OFFICAIR- On the reduction of health effects from combined exposure to indoor air pollutants in modern offices	2012-2014	4.0
– OFFICAIR Workshop: On Indoor Air Quality in Modern Office Buildings, 24 May 2013, Eötvös Loránd University, Budapest, Hungary		
– OFFICAIR Final Workshop, 22 October, 2013, Brussels, Belgium		
– Project meetings RetroKit - Toolboxes for systemic retrofitting	2012-now	2.0

Presentations (selection)

–	Presentation at Generation R seminar: 'Environment and child health', 19 April, 2012, Rotterdam, The Netherlands	2012	0.5
–	Presentations at several ENNAH workshop meetings	2009-2011	
–	Presentation at "Workshop stille, geluidluwe gevels", 15 May 2012, Den Haag, The Netherlands	2012	0.5

National and international conferences

Session organizing and/or chairing

–	Euro-Noise 2012, 9th European Conference on Noise Control, 10 – 13 June 2012, Prague, Czech Republic. *Session chair*	2012	1.0
–	Inter-Noise 2013 , the 42nd International Congress and Exposition on Noise Control Engineering , 15 – 18 September 2013, Innsbruck, Austria. *Session co-chair*	2013	1.0
–	ICBEN 2014, the 11th International Congress on Noise as a Public Health Problem, 1– 5 June 2014, Nara, Japan. *Session organization*	2014	0.5

Invited speaker

–	Inter-Noise 2007, the 36th International Congress and Exhibition on Noise Control Engineering, 28 – 31 August 2007, Istanbul, Turkey. *Oral presentation*	2007	1.0
–	ICBEN 2008, the 9th Congress of the International Commission on Biological Effects of Noise, Noise as a Public Health Problem, 21 – 25 July, 2008, Mashantucket, Connecticut, USA. *Conference paper*	2008	0.5
–	ISEE-ISEA Joint Annual Conference: Exposure and Health in a Global Environment, 12 – 16 October, 2008, Pasadena, USA. *Oral presentation*	2008	1.0
–	Euro-Noise 2009, the 8th European Conference on Noise Control, 26 – 28 October, 2009, Edinburgh, Scotland. *Conference paper*	2009	0.5
–	Inter-Noise 2009, the 38th International Congress and Exposition on Noise Control Engineering, 23 – 26 August, 2009, Ottawa, Canada. *Oral presentation*	2009	1.0
–	Inter-Noise 2013, the 42nd International Congress and Exposition on Noise Control Engineering, 15 – 18 September, 2013, Innsbruck, Austria. *Oral presentation*	2013	1.0

Other

– International Conference on Environmental Epidemiology & Exposure, 2 – 6 September 2006, Paris, France. *Poster presentation*	2006	1.0
– Inter-Noise 2010, the 39th International Congress on Noise Control Engineering, 13 – 16 June, 2010, Lisbon, Portugal. *Oral Presentation*	2010	1.0
– Euro-Noise 2012, the 9th European Conference on Noise Control, 10 – 13 June 2012, Prague, Czech Republic. *Oral presentation.*	2012	1.0

Other

– Review article: 'Health effects of chronic noise exposure in pregnancy and childhood: a systematic review initiated by ENRIECO', International Journal of Hygiene and Environmental Health, *Co-author*	2012	0.5

2. Teaching	**Year**	**Workload (Hours/ECTS)**
Lecturing		
– Guest lecture, Technische Universiteit Delft	2014	0.5
Supervising Master theses		
– Nienke Elske Dijkstra, MSc Health Sciences, Vrije Universiteit Amsterdam Project title: *Office related determinants of dry eye complaints: The OFFICAIR study*	2013	2.0
– Deborah Levie, MSc Health Sciences, Vrije Universiteit Amsterdam Project title: *Determinants of ventilation behavior in naturally ventilated dwellings; identification and quantification of relationships*	2014	2.0
Co-supervising PhD theses		
– Edith van den Hooven, Erasmus Universiteit Rotterdam Project title: *Air Pollution Exposure and Pregnancy Complications The Generation R Study*	2008-2012	6.0
Total		35.8

Dankwoord

Promoveren is een leerproces, waarin je een nieuwe manier van kijken, denken en creëren ontwikkelt. Ik ben dankbaar dat ik in de gelegenheid ben gesteld dit te doen vanuit TNO, in samenwerking met vooraanstaande onderzoeksgroepen: de afdeling Maatschappelijke Gezondheidszorg (Department of Public Health) van ErasmusMC, de afdeling Nefrologie (Department of Internal Medicine - Nephrology) en PREVEND studie van UMCG. Verbinden van kennis uit verschillende disciplines kan leiden tot waardevolle nieuwe inzichten. Tijdens mijn promotie heb ik de kans gekregen om met experts uit verschillende vakgebieden samen te werken en heb daarvan veel meer geleerd dan hetgeen beschreven staat in dit proefschrift alleen.

Promoveren vraagt motivatie en discipline. Het is een traject van jaren waarin obstakels, tegenslagen en gelukkig ook successen elkaar afwisselen. Ik ben dankbaar voor de steun uit mijn omgeving, van familie, vrienden en collega's, die mij heeft geholpen dit traject te doorlopen. Mijn dank gaat uit naar velen die direct of indirect hebben bijgedragen aan de totstandkoming van dit manuscript, waarvan ik hier graag een aantal mensen in het bijzonder wil noemen.

Mijn dank gaat uit naar mijn copromotor en voormalig afdelingshoofd Henk Miedema. Beste Henk, ik weet nog goed dat ik uit Ierland overkwam en bij jouw afdeling bij TNO solliciteerde en we elkaar voor het eerst spraken. Je wist dat ik graag promotieonderzoek wilde doen. Je hebt mij geholpen dit te mogelijk te maken. Bedankt dat je mij hiervoor de ruimte hebt gegeven. Bedankt ook voor jouw begeleiding, je wijze woorden en de inspirerende gesprekken over het vakgebied en daarbuiten. Het is al even geleden dat dit onderzoek onder jouw hoede is opgestart. Ik ben blij dat ik het met jou als copromotor nu ook mag afronden.

Prof.dr. J.P. Mackenbach, mijn eerste promotor, beste Johan, bedankt voor de mogelijkheden die je mij hebt gegeven en jouw begeleiding. Ik heb bewondering voor je wetenschappelijk inzicht en de manier waarop je altijd precies de juiste vragen wist te stellen. Hoe druk je het ook had, jouw reactie en input kreeg ik vaak dezelfde dag nog. De vriendelijke rust, aandacht en zorgvuldigheid waarmee je de dingen weet te doen, met een bijzonder grote efficiëntie, zijn voor mij een voorbeeld.

Prof.dr. P.E. de Jong, mijn tweede promotor. Beste Paul, bedankt dat je mij de mogelijkheid hebt gegeven en hebt gegund te werken binnen de bijzondere PREVEND studie. Bedankt voor je begeleiding en je kritische en relevante vragen die me hebben

geholpen het werk te verbeteren. Bedankt ook voor het warme welkom dat ik bij jullie in Groningen altijd heb mogen ervaren. Ik kijk met goede herinneringen terug op de tijd die ik in Groningen heb mogen doorbrengen.

Ron Gansevoort, en Frank van Lenthe, mijn 'dagelijks' begeleiders in Groningen en Rotterdam. Beste Ron, bedankt voor jouw begeleiding, de fijne samenwerking en de altijd hartelijke ontvangst in Groningen. Beste Frank, bedankt voor jouw begeleiding en waardevolle input. Ik kijk met positieve herinnering terug op de tijd dat ik bij jullie op de afdeling zat en wij een tijd een werkkamer deelden.

Paul, Ron, medepromovendi Nienke, Auke en Jacolien, PREVEND polimedewerkers en Winie, jullie maakten dat ik mij thuis voelde in Groningen. Ondanks de afstand en omstandigheden waardoor ik minder tijd in Groningen heb kunnen doorbrengen dan vooraf gehoopt, hebben jullie mij altijd het prettige gevoel gegeven deel uit te maken van het PREVEND onderzoeksteam. Bedankt voor de fijne tijd, het is dankzij jullie dat de uitdrukking "Er gaat niets boven Groningen" voor mij diepere betekenis heeft gekregen.

Leden van de leescommissie, Prof.dr. H Tiemeier, Prof.dr. H. Boersma en Prof.dr. S. Stansfeld, wil ik hartelijk bedanken voor de bereidheid mijn proefschrift te lezen en te beoordelen. Dear Prof.dr. Stansfeld, thank you very much for your kind willingness to be part of the evaluation committee and to assess my PhD dissertation.

De studies beschreven in dit proefschrift waren niet mogelijk geweest zonder de deelname van de vele duizenden deelnemers van de PREVEND cohort, de GLOBE cohort en de Amsterdam Health Monitor. Mijn dank gaat ook uit naar de gemeenten Groningen en Eindhoven en GGD Amsterdam voor het beschikbaar stellen van benodigde gegevens.

Hierbij wil ik ook mijn coauteurs bedanken voor de prettige samenwerking en jullie waardevolle bijdrage: Peter en Antoon (luchtkwaliteit), Erik en Han (akoestiek en GIS), Sabine, Frits (psychologie, effecten van geluid), en onze collega Henk Vos die door ons wordt gemist.

Mijn TNO collega's wil ik bedanken voor hun betrokkenheid en interesse, voor de fijne werksfeer, gezellige lunchpauzes en humor. Corrie, je stond altijd voor klaar om me dingen uit handen te nemen als het druk was, bedankt daarvoor. Jeroen, eerst collega, nu afdelingshoofd, wil ik bedanken voor de ruimte die me is gegund. Toen ik net bij TNO begon heb jij me met veel geduld 'ingewerkt' in de ruimtelijke modellering van milieublootstellingen. Je stond altijd klaar om me te helpen als dat nodig was. Jouw betrokkenheid als collega, nu ook als leidinggevende, waardeer ik heel erg.

Mijn vrienden wil ik bedanken voor al die gezellige momenten die voor de broodnodige ontspanning en afwisseling zorgen, maar verder weinig met dit proefschrift te maken hebben.

Sabine en Petra, bedankt dat jullie mijn paranimfen wilden zijn. Sabine, mijn collega bij TNO, we deelden de afgelopen jaren onze werkkamer, lief en leed en onze passie voor het geluid-gezondheidsonderzoek. Je bent een geweldige collega. Je staat altijd klaar om je collega's te helpen wanneer dat nodig is. Bedankt voor de leerzame gesprekken, je waardevolle adviezen en voor je vriendschap.

Petra we kennen elkaar al van kleins af aan en hebben elkaar zien opgroeien. Wat hebben we sinds het moment dat we elkaar voor het eerst zagen veel meegemaakt samen. Wat promoveren betreft ben jij mij lang geleden in Maastricht al voorgegaan, een hoogtepunt. De afgelopen jaren op moeilijke momenten werd eens te meer duidelijk hoe bijzonder en waardevol onze vriendschap is. Ik ben heel blij dat jij tijdens de verdediging aan mijn zijde wil staan.

Henk en Noor, mijn lieve schoonouders, de afgelopen jaren stonden jullie altijd klaar om ons te helpen. Regelmatig pasten jullie op de jongens, zodat ik kon werken aan de afronding van het proefschrift. Er zijn momenten geweest dat ik niet durfde geloven dat het ooit af zou komen. Dan kwamen jullie met de jongens op Skype en riepen met de kinderen in koor 'goed studeren hoor!'. Bedankt voor jullie steun. Nu is het er dan toch!

Remco, mijn lieve broer, fijn dat jij er bent. Ik bof met zo'n broer.

Mijn lieve ouders, nu ik zelf moeder ben realiseer ik me wat jullie voor ons hebben gedaan. Jullie opvoeding, toewijding, liefde en steun hebben me gemaakt tot wie ik nu ben en hebben mogelijk gemaakt te bereiken wat ik bereikt heb. Papa, bedankt voor je hulp bij de lay-out van dit boek, de afgelopen weken soms tot in de nachtelijke uurtjes. Het is mooi geworden! Ik koester de gedachte dat het daarmee (een klein beetje) 'van ons samen' is.

Niels en Rinze, lieve jongens, ik ben zo blij met jullie! Het leven met jullie is een feest. Jullie hebben me leren zien wat echt belangrijk is.

Lieve Mark, in de hoogtepunten en dieptepunten van de afgelopen jaren heb jij aan mijn zijde gestaan. Als een rots in de branding en met veel geduld, stond jij altijd klaar om mij te steunen, ook op de moeilijkste momenten. Ik ben blij dat ik nu deze mijlpaal met je mag delen en kijk uit naar de toekomst!