Transportation noise exposure and children's health and cognition

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De blootstelling aan transport geluid en de gezondheid en het cognitief functioneren van kinderen

(met een samenvatting in het Nederlands)

Proefschrift

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Contents

Glossary

ANEI	Australian Noise Exposure Index. This is a noise metric, expressing the level of aircraft noise in Australia. As opposed to equivalent noise metrics (such as $L_{Aeq,\ 7\text{-}23hrs}$), the ANEI not only takes into account the energy level of noise level events, but also the number of events and day/night loadings from social surveys in Australia
CRIE	CITO Readability Index for Elementary and Special Education
DALY	Disability-adjusted Life Years. Aggregated measure that gives an indication of the (potential) number of healthy life years lost in a population due to premature mortality or morbidity, the latter being weighted for the severity of the disorder.
DMST	Digit Memory Span Test
EMPARA	Environmental Model for Population Annoyance and Risk Analysis
HIA	Health Impact Assessment; a combination of procedures, methods and instruments used for assessing the potential health impacts of certain matters. These can vary from a single environmental factor (such as air pollution or noise) to a more complicated set of factors, for instance in an infrastructural or industrial project.
HECT	Hand-Eye Coordination Test
KINDL	KINDer Lebensqualitätsfragebogen. The KINDL is a short questionnaire to assess health-related quality of life in children
LAAS	Los Angeles Airport Study
LARES	Large Analysis and Review of European housing and health Status
L_{dn}	Day-Night Level. This is the equivalent sound level over 24 hours, increasing the sound levels during the night (23-07 hours) by 10 dB(A) since noise during the night is more annoying than during day-time
Likert-scale	A type of psychometric response scale often used in questionnaires; it is the most widely used scale in survey research. When responding to a Likert-questionnaire item, respondents specify their level of agreement to a statement
MAS	Munich Airport Study
NES	Neurobehavioral Evaluation System
OECD	Organisation for Economic Co-operation and Development
OR	Odds Ratio
RANCH	Road Traffic and Aircraft Noise Exposure and Children’s Cognition and Health: Exposure-Effect Relationships and Combined Effects
RR	Relative Risk
SAT	Switching Attention Test
SDST	Symbol Digit Substitution Test
SEHS	Schools Environment and Health Study

SRTT	Simple Reaction Time Test
TMS	Tyrol Mountains Study
VAS	Visual Analogue Scale. This is a measurement instrument that tries to measure a characteristic or attitude that is believed to range across a continuum of values and cannot easily be directly measured
WHO	World Health Organization
WLSS	West-London Schools Study

1 Introduction

Transportation is an essential component of modern life. There are different modes each associated with their specific impact on society. Most human transportation activities (e.g. driving a car, the landing of a plane) generate sounds. Transportation (road, rail and air traffic) is the most important source of community noise in Europe [1]. Recent studies show that a large part of the population is exposed to different sources of transportation noise [2]. Secondly, noise is also one of the environmental stressors purported to have adverse effects on health and well-being [3].

1.1 Noise exposure

Recently, the World Health Organization (WHO) estimated that approximately 20% of the population in European Union countries is exposed to road traffic noise at levels exceeding 65 dB(A) during daytime; more than 30% is exposed to levels exceeding 55 dB(A) during night-time [2] (see also Appendix 1). Scientists consider these levels to be unacceptable. A recent analysis including 53 European airports with more than 50.000 civil jet movements, revealed that at community level the total number of people exposed to aircraft sound levels exceeding 65 dB(A) (L_{den}) will increase by 57% in the period 2002 - 2015 (see also Figure 1.1); the number of people exposed to aircraft sound levels exceeding 55 dB(A) (L_{den}) will increase by 39% [4].

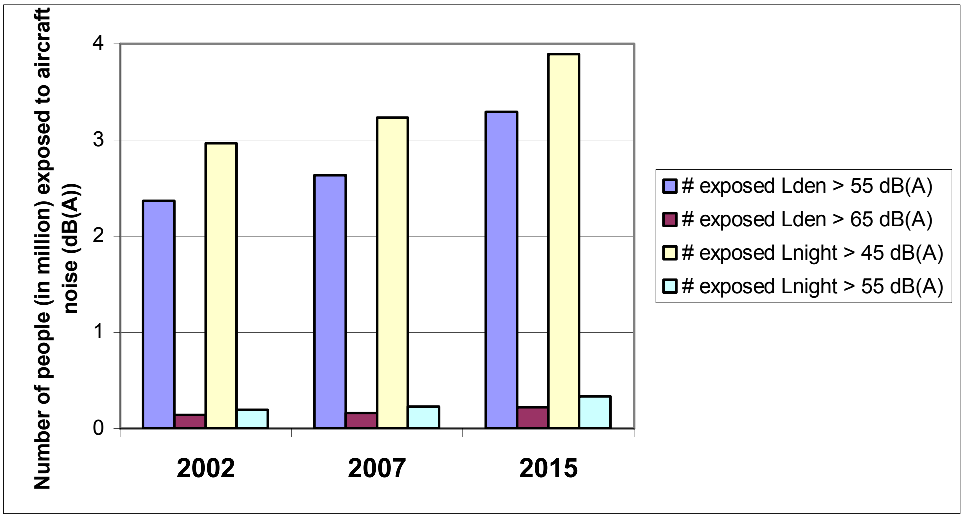

FIGURE 1.1 *The number of people exposed to aircraft noise (L_{den}, L_{night}) in Europe in the period 2002 - 2015 [4].*

Unfortunately, no improvement is expected in the sound exposure levels experienced by citizens across Europe [5]. During recent decades there has been a change in the relationship between transport vehicles and noise exposure: due to technological measures, the noise emission per vehicle has decreased substantially; on the other hand, more vehicles, carrying fewer passengers per vehicle, are making more and longer trips [1]. On average, the number of passenger cars has increased by around 3% a year in OECD-countries during the past 20 years; the number of road passenger kilometres has increased by around 5%. Travel by car doubled between 1970 and 1999 [9]. Despite the enforcement of increasingly stringent legislation on noise sources and the numerous measures in the field of noise abatement at European, national and local levels, the noise-problem has not decreased. Without additional policy measures, more people will be exposed to higher sound levels in future decades. This trend will be intensified by factors such as high population density, and increasing urbanisation [1].

Since noise is one of the environmental stressors purported to have adverse effects on human health and well-being [3], the noise related disease burden is expected to rise: Recently, Knol & Staatsen (2005) estimated that the noise-related disease burden will probably have risen by 20% in 2020 (compared to the year 2000). This trend is mainly driven by the number of people with severe annoyance and sleep disturbance [10].

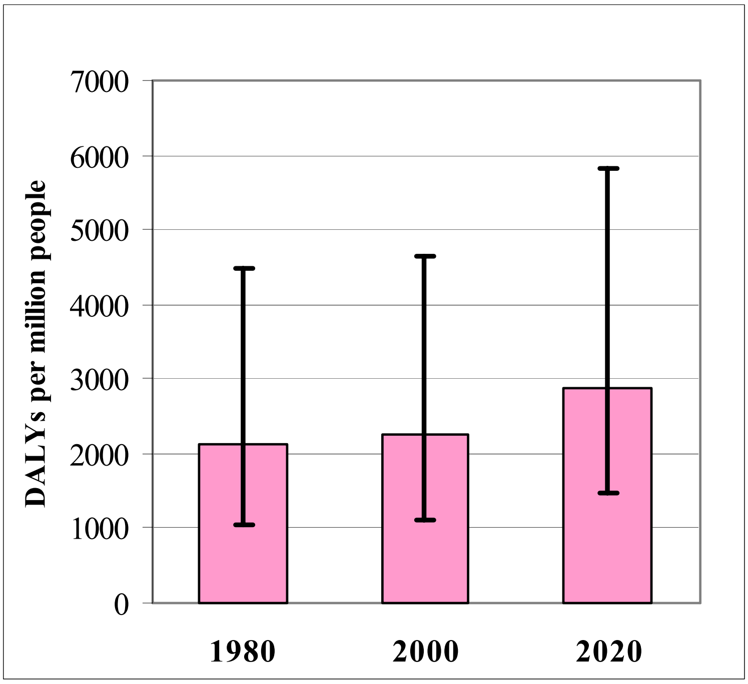

FIGURE 1.2 *Burden of disease (DALYs per 1 million people) caused by exposure to noise, 1980 – 2020, with 90% prediction intervals [10]. DALY: Disability-adjusted Life Year.*

1.2 The effects of transportation noise on children

This thesis focuses on the effects of transportation noise exposure on children. Children's exposure may differ from adults' exposure to noise, since children spend their time in different settings to adults and because they behave differently. Furthermore, children are suspected of being more susceptible to noise exposure for different reasons: (i) their organs are not fully developed; (ii) children are not always aware of the dangers; and (iii) children have not (fully) developed coping mechanisms and cannot change their situation, whereas adults may have the power and/or resources to do so [11]. In addition, results from observational studies have shown that many adult diseases may originate in childhood. Understanding the way the environment affects children's health and development could therefore be important for the prevention of adult illness [12].

Based on recent overviews, a set of outcomes related to health and well-being that are often reported in relation to transportation noise exposure, can be identified: behavioural responses such as coping strategies and complaints, 'social' responses such as annoyance or perceived sleep disturbance, acute physiological responses, cognitive responses such as task interference, effects on children's learning, chronic physiological responses (hypertension), clinical morbidity such as mental health effects, cardiovascular disease, immune system deficiencies, and hearing loss [3, 6 - 8].

In past decades there has been a great deal of research into the effects of noise on children. A broad range of effects have been observed and reported: Effects on hearing, cognition, motivation and the cardiovascular and endocrine system. But also effects on mental health, annoyance, self-reported health and sleep have been investigated. Only a few studies investigated the effects of noise exposure on congenital abnormalities, birth weight or disorders related to the immune system [6, 13 - 18]. Current insights in childhood effects of transportation noise, however, are not sufficiently sound and consistent to allow an assessment of the effect of transportation noise on the health and well-being of children in The Netherlands.

This thesis focuses on cognition, annoyance, perceived health and blood pressure. These are the end points most likely to occur in children in The Netherlands. Below, the current understanding of transportation noise on these end points is summarised. A conceptual model of how noise may affect health is briefly introduced in section 1.3. In section 1.4, some methodological issues and shortcomings in previous studies are described. Section 1.5 then formulates the specific objectives for this thesis.

Most studies investigating the impacts of noise exposure on children have focused on cognition. In the studies investigating the effects of long-term exposure to air-, rail, and road traffic noise, cognitive effects were found on reading, attention, problem solving and memory. The general finding was that performance on the complex tasks was mainly affected [6].

Annoyance is a collective term for several negative reactions such as irritation, dissatisfaction or anger, which arise when noise disturbs someone's daily activities [3]. In the few child studies that have assessed residential noise annoyance in a quantitative and systematic manner, children living in noisy areas were significantly more annoyed by noise in their community than children living in quieter areas [19 - 25]. The conclusions from studies investigating the effects of noise exposure on children's blood pressure and self-reported health are limited and inconsistent [26]. Although a few studies have been carried out that have done an attempt to derive valid exposure-response relations [27, 28], no source-specific exposure-response relations for the above mentioned effects are as yet available for children. Exposure-response relations are important when we want to determine guideline values. Alternatively, they can be used to estimate the noise-related disease burden; finally, exposure-response relations can be used to inform the public and to increase the public and political awareness of noise effects [26].

1.3 Transportation noise, health and cognition: underlying (biological) mechanisms

1.3.1 The effects of noise on health and well-being

In the complex relation between noise and health it is often assumed that noise acts as a stress factor and as such has the potential of precipitating diseases which are partly caused by stress as a co-factor [18]. At the moment several models describing the relation between noise and health are available [13, 29, 30]. Exemplary for these models is the framework of the Dutch Health Council [29] (see also Figure 1.3). In this approach it is assumed that health is determined by a combination of endogenous and exogenous factors such as the physical and social environment and life style. Noise exposure is only one of these exogenous factors. The influence of noise may be modified by personal characteristics such as attitude and coping style. Noise exposure can induce disturbance of sleep and daily activities, annoyance and stress, which may lead to all sorts of long-term responses, such as hypertension which is in turn a risk factor for cardiovascular disease. Noise exposure may also induce a vegetative response directly, causing somatic and psycho-somatic responses. In turn, these may affect the risk of disease.

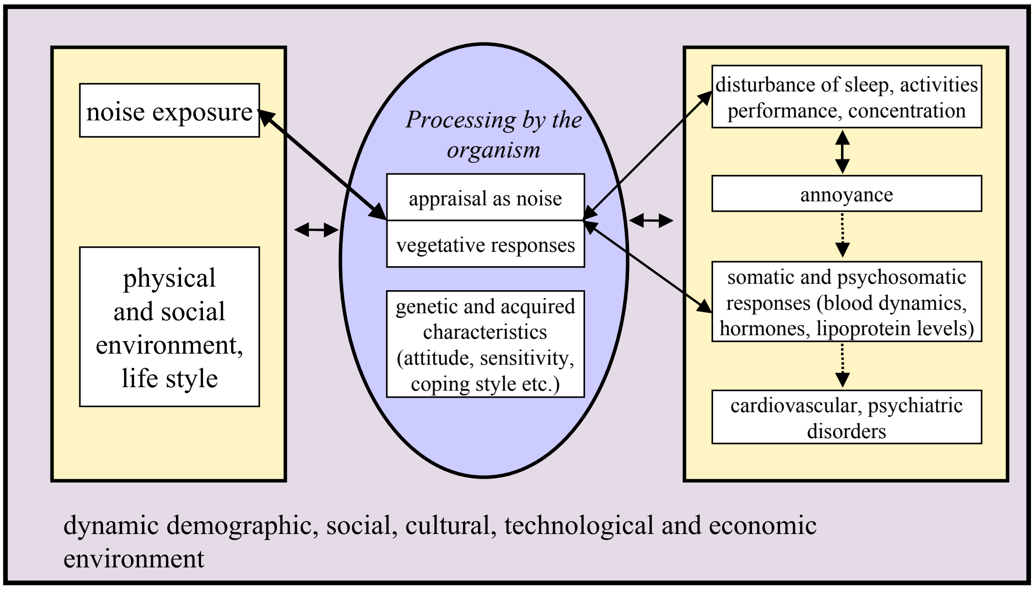

FIGURE 1.3 *Conceptual model of how noise exposure may affect human health and well-being [29].*

Appraisal is a process that determines whether or not sounds, that are present in our environment, are regarded as being noisy [13]. In earlier research investigating adults, it was suggested that the appraisal of the stressor is one of the essential factors predicting short- and long-term health effects of exposure to daily repeated chronic stressors such as environmental noise [31]. It is unknown how this mechanism operates for children's health and cognitive functioning in relation to noise.

1.3.2 The effects of noise on cognitive functioning

As opposed to the effects of noise on health and well-being, there is still no theory that can adequately account for the circumstances in which noise will affect cognitive performance. One of the mechanisms which are often mentioned is allocation of attention: When attention must be shared among several items, errors in performance during noise occur in the less important cues, reflecting allocation of attention to more important, primary cues at the expense of attention to secondary cues [13, 19]. Alternatively, noise may affect the quality of verbal communication (awareness of speech). This might cause difficulties in written and spoken language, and delays in language acquisition. Furthermore, it might affect children's ability to read, which might limit the scope of their vocabulary. Disturbance in the intelligibility of speech communication may have serious repercussions on the education and intellectual development of young people. If a message is degraded, one has to reconstitute the fragments that may be masked by the noise: as a consequence there may be loss of meaning in the content of teachers' instruction and problems with the intelligibility of letters, words or even entire sentences. In a noisy environment, children may confuse certain consonants; sound distortion makes certain parts of words, and particularly endings, unintelligible [6, 32].

Children who are exposed to noise during the long term, or who were reared in noisy settings may become inattentive to acoustic cues; they adapt to noise interference during activities, filtering out the unwanted, disturbing, distracting sound stimuli or acoustic cues. However, at a certain moment there is a risk that this 'tuning out strategy' might over-generalise such that the child tunes out the acoustic information indiscriminately: no distinction is made between relevant and irrelevant sounds. This lack of insensitivity to acoustic cues may have negative repercussions for the acquisition of verbal skills, such as reading [12, 13, 19, 33]. However, mechanisms such as tuning out and awareness of speech, are suspected to play a role especially in relation to the effects on reading, since they are important in the child's language acquisition.

According to the literature, irritability and negative affect are increased by exposure to noise. It is hypothesised that noise can potentiate the expression of aggression. Behavioural changes might affect the social climate at school [19, 32]. E.g. it appears that people exposed to noise are significantly less likely to help others in need of assistance. Community noise not only affects the children but also their teachers and parents: studies have found that road traffic noise exposure is generally associated with teacher rated behaviours [19]. Teacher frustration and interruptions in communication between parents or teachers and children could also be a mechanism for cognitive effects [33 in: 12].

The noise-related effects found in children might not only be a direct effect of noise exposure, but might also be the consequence of a decrease in sleep quality, caused by noise exposure during the night. Time activity studies show that children spend a large part of their time sleeping [34, 35]. A person's sleep is important for learning and memory; sleep periods are favourable for brain plasticity and for learning and memory [36]. One of the hypotheses that result from this is that sleep disturbances may act as a mediator for the anticipated noise effects on e.g. attention and aspects of memory [37, 38]. Furthermore, chronic night-time noise exposure might disturb the secretion of stress hormones such as cortisol which could affect children's health [39]. Since most studies only focused on the effects during daytime at school, there is a gap in the knowledge of the impact of night-time noise.

1.4 Studies investigating the effects of noise in children: methodological issues

Several methodological problems emerge from previous studies investigating the effects of noise exposure in children, such as an inadequate exposure assessment, the lack of adjustment for potential confounding factors, the often inadequate statistical techniques employed and the diversity of methods used for the measurement of effects. The next sections will give more detail on some of these issues that are specific for studies investigating the effects of noise in children.

1.4.1 Exposure assessment

In studies investigating the impacts of noise in children, noise exposure is usually expressed as the average of the levels of noise over a certain time (T), expressed in dB(A): the so-called equivalent noise metrics [40]. The available noise exposures in these studies usually relate to noise levels outside schools and/or dwellings, and are averages for a longer period (3 months or 1 year). Especially in recent years, the level of noise exposure has been estimated by means of noise models incorporated in Geographic Information Systems (GIS). For example: for exposure to road traffic noise, these models are able to predict equivalent noise levels as a function of traffic data provided by a traffic model, under the condition that a number of parameters (such as the characteristics of the road network, the town buildings, and the site of the environment and the meteorological conditions) are known and acquired as input data. A noise model will predict equivalent noise levels at user defined outdoor points. From this, conventional noise indicators can be calculated (e.g. L_{den}, $L_{Aeq,\ 7\text{-}23\ hrs}$).

Most studies investigating the impacts of noise exposure on children have involved between-group comparisons (high versus low): noise levels were measured or modelled for a residential area, a neighbourhood or a city. Subsequently, this noise level was assigned to everybody who is a member of that group: the children living or attending a school in that particular neighbourhood or residential area. It is recognized that the results of these studies may be sensitive to decisions about cut-off points used to categorise continuous exposure variables and the method used to assign scores to exposure categories [41]: the exposure assessment and the inability to apply individual exposure estimates (if available) to larger study populations might have caused exposure misclassification.

When investigating the effects of noise on children’s cognitive functioning, most studies focus on exposure at school, since much cognitive work is expected from children while they are at school. As is already addressed in Section 1.3.2, it is, however, unknown whether these effects should be exclusively attributed to the noise exposure in school. Thus, under such mechanisms, night-time noise levels at home might be a better exposure indicator than day-time school levels.

1.4.2 Operationalisation and measurement of health and cognition

The diversity of methods used for the operationalisation and measurement of the study end points can complicate the comparison of the results of studies. This is quite evident for annoyance, perceived health and cognition; for blood pressure this is not an issue.

Annoyance

In the studies investigating children's annoyance reactions, different methods to assess children's annoyance were used: In the Munich Airport study, the general rating of annoyance was based on magnitude estimates of noise annoyance for a range on sounds, using a Visual Analogue Scale (VAS) together with a questionnaire of 21 Likert-scale items including the assessment of different degrees of perception of several noise sources and air quality. In addition, the annoyance was measured with seven child-adapted standard questions, assessing the level of annoyance felt by the child when they heard four sources of environmental noise [19, 20]. In the Schools Environment and Health Study (SEHS) and the West London Schools Study (WLSS), annoyance was measured with child-adapted questions with 4- and 5-points Likert-scales, respectively [21-23]. To assess children's annoyance in the Tyrol Mountains Study (TMS), amongst others an environmental list of 19 items, assessing perception and annoyance or disturbance was used [24, 25]. Although each of the studies purports to measure annoyance, it is not fully clear what is being measured. Because of the lack of a standard methodology for measuring annoyance in children, the translation of scores from one method to the others is largely unknown; as a consequence it is not possible to pool or summarise the results of these studies in order to derive exposure-response relations.

Cognition

Recent observational studies have investigated the effects of noise on cognitive performance by means of selected paper-and-pencil tests measuring reading (comprehension), sustained attention, and long-term or working memory [13, 19-23]. However, comparison between studies investigating the effects of noise on these cognitive end points shows that the same concepts are not always measured in these studies: For example, while some studies measure more technical aspects of reading (e.g. spelling and grammar), others measure reading comprehension. Alternatively, when administering the same reading test in different countries, cultural differences might affect the outcome. In addition, it is difficult to select appropriate tests that are sensitive to the effects of noise at specific stages of development, because of the many developmental stages through which children progress [42]. Reliance upon insensitive developmental outcomes (simple cognitive tasks) may cause underestimation of the effect of noise [18].

Perceived health

With regard to perceived health, comparison is also difficult because a lot of definitions and terms for perceived health were used across studies. Terms mentioned for perceived health were “symptoms”, “stress responses”, “quality of life impairment”, “general health”, “mental health”, and “psychosomatic health”. As is the case for annoyance, it was not measured in a uniform way. In general we can distinguish studies (i) using symptoms or symptom lists, and (ii) studies using quality of life scales (with symptoms included) such as the KINDer Lebensqualitätsfragebogen (KINDL).

1.4.3 Conclusion

Different, sometimes competing, working mechanisms of how noise affects children’s health are suggested. Some effects are supposed to be precipitated through (chronic) stress, while others may arise directly. There is still no theory that can adequately account for circumstances in which noise will affect cognitive performance. Given the variety of the assumed working mechanisms, no single exposure indicator emerges as the indicator of choice. Day-time and night-time exposure both appear relevant. Due to a lack of source-specific exposure-response relations describing the association between noise exposure and specific health and cognitive end points in children, it is not possible to estimate the magnitude of the effects among children attributable to sound exposure levels in The Netherlands. The gaps encountered are the consequence of a limited noise exposure range, and the lack of uniformity of the measurement of end points. Moreover, shortcomings in design hamper the possibilities for quantitative meta-analysis and subsequent assessment of the noise impact on children in The Netherlands.

1.5 Objectives

This thesis had the following objectives:

- To quantify the relation between aircraft and road traffic noise exposure in both the home and the school setting and cognitive performance, annoyance, perceived health and blood pressure in children;
- To investigate whether the appraisal of noise affects the association between aircraft-and road traffic noise exposure and blood pressure, perceived health and cognitive performance in children;

- To investigate whether the effects of noise exposure on blood pressure and annoyance found in children differ from those found in adults; and
- To estimate the number of children affected by noise exposure for the Dutch situation.

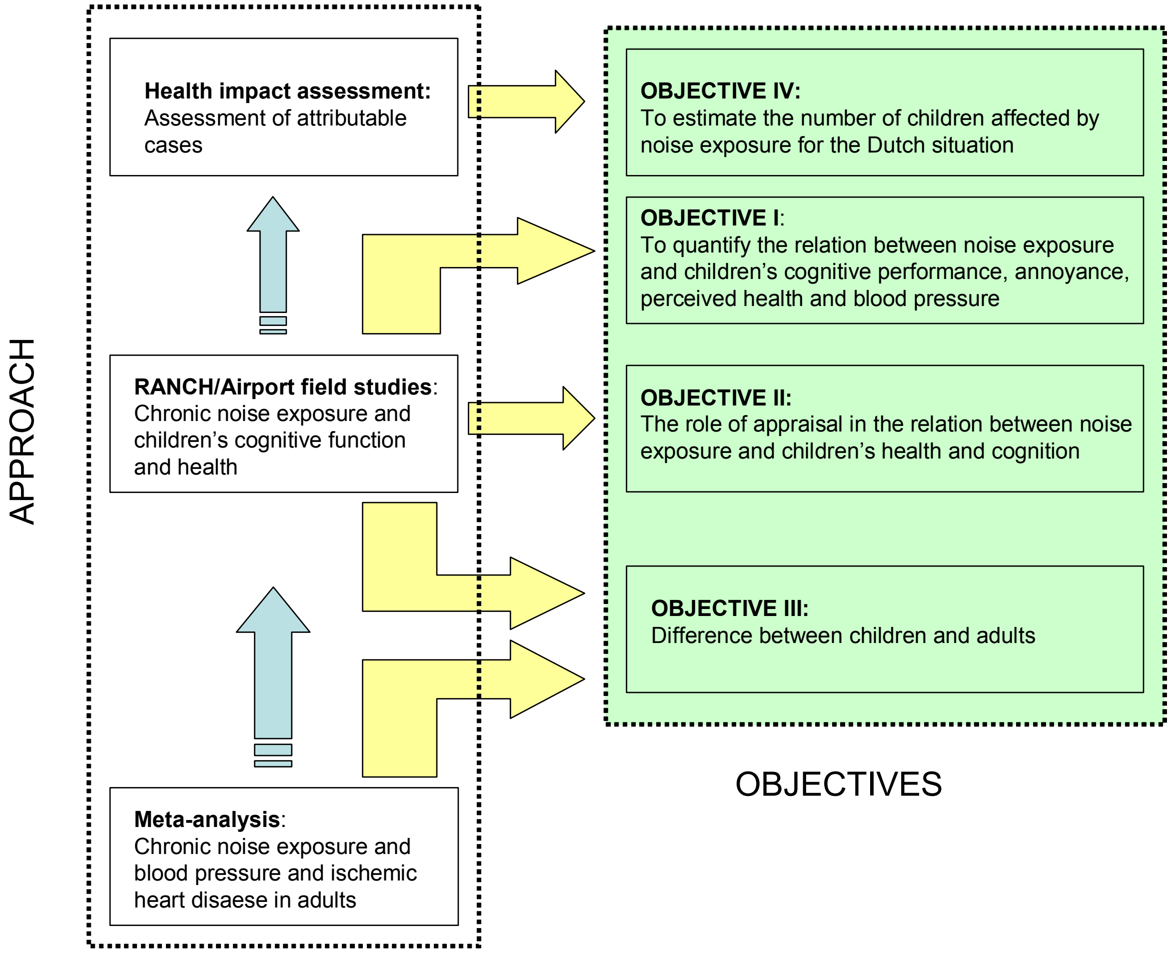

FIGURE 1.4 *The relationship between the different study methods used and the objectives of this thesis.*

1.6 Approach

In order to investigate the first three objectives of this thesis, the results of a meta-analysis and the data from a cross-sectional multi-centre study were used. Finally, the number of primary schoolchildren living around Schiphol Airport affected due to aircraft noise exposure was estimated. To this end the exposure-response relations that were derived in this thesis were applied (see also Figure 1.4).

1.6.1 Meta-analysis

Since no applicable source-specific exposure-response relations were available at the time, the Dutch Ministry of Housing, Spatial Planning and the Environment commissioned the Dutch National Institute of Public Health and the Environment in 1998 to carry out a study investigating the effects of noise on cardiovascular disease. As a result, a meta-analysis on noise and blood pressure and cardiovascular disease, was carried out [45]. A meta-analysis is a systematic review that employs statistical methods to combine and summarise data from several studies [43]; a study of studies. To this end, it is possible to analyse possible exposure-response relations and to investigate the heterogeneity between different studies. In addition to a traditional narrative review, an assessment of the possible extent of publication bias also can be made. The outcome of the meta-analysis was used to assess the cardiovascular burden attributable to noise exposure in The Netherlands [44]. Originally only adult studies that were published between 1970 and 2000 were included into the meta-analysis [45]. However, in the meantime several new studies have been published. For the purpose of this thesis, the meta-analysis was extended with a) observational studies investigating the association between community noise exposure and blood pressure and ischemic heart disease in adults, published after 2000, and b) observational studies investigating the association between road and aircraft noise exposure and blood pressure in children. The aim was (i) to investigate whether the conclusions that were drawn in 2002 with regard to the effects of road and aircraft noise exposure have changed; and (ii) to investigate whether the effect of noise exposure in children is different from that in adults.

1.6.2 RANCH

The European 5th Framework project ‘Road traffic and Aircraft Noise Exposure and Children‘s Cognition and Health: Exposure-Effect relationships and Combined Effects’ (RANCH), which started in 2001, offered an opportunity to study the effects of noise on children extensively. RANCH is a multi-centre study, involving four countries: The United Kingdom, Spain, Sweden and The Netherlands [12]. The main objective was to derive possible exposure-response relations between long-term aircraft and road traffic noise exposure and cognitive functioning, health (including blood pressure) and annoyance in children. RANCH contained several work packages:

- a cross-sectional field study investigating the effects of aircraft and road traffic noise on cognition, annoyance, behaviour and health in children attending primary schools around three airports in The United Kingdom, Spain and The Netherlands;
- a field study investigating the relation between road traffic noise and sleep disturbance in Sweden;

- a quasi-experimental psychological field study in Sweden and The United Kingdom; and
- a laboratory study investigating the effects of short-term noise exposure in Sweden and The United Kingdom.

The data gathered during the cross-sectional field study conducted around 3 European airports: Heathrow Airport, London (UK), Madrid-Barajas Airport (Spain) and Schiphol-Amsterdam-Airport (The Netherlands) were used for this thesis. In this field study, children (aged 9-11 years) attending primary schools that were situated around the above-mentioned airports were selected to take part. Schools were selected according to the modelled noise exposure of the school area (expressed as $L_{Aeq,\ 7\text{-}23hrs}$), and were matched on indicators of socio-economic status (SES) and ethnicity.

In the period March-October 2002, the participating children were subjected to a battery of paper-and-pencil tests during a 3 hour testing session under exam conditions. In the Dutch sample, the children were also subjected to a battery of automated cognitive tests selected from the Neurobehavioral Evaluation System (NES) [46]. The NES was administered in groups of 8 children in a quiet room in school with the help of a personal computer and additional hardware (joystick/push button). The duration of the test was approximately 30 minutes. Blood pressure was measured in The United Kingdom and The Netherlands only, in groups of 4-6 children in a quiet room in the school building during the afternoon.

TABLE 1.1 *Overview of research instruments used per study location*

Instrument	**Participating country**		
	United Kingdom	**The Netherlands**	**Spain**
Paper-and-pencil tests testing cognitive abilities	+	+	+
Automated neurobehavioral test battery (NES)	-	+	-
Questionnaires regarding health, annoyance, behaviour and confounding factors	+	+	+
Blood pressure measurements	+	+	-
Noise measurements at school	+	+	+
Exposure characterisation using noise modelling	+	+	+

+: instrument is applied in the participating country; -: instrument is not applied in the participating country

Information regarding the health, noise perception, and annoyance reactions of the children was gathered by means of self-administered questionnaires filled out by the children, their teachers and one of their parents/caregivers. The children and their teachers completed their questionnaire in school. The children were also given a questionnaire to take home for their mother (preferably), or other caregiver to complete. The questionnaire requested information on the health and behaviour of the child, and potential confounding factors such as window glazing, length of residency, country of birth, socioeconomic factors such as home ownership, crowding, and the language primarily spoken at home.

Long-term noise exposure from aircraft and road traffic noise was estimated by means of noise models. The equivalent noise level for the period 7-23 hr at school an at home ($L_{Aeq,\ 7\text{-}23hrs}$) and for the period 23-7 hr at home ($L_{Aeq,\ 23\text{-}7hrs}$) were chosen as exposure indicator. In all countries, acute noise measurements were taken both inside and outside the classroom during paper-and-pencil testing. More details can be found in the Method-sections of Chapters 2 to 6.

1.6.3 Assessment of the attributable cases

Figure 1.5 summarises the methodology which was used for the estimation of the number of children affected by noise exposure for the Dutch situation. The methodology was based on the usual procedures for environmental health risk assessment [47] and is often done as a Health Impact Assessment (HIA), which is a “combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those health effects within the population [48]” [49].

Outline of this thesis

Chapter 2 of this thesis describes children’s annoyance reactions. In Chapter 3 the effects on the cardiovascular system on children and adults are presented. The effects on children were investigated by means of data gathered in the RANCH project; the effects on adults were investigated by means of a meta-analysis. The Chapter ends with a comparison between children and adults for the relation between noise exposure and blood pressure. Chapter 4 presents the association between aircraft and road traffic noise exposure and cognition using selected tests from the NES. Chapter 5 investigates whether negative appraisal of noise, as indicated by a high annoyance score, affects the association between aircraft- and road traffic noise exposure and blood pressure, perceived health and cognitive performance in children. The estimation of the number of children affected by noise exposure is presented in Chapter 6. Finally, the different findings described in this thesis and their implications are discussed in Chapter 7.

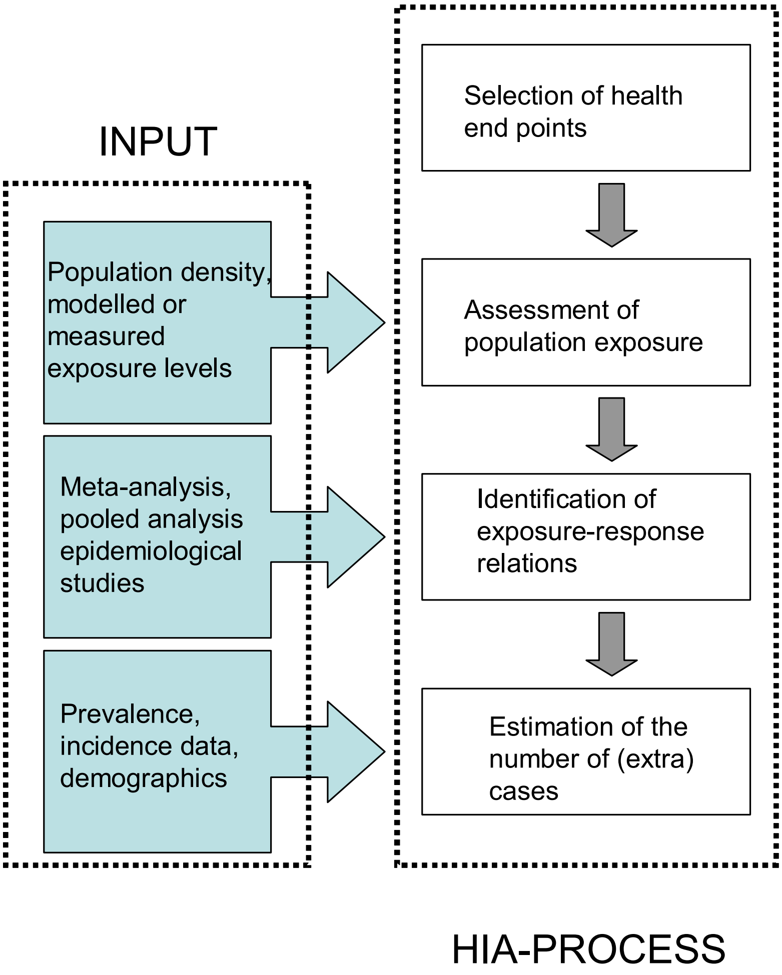

FIGURE 1.5 *Overview of the methodology and data used for the estimation of the number of children affected by noise exposure*

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2 Children's annoyance reactions to aircraft and road traffic noise: the RANCH study

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ABSTRACT

Background: Annoyance reactions of children to environmental noise have rarely been investigated. As a consequence, no source specific exposure-response relations are available for noise annoyance in children. The aim of this paper is to investigate children's reactions to aircraft and road traffic noise and to derive exposure-response relations.

Methods: Data were collected in the RANCH study around 3 major European airports among 2,844 schoolchildren aged 9-11 years old and their parents. Annoyance and other variables related to well-being were measured with a questionnaire. Multilevel logistic regression analyses were applied to estimate the association between noise exposure and severe annoyance, accounting for demographic and school related confounders.

Results: An exposure-response relation was demonstrated between exposure to aircraft noise at school and severe annoyance in children: after adjustment for confounders, the percentage severely annoyed children was predicted to increase from about 5.1% at 50 dB(A) to about 12.1% at 60 dB(A). Aircraft noise at home demonstrated a similar relation with severe annoyance. Children attending schools with higher road traffic noise were more annoyed. Exposure-response relations found among children were comparable to those found in their parents.

Conclusion: Exposure-response relations were demonstrated between aircraft and road traffic noise exposure and severe annoyance among primary schoolchildren. These were broadly comparable to those among their parents.

2.1 Introduction

Annoyance is one of the most widespread and well-documented responses to noise. It is a collective term for several negative reactions such as irritation, dissatisfaction or anger, which appear when noise disturbs someone's daily activities [1]. While adult reactions to noise have been well-described [2-4], this is not so for noise annoyance in children. In comparison with adults, children may be particularly vulnerable to the effects of noise because they have less capacity to anticipate, understand and cope with stressors [5].

Exposure-response relations for noise annoyance among adults have been widely studied, and large datasets have allowed the construction of generalised curves [6-11]. For children, generalised exposure-response relations are lacking. According to Lercher (2003), this omission is due to a lack of a standard methodology for measuring annoyance in children and insufficient representative data on which to base a generalised exposure-response relation [12]. Four previous studies have assessed residential noise annoyance in children in a quantitative and systematic manner: the Munich Airport Study (MAS) [13, 14], the Heathrow studies [15-17] and the Tyrol studies [18, 19]. In these studies, children living in noisier areas in their community were significantly more annoyed by noise than children living in quieter areas.

Most studies have only focused on exposure at school when investigating the effects of noise exposure in children. This is a gap in the research since the impact of noise on children's health can occur in different environments over a 24 hour period: at home and at school, indoors and outdoors and over different times of the day.

Among adults, annoyance is usually measured by means of one or more questions as part of a questionnaire or interview [20]. In the past, a wide variety of questions and scaling methods has been employed to measure annoyance [11]. As with adult studies, different methods have been used to measure children's annoyance reactions. Although each of the studies purports to measure annoyance, it is not fully clear what is being measured. Some studies [13,14] define annoyance as an affective response that indicates a chronic decline in well-being; others [21] conclude that noise annoyance in children pertains to the same construct as in adults, since the emotional response to aircraft noise was consistent with adult reactions. In previous studies among adults [22, 23], interference and annoyance were highly related whilst well-being formed a separate dimension. It is uncertain whether children are also able to make such distinctions and thus show a comparable pattern to adults.

The aim of this paper is to investigate children's annoyance reactions to aircraft and road traffic noise in both the home and the school setting, using data collected from children living around three European airports, gathered in the framework of the

European 5th Framework project Road traffic and Aircraft Noise exposure and Children's cognition and Health (RANCH). A secondary objective was to compare children's annoyance reactions with those of their parents. Some results of RANCH have already been reported elsewhere [24], focusing on the effects of noise exposure at school on cognition and annoyance.

2.2 Methods

Selection and recruitment
Children aged 9-11 years were recruited from primary schools in areas around Heathrow Airport (London, UK), Schiphol Airport (Amsterdam, The Netherlands) and Madrid-Barajas Airport (Spain). Schools were selected according to the modelled noise exposure of the school area (expressed as $L_{Aeq,\ 7\text{-}23hrs}$), and were matched on indicators of socio-economic status (SES) and ethnicity. Out of 767 primary schools available, 134 were invited to participate and 89 agreed. The parents or caregivers of 3,207 children were approached through the schools by letter to give consent for their children to participate. Written consent was also obtained from the children. The final sample contained 2,844 children. For full details of selection and recruitment, see Stansfeld et al. 2005 [24].

Procedure
The children completed a self-administered questionnaire as part of a two-hour group testing session that also included various paper-and-pencil tests measuring cognitive abilities [24]. The children were also given a questionnaire to take home for their mother (preferably) or other caregiver to complete, and requested information on the health and behaviour of the child, noise exposure and noise annoyance, and potential confounding factors such as glazing of the child's home, length of residency, indicators for socio-economic status (employment status, crowding, maternal education, and parental home ownership), ethnic origin and main language spoken at home. These variables were only available for those children whose parents also completed the questionnaire, so parents' participation served as a criterion for inclusion in the statistical analysis. To ensure accurate conceptual translation, all questionnaires were translated from English into Dutch and Spanish and subsequently back-translated. Before data-collection, all procedures and materials were tested in a pilot study in October 2001. In all three participating countries, ethical approval of the study was obtained.

Noise exposure assessment
In the UK and Spain, aircraft noise exposure levels for both the school and children's home were based on the 16 hour (7-23 hrs) outdoor L_{Aeq} contours for the year 2000,

provided by the British Civil Aviation Authority and the Spanish Airports and Air Navigation. In The Netherlands, modelled aircraft noise levels ($L_{Aeq\ 7\text{-}23\ hrs}$) with a resolution of 250x250 meter grids were obtained from the Dutch National Aerospace Laboratory (NLR) for the year 2001 and were linked to school and home locations using Geographical Information Systems (GIS).

In the UK, school road traffic noise levels were estimated from a combination of data regarding proximity to motorways, major roads, minor roads and traffic flow [25]. In Spain, direct external measurements were taken of road noise during school visits. Taking into account factors such as traffic flow, speed limits and distance to the street, these were transformed into 7-23h L_{Aeq}-values. In The Netherlands, modelled composite data from 2000 and 2001, with a resolution of 25x25 meter grids, were linked to school addresses using GIS [26]. Road traffic noise levels were only available for the school situation, and were expressed in $L_{Aeq\ 7\text{-}23\ hrs}$.

Child and parent noise annoyance

For both children and parents, annoyance was measured as part of a self-administered questionnaire by means of standard questions. For children the following wording was used: '*Thinking about the last year, when you are at [school][home], how much does the noise from [aircraft][road traffic] bother, disturb or annoy you when you ?'*. Answers were indicated on a 5-point category scale (*'not at all, a little, quite a bit, very much, extremely'*). For parents the following wording was used *'Thinking about the last 12 months, when you are at home, how much does noise from [aircraft][road traffic] noise bother, disturb or annoy you?*' Answers were indicated on a 5-point category scale (*'Not at all, Slightly, Moderately, Very, Extremely'*) [20].

Children and parents were also asked how frequently they heard the noise from road traffic or aircraft when they were at school or home. Answers were indicated on a 4-point category scale (*'never, sometimes, often, always'*). For the children, this set of questions was asked for both the home and school situation. If parents indicated never hearing noise, annoyance was recoded to 'not at all annoyed'. Since we could not necessarily expect children to answer these questions in such a consistent way, this transformation was not used for children. The annoyance questions were subsequently dichotomized, with 'very much' and 'extremely' annoyed defined as being severely annoyed.

Interference with activities at school and at home was measured by asking the children whether noise from road or aircraft noise interfered with (i) playing outdoors, (ii) working in a group, (iii) working individually, (iv) listening to the teacher, (v) listening to TV, radio or music, (vi) talking, or (vii) reading or doing homework. Answers were indicated on a 4-point category scale (*'never, sometimes, often, always'*).

In order to measure perceived health, the children were asked how often they had the following symptoms during the past month: headache, vomiting, stomachache, difficulty falling asleep, and the number of times woken at night or felt sleepy during the day. Answers were indicated on a 5-point category scale (*'never, a few times, once a week, a few times a week, every day or night'*).

Analysis

In order to test the convergent and divergent validity of the annoyance scale, a principal component analysis (PCA) was carried out using SPSS for Windows (version 12.0.1) on the annoyance and interference questions for both the school and home situation and perceived health. Home and school annoyance and interference questions were combined in the PCA, and subjective health symptoms were included, in order to determine whether children could distinguish between the home and school situation, and between annoyance interference and perceived health. We expected high correlations between annoyance and/or interference at school and at home for aircraft noise, respectively, but not necessarily for road traffic noise. In PCA, linear combinations of the observations were found. Only components that accounted for variances greater than 1 were included. To make the components more interpretable a rotation with the Varimax method was performed. However, at the basis of age, gender etc., one would expect a certain correlation between the components. As a kind of sensitivity analysis an oblique rotation (with Delta = 0) was performed in addition to Varimax rotation, assuming that the resulting components may be correlated. Cronbach's alphas were calculated to test the internal consistency of the obtained components.

To assess the association between aircraft and road traffic noise exposure and severe annoyance, multi-level logistic regression analyses by means of generalized linear mixed models were carried out using the GLIMMIX procedure in SAS version 9.1. Multilevel modelling takes into account the hierarchical structure of the data (children grouped within schools) and enables effects at both the level of school and pupil to be included in the same model. Two-level (pupil and school) random intercept models were used, and country was included as a fixed effect. Coefficients (B) and standard errors (SE) were estimated under residual pseudo-likelihood (RSPL) estimation. In all models, aircraft or road traffic noise exposure (either at school or at home) was the main independent variable and was included as a continuous variable. For the association with aircraft noise, a quadratic term for aircraft noise was also included, because this increased the model fit (see also Stansfeld et al., 2005) [24]. The logistic regression models included age (yrs), sex, ethnicity (white/non-white), school glazing (single, mixed, double, triple) or double glazing at home (yes/no), length of school enrolment (< 1 yr, 1-2 yrs, 3-6 yrs, > 6 yrs) or residency (< 1 yr, 1-5 yrs, 6-10 yrs, > 10 yrs), and indicators of socio-economic status (crowding, home ownership, parental employment and mother's education) as potential confounders. Models were estimated for the pooled data. Heterogeneity in the exposure-response relations among countries was tested in the models on the pooled data by examining the interaction between country and noise exposure. Statistical significance of a coefficient was tested under maximum pseudo-likelihood (MSPL) estimation, using a Wald Chi-square test.

2.3 Results

The British sample contains fewer employed parents, fewer home owners and more non-white children than the Dutch and Spanish samples. The prevalence of severe annoyance due to aircraft and road traffic noise in the Dutch and Spanish samples was somewhat lower than in the British sample (Table 2.1).

Annoyance in children: construct validity

In the PCA on interference, annoyance and perceived health, a 5-component solution appeared to be the most appropriate for the 26 items (Table 2.2). The total percentage of variance explained by these five components is 56.3%. The first component consists of items referring to annoyance and interference from aircraft noise annoyance (without distinction between home and school situation). The second component consists of items regarding annoyance and interference from road traffic noise at school. The items forming the third component refer to interference at home from road traffic noise. The fourth component consists of the self-reported health symptoms. The fifth component consists of items regarding interference when playing outdoors at home, and school due to aircraft and road traffic noise, and annoyance from road traffic noise at home. The oblique rotation resulted in the similar grouping of variables as the Varimax rotation. The interpretation of the components did not change.

TABLE 2.1 *General characteristics of the children and their parents included in the analysis.*

Characteristic	**UK (*N*=863)**	**Netherlands (*N*=612)**	**Spain (*N*= 553)**
# participating schools	29	33	27
Girls, %	54.5	50.1	53.0
Mothers, %	93.3	90.8	92.0
Mean age (SD)			
Children	10.3 (0.3)	10.5 (0.6)	10.9 (0.4)
Parents	37.7 (5.5)	40.9 (4.1)	39.6 (5.0)
Socio-economic status			
Crowding in the home, %	22.1	31.4	9.6
Parental home ownership, %	59.4	81.7	85.5
Employed parents, %	78.5	93.0	89.3
Mean mother's education (SD)*	0.5 (0.3)	0.5 (0.3)	0.5 (0.3)
White British/Dutch/Spanish %	66.2	89.4	91.5
Length of time at school, %			
Less than 1 year	3.5	0.2	0.2
1 – 2 years	10.4	6.6	3.4
3 – 6 years	49.7	21.3	9.0
More than 6 years	36.5	72.0	87.5
Length of residence, %			
Less than 1 year	7.0	4.1	7.1
1 – 5 years	33.8	19.8	21.3
6 – 10 years	26.7	19.3	17.5
More than 10 years	32.5	56.9	54.1
Severe annoyance, %			
Aircraft noise at school, child	10.9	9.4	7.4
Aircraft noise at home, child	12.2	7.1	7.8
Road traffic noise at school, child	6.5	4.0	4.9
Aircraft noise at home, parent	11.6	8.7	6.2
Mean modelled noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) levels, dB(A) (range)†			
Aircraft noise at school	53.0 (34.0 – 68.0)	54.2 (41.0 – 68.0)	46.1 (30.0 – 77.0)
Aircraft noise at home	53.1 (33.9 – 72.8)	49.1 (34.5 – 64.5)	46.4 (31.9 – 72.8)
Road traffic noise at school	50.6 (37.0 – 67.0)	49.3 (34.0 – 62.0)	54.1 (43.0 – 71.0)
Insulation			
School glazing, %			
Single	51.9	44.3	71.3
Mixed	9.0	-	-
Double	39.1	46.6	28.8
Triple	-	9.2	-
Double glazing at home, %	82.8	58.1	57.1

* Ranked index of standard qualification in every country. †The range runs from the minimum value to the maximum value. ‡ Abbreviations: N: sample size; SD: Standard deviation; %: percentage; $L_{Aeq,\ 7\text{-}23hrs}$: Equivalent noise level from 7 to 23 hrs.

TABLE 2.2 *Factor loading matrix (N = 2,185), using Varimax rotation* *

Item	**Factor I**	**Factor II**	**Factor III**	**Factor IV**	**Factor V**
Annoyed road traffic school		0.617			
Annoyed aircraft school	0.740				
Annoyed road traffic home					0.410
Annoyed aircraft home	0.655				
Road traffic interferes play outdoors school					0.665
Road traffic interferes group work school		0.692			
Road traffic interferes own work school		0.736			
Traffic interferes listening to teacher school		0.699			
Aircraft interferes play outdoors school	0.595				
Aircraft interferes group work school	0.702				
Aircraft interferes own work school	0.700				
Aircraft interferes listening to teach school	0.691				
Road traffic interferes play outdoors home					0.740
Road traffic interferes TV home			0.701		
Road traffic interferes talking home			0.635		
Road traffic interferes reading home			0.685		
Aircraft interferes play outdoors home					0.564
Aircraft interferes TV home			0.575		
Aircraft interferes talking home	0.571				
Aircraft interferes reading home	0.565				
Headaches				0.610	
Vomiting				0.620	
Stomachache				0.579	
Difficult to sleep				0.590	
Times awake				0.641	
Sleepy in day				0.573	

Factor	**Interpretation**	**Variance explained**	**Alpha** †
I	Disturbance and annoyance due to aircraft noise	32.471	0.89
II	Disturbance and annoyance due to road traffic noise at school	7.512	0.79
III	Interference from road traffic noise at home	6.220	0.77
IV	Health	5.225	0.67
V	Interference playing outdoors	4.843	0.69
Total		56.272	

* Only the highest loadings were presented. † Cronbach's alpha (standardized): function of the item-inter-correlation and the number of items included in the scale, based on the items given in the factor loading matrix. ‡ Abbreviations: N: sample size.

Aircraft noise and children's annoyance reactions

Aircraft noise exposure at school was significantly related to the severe annoyance (χ^2 = 52.7, df =2, p<0.0001): in schools in areas with higher aircraft noise exposure the proportion severely annoyed children was significantly higher. The percentage severely annoyed children was predicted to increase from about 5.1% at 50 dB(A) to about 12.1% at 60 dB(A) (Figure 2.1).

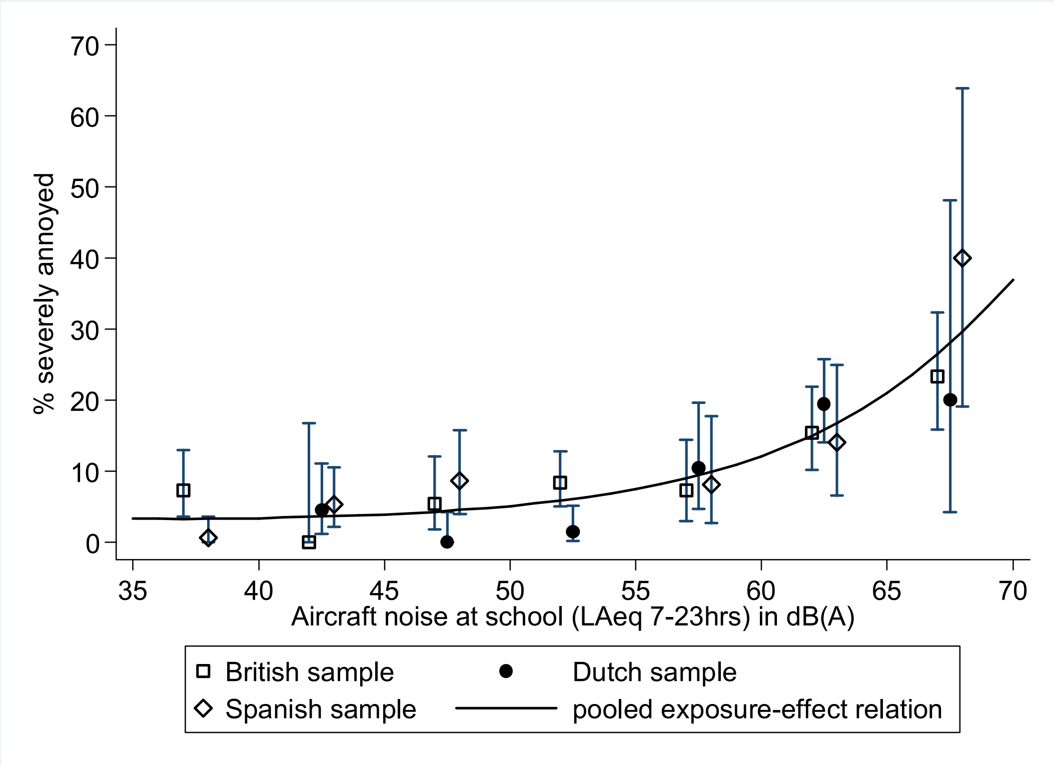

FIGURE 2.1 *The country-specific percentage severely annoyed children by 5 dB(A) bands of aircraft noise ($L_{Aeq,\ 7\text{-}23hrs}$) at school and the relation between aircraft noise at school and the percentage of children severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.*

The only potential confounder that had a significant effect on annoyance was mother's education (χ^2 = 6.8, df =1, p=0.009); children of mothers with a higher level of education were more annoyed by aircraft noise at school; an odds ratio (OR) of 2.24 (95%CI: 1.22 – 4.12) was estimated. Country had not a significant effect on annoyance (χ^2 = 1.6, df =2, p = 0.457). Although the proportion of severely annoyed children in the Dutch sample was higher compared to the British and Spanish samples at aircraft noise levels ($L_{Aeq,\ 7\text{-}23hrs}$) of 63 dB(A) and higher, the change in the percentage severely annoyed per 1 dB(A) increase of the noise did not differ significantly between the three countries (test of heterogeneity: χ^2 = 8.9, df = 4, p = 0.064).

Aircraft noise exposure at home was significantly related to severe annoyance (χ^2 = 50.5, df =2, p<0.0001): the proportion of severely annoyed children was higher in areas with higher aircraft noise levels. The percentage severely annoyed children was predicted to increase from about 6.9% at 50 dB(A) to about 14.6% at 60 dB(A) (Figure 2.2). Country had not a significant effect on annoyance. The only potential confounder that had a significant effect on annoyance was sex: girls were less annoyed due to aircraft noise at home than boys (χ^2 = 8.3, df =1, p = 0.004) (OR = 0.62 [95%CI: 0.45 – 0.86]). The difference in the effect size at different noise levels for each country was statistically not significant (test of heterogeneity: χ^2 = 5.9, df = 4, p = 0.209). Comparison between Figures 2.1 and 2.2 indicate that the exposure-response relations for the home and school situation are similar.

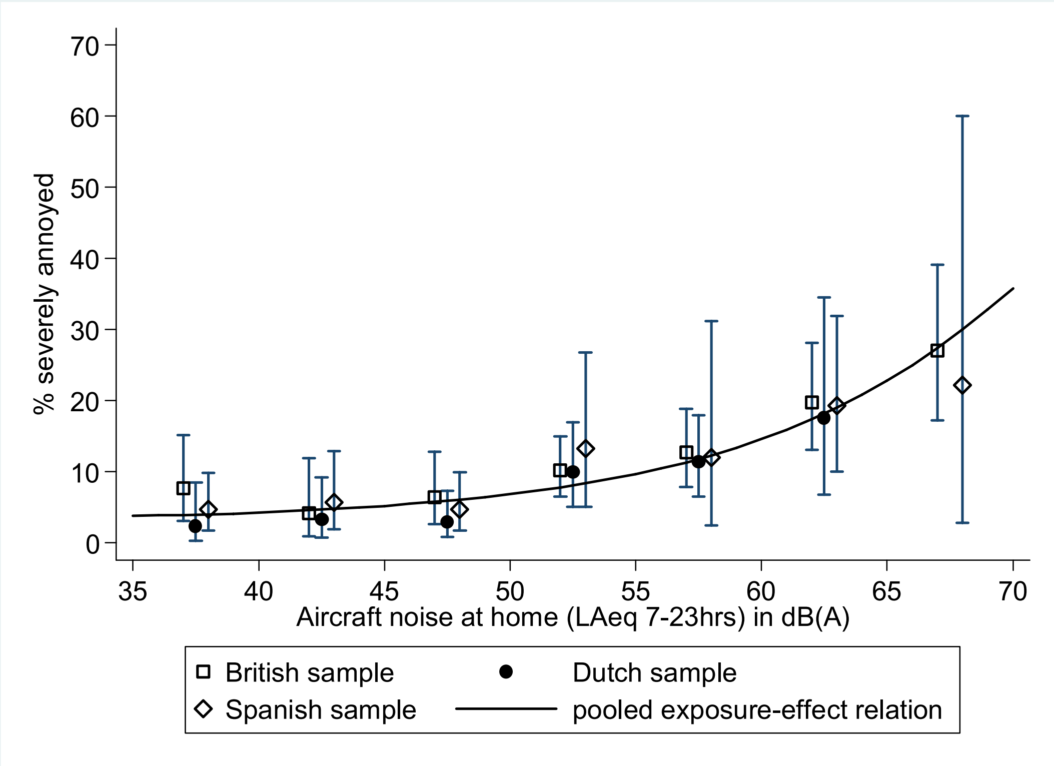

FIGURE 2.2 *The country-specific percentage severely annoyed children by 5 dB(A) bands of aircraft noise ($L_{Aeq,\ 7\text{-}23hrs}$) at home and the relation between aircraft noise at home and the percentage of children severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.*

Road traffic noise and children's annoyance

Chronic road traffic noise exposure at school was significantly related to severe annoyance from road traffic noise at school: Children attending schools with higher road traffic noise were more annoyed (χ^2 = 7.4, df = 1, p=0.007). The percentage severely annoyed children was predicted to increase from about 3.8% at 50 dB(A) to about 5.7% at 60 dB(A) (see also Figure 2.3). Potential confounders that had a significant effect on annoyance were mother's educational attainment (χ^2 = 16.6, df = 1, p<0.0001) (OR = 5.04 [95%CI: 2.28 – 11.8]), school enrolment (χ^2 = 8.4, df = 3, p=0.040) and school glazing (χ^2 = 7.2, df = 2, p=0.028). There was no significant difference in the change in the percentage severely annoyed per 1 dB(A) increase of the noise between the three countries (test of heterogeneity: χ^2 = 0.70, df =2, p=0.704).

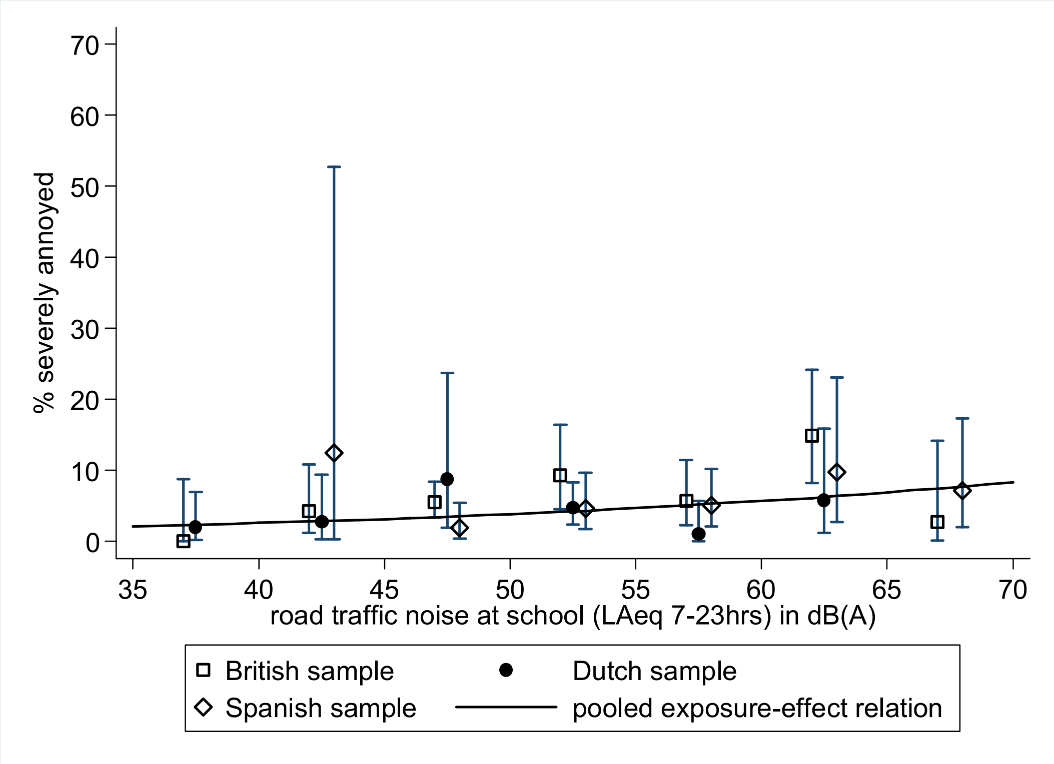

FIGURE 2.3 *The country-specific percentage severely annoyed children by 5 dB(A) bands of road traffic noise ($L_{Aeq,\ 7\text{-}23hrs}$) at school and the relation between road traffic noise at school and the percentage of children severely annoyed, derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.*

Aircraft noise and annoyance in children and parents

In Figure 2.4 the exposure-response relations for both children and parents are presented for home exposure to aircraft noise. The percentage severely annoyed children was predicted to increase from about 6.9% at 50 dB(A) to about 14.6% at 60 dB(A); the percentage severely annoyed parents was predicted to increase from about 4.8% at 50 dB(A) to about 16.8% at 60 dB(A). There was a significant difference in the change in the percentage severely annoyed per 1 dB(A) increase of the noise between the children and their parents (χ^2 = 18.7, df =2, p < 0.0001). At levels above 55 dB(A) the percentage of severely annoyed children is lower than the percentage of severely annoyed parents, but under 45 dB(A) the percentage of severely annoyed children is slightly higher than the percentage of severely annoyed parents.

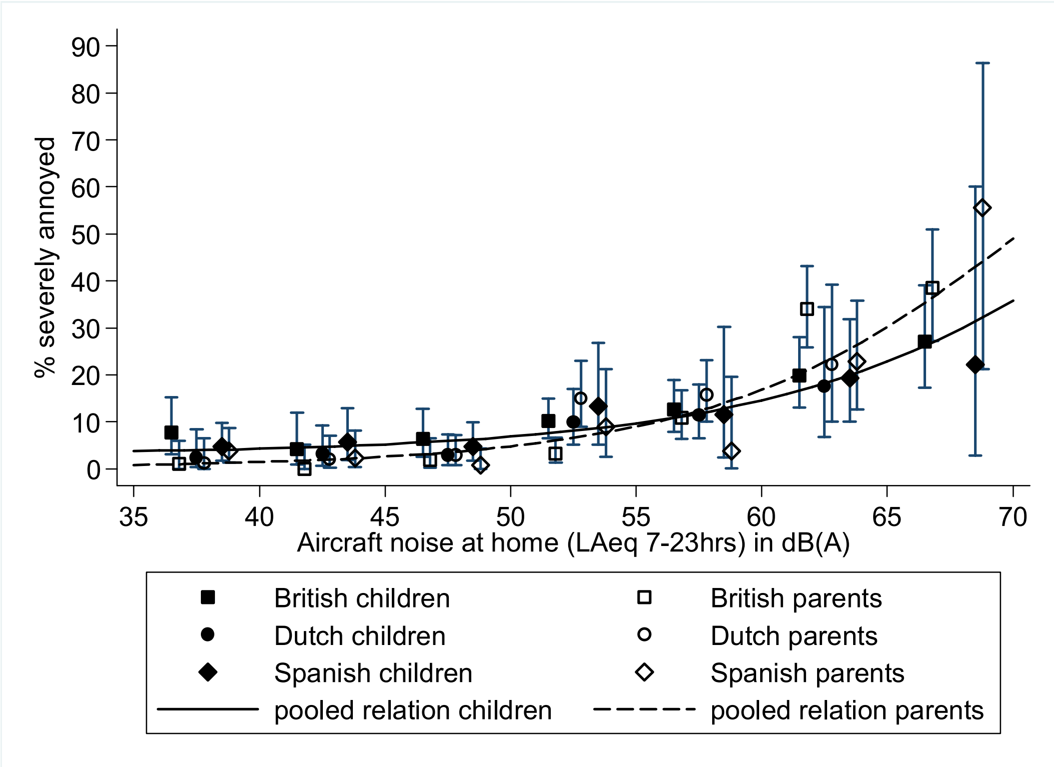

FIGURE 2.4 *Comparison between children and their parents: the country-specific percentage severely annoyed children and parents by 5 dB(A) bands of aircraft noise ($L_{Aeq,\ 7\text{-}23hrs}$) at home and the relation between aircraft noise at home and the percentage of children and parents severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.*

2.4 Discussion

We found significant associations between aircraft and road traffic noise exposure and annoyance among school children living near three major European airports. This is consistent with results of previous studies investigating children's reactions to aircraft and road traffic noise [13-18], which demonstrated that annoyance was significantly higher among children in high noise schools and areas compared with low noise schools and areas.

Measurement of annoyance in children

The results of the PCA show that children can make a clear distinction between annoyance and perceived health as measured by means of self-reported symptoms. As in adults [22, 23], the correlation found between annoyance and interference or disturbance of activities was high. This is consistent with the findings of a survey among 207 children (aged 13-14 yrs) of Enmarker and Boman (2004) investigating the effects of road traffic noise [27]. Our results are partly in keeping with those of Haines and Stansfeld (2000) [28] investigating the effects of aircraft noise; they found that severely annoyed children agreed more often that 'noise makes it hard to work' than children who were less annoyed. However, aircraft noise annoyance at school was not found to be associated with other aspects of classroom interference.

We also found that interference with playing outdoors at home and school due to aircraft and road traffic noise, and annoyance from road traffic noise at home, were separate factors, suggesting that children, in their response to noise, distinguish between indoors and outdoors rather than between school and home. There was a clear distinction between annoyance from aircraft and road traffic noise, but not between annoyance from aircraft noise at school and at home. This was not the case for road traffic noise. This is consistent with the distribution of noise exposure; in this study aircraft noise levels at school and at home were highly correlated in each country (r ~ 0.85 – 0.93) [29]. Since primary schools are usually located in the residential area of the child, we expect a great similarity in exposure levels between the school and home situations. Children aged 9-12 years appear to be able to discriminate their annoyance responses to road and aircraft noise sources and are consistent in their annoyance responses to aircraft noise across contexts such as school and home. Our results also indicate that children clearly distinguish between sources of noise as well as between annoyance and other indicators of well-being.

Annoyance reactions to aircraft and road traffic noise

After pooling the data, noise exposure levels of both aircraft and road traffic were significantly related to the percentage of severely annoyed children. No significant differences were found in the fraction severely annoyed at different exposure levels between countries. This is different from the variability that is observed across studies investigating adults' noise annoyance reactions [30].

Another finding of our study was that the association with annoyance in children is stronger for aircraft than for road traffic noise, as in adults. Firstly, it is likely that aircraft noise has a greater effect on children's annoyance reactions than road traffic noise amongst others because of its intensity, its variability and unpredictability in comparison with road traffic noise, which might be of a more constant intensity [24]. Secondly, with the current available methods and data it is more difficult to predict road traffic noise exposure accurately. Differences between calculation methods might account for the quality of the road traffic noise exposure assessment: previous comparisons of different national calculation methods for certain road traffic situations revealed that differences up to 15 dB(A) may exist [31]. Exposure misclassification may also have occurred because classrooms were at varying distance from the façade of the school building [29]. Another possible explanation is that the combined exposure to aircraft noise and road traffic noise might have affected children's annoyance response: children in high aircraft noise areas might report more annoyance from aircraft noise in high road traffic noise areas than children in low road traffic noise areas and vice versa. Finally, differences in schooling system and teachers attitudes and/or responses towards noise might have differential effects on the children's reactions to noise sources at school. There might be differences in frequency and type of insulation of both schools and homes, which could result in different annoyance reactions, even though both design and analysis accounted for the influence of insulation. Unfortunately, most of these possible explanations can not be further investigated with the RANCH-data.

Annoyance reactions of children and their parents

In general, the exposure-response relations of children and their parents display a comparable trend, in spite of some significant differences: children have lower responses than their parents at higher noise levels. This is consistent with earlier findings from the Tyrol Mountains Study (TMS) [18] which investigated the relation between road and rail traffic noise and annoyance in children and their parents.

A possible explanation for the differences between children and adults' response to noise could be sought in non-acoustical factors such as noise-sensitivity, attitudes towards the noise source, perceived control, expectations, and coping behaviour. Boman and Enmarker (2004) observed that teachers were more annoyed due to road traffic noise than children, and perceived the noise of road traffic noise to be more unpredictable than their pupils [32]. In addition, the teachers described themselves as more sensitive to noise. Conversely, teachers perceived more personal control over the noise than did the pupils. Unfortunately, the RANCH data do not enable us to analyse the influence of such non-acoustical factors.

The observation that children have significantly lower responses than their parents at higher noise levels, could also mean that children are more sensitive at lower noise levels, and that children's annoyance at higher noise levels is less influenced by non-acoustical factors than is the case in adults. To what extent this is the case for children can not be determined based on the RANCH data.

Strengths and limitations

This study represents an improvement on previous studies [12-19] due to its large sample size both in the number of participants and number of schools. Despite the heterogeneity of the countries, results for noise and annoyance were rather similar across the three countries; i.e., we noted cross-cultural replication of the findings. A further strength of this study is the comprehensive inclusion of potential confounders and determinants. The hierarchical structure of the data (children within schools) has been taken into account, which was not the case in analyses of previous studies. The participants were distributed over a broad exposure range, and a continuous noise exposure measure was used, adding to the statistical power of the study. Most

studies investigating the impact of noise exposure have involved between-group comparisons (high versus low): results of these studies may be sensitive to decisions about cut-off points used to categorise continuous exposure variables and the method used to assign scores to exposure categories [33].
Despite the standardised selection-procedures, differences emerged between the countries: e.g. differences in school glazing. As already indicated, the estimation of exposure to road traffic noise remains problematic: during their time at school, road traffic noise exposure changes as children move to a different classroom each year. Thus, the road traffic noise levels at the façade of their current classroom might not reflect the average level of exposure during their time at school.

Implications

The WHO guidelines for noise suggest that children are more sensitive to noise than adults because they are exposed to noise during critical developmental periods [1]. Children may also have fewer possibilities for controlling noise or have a less developed coping repertoire than adults [5]. However, we found that the exposure-response relations found among children were broadly comparable to those among their parents; if anything, effects at high exposures were smaller among the children. Furthermore, annoyance is not the only indicator of the effects of community noise in children. As demonstrated in the different parts of the RANCH study, cognitive [24, 29], behavioural [34] and physiological measures [35] are necessary to fully describe the impact of environmental noise on children.

For annoyance, the WHO guidelines recommend a L_{Aeq} of 55 dB(A) for noise from external sources for school [1]. Our results indicate that some children were already severely annoyed at lower levels (45 dB(A)) which suggests the WHO community guidelines may need to be lowered to protect these children.

Conclusions

Children's annoyance can be reliably measured within a questionnaire. Exposure-response relations were demonstrated between aircraft and road traffic noise exposure and severe annoyance among primary schoolchildren. Although children were less annoyed at levels above 55 dB(A), these relations were broadly comparable to those among their parents.

2.5 References

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3 Transportation noise, blood pressure and ischemic heart disease

3.1 Noise exposure and children's blood pressure and heart rate: The RANCH-project

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ABSTRACT

Objectives: Conclusions that can be drawn from earlier studies on noise and children’s blood pressure are limited due to inconsistent results, methodological problems and the focus on school noise exposure. This paper reports on a study investigating the effects of aircraft and road traffic noise exposure on children’s blood pressure and heart rate.

Methods: Participants were 1,283 children, (age 9-11 years) attending 62 primary schools around two European airports. Data were pooled and analysed using multilevel modelling. Adjustments were made for a range of socio-economic and lifestyle factors.

Results: After pooling the data, aircraft noise exposure at school was related to a statistically non-significant increase in blood pressure and heart rate. Aircraft noise exposure at home was related to a statistically significant increase in blood pressure. Aircraft noise exposure during the night at home was positively and statistically significantly associated with blood pressure. The findings differed between the Dutch and British samples. Negative associations were found between road traffic noise exposure and blood pressure, which cannot be explained.

Conclusion: On the base of this study and previous scientific literature no unequivocal conclusions can be drawn about the relationship between community noise and children’s blood pressure.

3.1.1 Introduction

Road and aircraft noise are two of the most important sources of community noise [1]. It has been estimated that approximately 30% of the European Union's population is exposed to levels of road traffic noise of more than 55 dB(A); 20% of the European population experiences noise levels that are considered unacceptable [2]. Long-term noise exposure is associated with a number of effects on health and well-being. These include community responses such as annoyance, sleep disturbance, disturbance of daily activities, and physiological responses such as hearing loss, hypertension and ischemic heart disease [2].

This paper focuses on blood pressure changes in children. From a public health perspective, blood pressure elevations at population level are undesirable [3]. In relation to noise, blood pressure elevations are regarded as a non-specific response. However, they are typically associated with stress which is hypothesized to arise either as a consequence of the activation of the autonomic nervous system and the endocrine system or as a consequence of the appraisal of noise [4, 5]. With the preponderant influence of lifestyle and genetic predisposition, it is difficult to gain insight into the contribution of noise to cardiovascular disease. This is probably one of the reasons that conclusions from earlier studies investigating the effects of noise exposure on children's blood pressure are limited and inconsistent. Secondly, a number of methodological problems emerge from these earlier studies (e.g. small differences in noise levels between the exposure groups, potential selection bias, a lack of control for socio-economic status factors, differences in insulation and parental history of high blood pressure) [3 - 5]. Thirdly, most studies usually only focus on exposure at school when investigating the effects of noise exposure on children. It is questionable whether the health effects could be exclusively attributed to the noise exposure in school. The effect of night-time exposure has been hardly investigated in children [6]. This is an important gap in the research, because time-use studies not only show that children spent a lot of time in and around their home, but also that children spend a large part of their time sleeping [7, 8]. Chronic night-time noise exposure might disturb the excretion of stress hormones (such as cortisol) which is affecting children's health [9].

To investigate the possible association between noise exposure and children's blood pressure and heart rate we collected data from children living around Heathrow Airport and Schiphol Airport gathered in the framework of the RANCH project. The aim of this project was to investigate the effects of aircraft and road traffic noise exposure at school on children's cognition and health [10]. In a later stage of the project the home noise exposure levels also became available.

3.1.2 Methods

Selection and recruitment

Children aged 9-11 years were recruited from primary schools in areas around Heathrow Airport and Schiphol Airport. Schools were selected according to the modelled noise exposure due to both aircraft and road traffic of the school area (expressed as $L_{Aeq,\ 7\text{-}23hrs}$), and were matched on indicators of socio-economic status (SES) and ethnicity. Schools for children with special needs were excluded. Since degrees of achievement can appreciably differ between school types in the UK, we excluded non-state schools in the UK from our study; in The Netherlands the degrees of achievement do not differ between school types. Furthermore, we excluded schools with the presence of a dominant noise source other than aircraft or road traffic noise, or at which insulation against noise was above a certain threshold; in The Netherlands all schools with high aircraft noise levels were highly insulated.

Out of 118 primary schools available in the British study area, 30 were invited to participate and all but one agreed. In The Netherlands, out of 366 available schools in the selected areas, 77 schools were invited to participate, and 33 agreed. The parents or carers of 2,179 children were approached through the schools by letter and 2,012 children had permission to take part. In The Netherlands all the children who had permission to take part and who were available on the day of testing had their blood pressure measured (n = 730); in the United Kingdom every second participating child was selected from the class list for blood pressure measurement (n = 553).

Noise exposure assessment using modelled data

Noise exposure was assessed for each child by linking home and/or school addresses to modelled equivalent aircraft and road traffic noise levels. These predict the average outdoor noise exposure during a specified time interval. In both centres, aircraft noise levels ($L_{Aeq,\ 7\text{-}23\ hrs}$, and $L_{Aeq,\ 23\text{-}7hrs}$) were obtained from nationally available noise contours for both the home and school situation. In The Netherlands, modelled aircraft noise levels for the year 2001 were obtained from the Dutch National Aerospace Laboratory (NLR) [11]. In the United Kingdom modelled aircraft noise levels were based on the 16hr outdoor LAeq contours provided by the Civil Aviation Authority (CAA) for a three month period (July-September) for the year 2000.

In both centres, road traffic noise levels ($L_{Aeq,\ 7\text{-}23\ hrs}$) were obtained for the school situation. Road traffic noise levels ($L_{Aeq,\ 7\text{-}23\ hrs}$) for the home situation were only available for the Dutch sample. For the calculation of road traffic noise levels in The Netherlands, national standard methods were adopted to obtain grids with resolutions of 25x25m [11]. In the United Kingdom, road traffic noise levels were calculated by means of the UK standard CRTN noise prediction method, using a combination of information including proximity to motorways, A-roads, B-roads and traffic flow data [12].

Blood pressure

Blood pressure measurements were taken in the afternoon in a quiet room in the school building using automatic blood pressure meters (OMRON 711, OMNILABO International BV). Cuff-sizes of either 15-22 (small) or 22-32 cm (normal) were used. The cuff was placed on the right arm. While the child was seated and after an initial period of five minutes rest, systolic and diastolic blood pressure and heart rate were measured three times with 1-2 minutes intervals by researchers trained according to a standard protocol. Children were not allowed to talk during the measurement session. Body height and weight were measured without shoes or heavy clothing. At the beginning of each session room temperature was assessed. In the data-analysis the mean value of the three blood pressure measurements was used.

Parent questionnaire

Children were given a questionnaire to take home for their mother (preferably), or other carer to complete. The questionnaire provided information on potential confounding factors (e.g. socio-economic status, birth weight, country of birth and parental history of high blood pressure). 84.8% of the parents (n = 1,175) returned the questionnaire.

Statistical analysis

Before running the analyses, the residuals were checked for outliers. Missing values were few, except for parental hypertension (11%) and cuff-size (9%). Because small cuffs were used 95% of the time, the missing cuff sizes in the UK-sample were imputed as small. To produce persistent effects, noise may have to be present for a certain length of time. Therefore, only those children who attended their present school for at least 1 year were included in the analyses.

To take into account the hierarchical data structure (children grouped within school), multi-level modelling was applied, using the MIXED procedure of SAS version 8.1. A two-level random effects model was used. Country was included as a fixed effect. For the school situation the following two models were run: a model including noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school, age (yrs), sex, ponderosity (weight/height ^{3}), school glazing (single/double/mixed/triple) and country (UK/NL); the second model equals the first model with the addition of indicators for socio-economic status (crowding, home ownership, employment and mother's education), ethnicity (white/non-white), cuff-size (small, normal), room temperature (°C), birth weight (< 2500 gr./ ≥ 2500 gr.), (self-reported) parental high blood pressure (yes/no), prematurity (born before week 36), double glazing at home and the other school noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) source. For the home situation the following two models were run: a model including noise exposure at home ($L_{Aeq,\ 7\text{-}23\ hrs}$ or $L_{Aeq,\ 23\text{-}7\ hrs}$), age (yrs), sex, ponderosity (weight/height ^{3}), double glazing at home (yes/no) and country (UK/NL); the second model equals the first model with the addition of indicators for socio-economic status (crowding, home ownership, employment and mother's education), ethnicity (white/non-white), cuff-size (small, normal), room temperature (°C), birth weight (< 2500 gr./ ≥ 2500 gr.), parental hypertension (yes/no), and prematurity (born before week 36).

The variables included in the models were chosen according to the literature. Furthermore, variables were retained in the main analysis if an analysis of covariance showed a significant relation between the confounding factor and aircraft noise exposure and/or road traffic noise exposure and/or blood pressure. As a result of these analyses coefficients (B) and standard errors (SE) are presented indicating the change in blood pressure per dB(A) increase. These were estimated under restricted maximum likelihood estimation. 95% confidence intervals (95%CI) were calculated by means of the estimated standard errors. Statistical significance was tested under full maximum likelihood estimation, using a chi-square test of deviance. Heterogeneity between the countries was tested in the models on the pooled data by examining the interaction between country and noise exposure.

In order to compare the results of our study systematically with the results of 5 other recent studies that investigated the association between community noise and children’s blood pressure, we calculated the blood pressure change (mmHg) per noise level increase and its variance for both systolic and diastolic blood pressure [13 – 19]. To this end we evaluated the studies systematically and extracted average blood pressure values that were presented in these studies and their noise levels. This was done in the same way as was done by Van Kempen et al (2002) [3].

3.1.3 Results

Descriptives

853 children were eligible for data-analysis (see also Figure 3.1). Table 3.1 presents the general characteristics of these children and the schools they attended. It shows that: (i) the UK-sample contains fewer employed parents and fewer home owners; (ii) the children in the UK-sample had a lower average birth weight and had a higher prevalence of prematurity than the Dutch sample; (iii) on average the children of the UK-sample have higher blood pressure than the children of the Dutch sample; and (iv) the UK-sample contains relatively more non-white children than the Dutch sample.

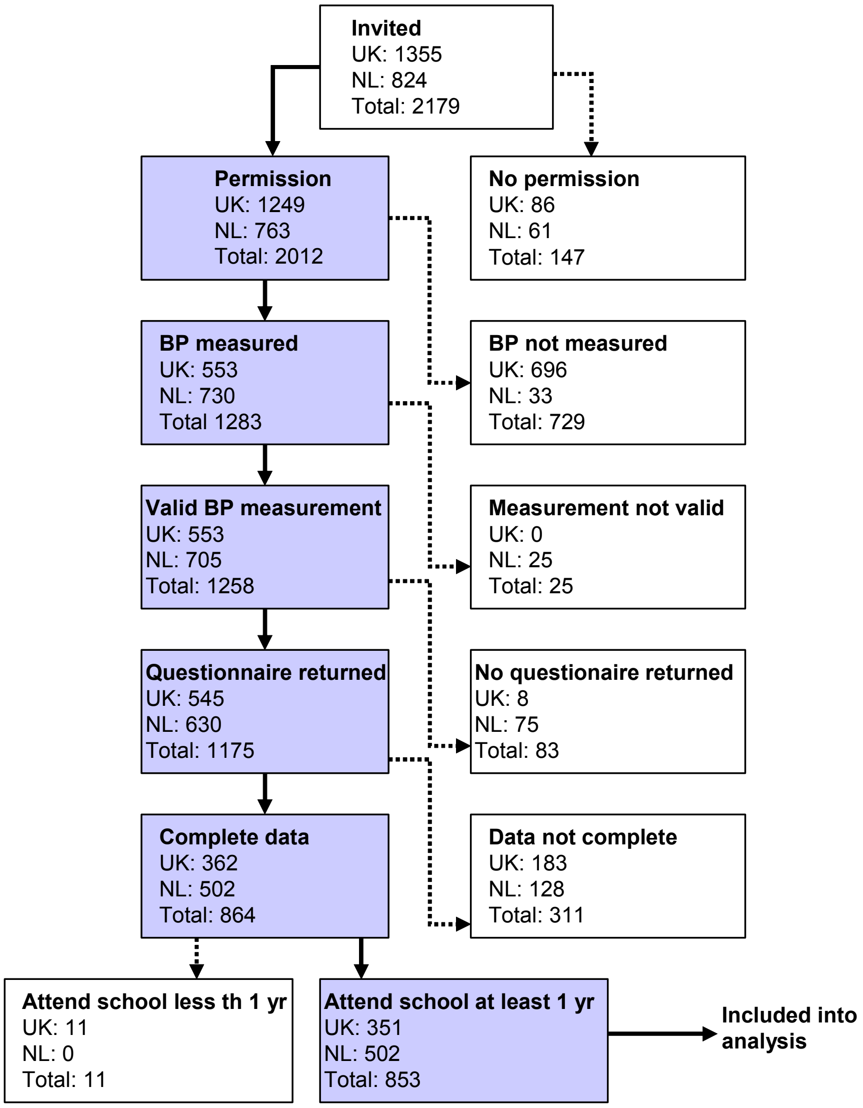

FIGURE 3.1 *Flowchart indicating what has happened with the children that were invited to participate in RANCH. Abbreviations: BP = Blood pressure.*

TABLE 3.1 *General characteristics of the children included in the analysis and the schools they visit*

Characteristic	**Overall (*N* = 853)**	**UK (*N* = 351)**	**NL (*N* = 502)**
Number of participating schools	62	29	33
Girls, %	51.5	53.3	50.2
Mean age (yrs) (SD)	10.4 (0.5)	10.3 (0.3)	10.5 (0.6)
Mean blood pressure (mmHg) (SD)			
Systolic blood pressure	106.8 (10.4)	108.9 (9.7)	105.4 (10.6)
Diastolic blood pressure	66.2 (8.3)	67.1 (7.9)	65.6 (8.4)
Mean heart rate (beats/min) (SD)	83.9 (11.9)	89.4 (11.5)	80.1 (10.7)
Small cuff size used, %	90.4	95.2	87.1
Mean room temperature (°C) (SD)	22.4 (2.0)	23.1 (1.6)	22.0 (2.1)
Biometrics			
Ponderosity (kg/m^3) (SD)	12.61 (2.04)	13.25 (2.21)	12.17 (1.77)
Birth weight < 2500 gram, %	7.7	9.1	6.8
Premature[#], %	7.3	12.5	3.6
Mean modelled noise exposure levels, dB(A) (range)			
Aircraft noise at school ($L_{Aeq,\ 7\text{-}23hrs}$)	58 (34 – 68)	60 (34 – 68)	54 (36 – 63)
Aircraft noise at home ($L_{Aeq,\ 7\text{-}23hrs}$)	51.0 (34 – 73)	53.4 (34 – 73)	49.3 (35 – 65)
Aircraft noise at home ($L_{Aeq,\ 23\text{-}7hrs}$)	40.9 (28 – 67)	43.2 (28 – 67)	39.2 (29 – 57)
Road traffic noise at school ($L_{Aeq,\ 7\text{-}23hrs}$)	56 (34 – 67)	57 (37-67)	55 (34 – 62)
Road traffic noise at home ($L_{Aeq,\ 7\text{-}23hrs}$)	-	NA[††]	55.7 (28 – 67)
School glazing, %			
Single	48.4	51.7	45.5
Mixed[‡‡]	3.2	6.9	-
Double	41.9	41.4	42.4
Triple	6.5	-	12.1
Double glazing at child's home, %	70.1	85.5	59.4
Socio-economic status			
Crowding in the home[†], %	27.9	21.9	31.9
Parental home ownership, %	76.0	64.4	84.1
Employed parents[‡], %	88.3	81.2	93.2
Mean mother's education[§] (SD)	0.493 (0.279)	0.492 (0.270)	0.493 (0.285)
White British/Dutch[*], %	80.5	68.4	89.8
Parental high blood pressure[**], %	28.3	21.4	33.1

Ethnicity of the child's mother was used as a proxy for the child's ethnicity. [†] Crowding is an objective measure of the number of people per room in a dwelling. In the UK, the official definition of crowded from the census is more than 1.5 people per room per dwelling; in the Netherlands crowding is defined as the number of people being smaller or equal to the number of rooms in a dwelling. [‡] This is a measure of the highest employment status in the child's household. In the UK employed means that the parent is working full-time or part-time and in the Netherlands employed means that the parent does paid work for at least 19 hrs a week. [§] Mother's education was measured using a ranked index of standard qualifications in each country. A relative index was then calculated for this variable, so that comparisons could be made between the different measures in each country (index ranges from 0-1, with higher number indicating low educational attainment). [#] Prematurity means that the child was born before week 36 of the pregnancy. [**] Parental high blood pressure indicated whether one or both parents had high blood pressure and/or used antihypertensive drugs either currently or in the past. [††] Abbreviations: N: Sample size; SD: Standard deviation NA: Not available; range: the range runs from the minimum value to the maximum value. [‡‡] School buildings containing double and single glazed windows.

Exposure characterisation
In the UK-sample high correlations between home and school aircraft noise levels ($L_{Aeq,\ 7\text{-}23hrs}$) were found (r ~ 0.9). High correlations were also found in the Dutch sample between the aircraft noise level at school ($L_{Aeq,\ 7\text{-}23hrs}$) and the aircraft noise level at home (r > 0.7). The correlation between home and school road traffic noise levels ($L_{Aeq,\ 7\text{-}23hrs}$) in the Dutch sample was moderate (r ~ 0.6).

Aircraft noise exposure
The results of multilevel analysis (Table 3.2) show that after pooling the data, aircraft noise exposure at school and at home were related to a statistically significant increase in systolic blood pressure. Only the effect of aircraft noise exposure at home remained when the model was further adjusted for socio-economic status, ethnicity, cuff-size, room temperature, birth weight, parental hypertension, and prematurity. Strong associations with systolic blood pressure were found for ponderosity, centre, parental high blood pressure and cuff size.

Table 3.3 shows the fully adjusted associations (model 2) between aircraft and road traffic noise exposure at school and at home and blood pressure and heart rate, for the pooled sample and the country-specific samples.

After pooling the data, chronic aircraft noise at school ($L_{Aeq,\ 7\text{-}23\ hrs}$) was related to a statistically non-significant increase in systolic (χ^2= 2.7, df =1, p= 0.10) and diastolic (χ^2= 1.4, df =1, p= 0.22) blood pressure and heart rate (χ^2= 1.0, df =1, p= 0.33). Chronic aircraft noise at home (expressed as $L_{Aeq,\ 7\text{-}23hrs}$) was statistically related to systolic (χ^2= 4.2, df =1, p= 0.04) and diastolic (χ^2= 3.9, df =1, p= 0.05) blood pressure: Increases of 0.10 (95% CI: 0.00, 0.20) and 0.19 (95% CI: 0.05 – 0.32) mmHg/dB(A) were found for systolic and diastolic blood pressure, respectively. Chronic aircraft noise exposure during the night ($L_{Aeq,\ 23\text{-}7hrs}$) at home was positively associated with blood pressure. Only for systolic blood pressure was this association statistically significant (χ^2= 4.7, df =1, p= 0.03): after pooling the data an increase of 0.09 (95% CI: 0.00, 0.18) mmHg/dB(A) was found.

The effect of chronic aircraft noise on blood pressure differed somewhat between the samples: In the Dutch sample, chronic aircraft noise exposure at school was related to an increase in blood pressure. Statistically significant increases of 0.17 (95% CI: 0.01, 0.33) mmHg/dB(A) and 0.20 (95% CI: 0.06, 0.34) mmHg/dB(A) were estimated for systolic and diastolic blood pressure, respectively. In the British sample, aircraft noise exposure at school was related to small and statistically non-significant increases in blood pressure. For diastolic blood pressure, the results differed statistically significantly between the samples (Test of heterogeneity: χ^2=7.1, df =1, p=0.01). In relation to chronic aircraft noise at home (expressed as $L_{Aeq,\ 7\text{-}23hrs}$ and $L_{Aeq,\ 23\text{-}7hrs}$) similar differences between the samples could be observed (see also Table 3.3).

TABLE 3.2 *The fully adjusted multilevel models† on the pooled sample for noise exposure and systolic blood pressure (only children visiting their school for at least 1 year) (n = 853).*

Situation →	**At school**		**At home**	
	Model 1	**Model 2**	**Model 1**	**Model 2**
	B (95% CI)*	**B (95% CI)***	**B (95% CI)***	**B (95% CI)***
Fixed coefficients ↓				
Intercept	78.01 (60.58 – 5.43)	75.01 (55.14 - 94.87)	74.74 (58.39 –1.08)	69.03 (49.23 – 8.83)
Noise exposure ($L_{Aeq\ 7\text{-}23\ hrs}$) in dB(A)				
Air traffic noise at school	0.11 (0.00 – 0.21) ‡	0.08 (-0.02, 0.18)		
Road traffic noise at school		-0.11 (-0.21, 0.00) ‡		
Aircraft noise at home		-	0.14 (0.04 – 0.24) ‡	0.10 (0.00 – 0.20) ‡
UK	1.94 (0.04 – 3.84) ‡	1.95 (-0.01, 3.91) ‡	1.55 (-0.25 – 3.35)	1.68 (-0.33 – 3.68)
Age (yrs)	0.45 (-1.05 – 1.95)	1.08 (-0.40, 2.55)	0.47 (-1.01 – 1.94)	0.90 (-0.57 – 2.37)
Boys	0.50 (-0.81 – 1.80)	0.52 (-0.76, 1.81)	0.50 (-0.81 – 1.80)	0.55 (-0.74 – 1.84)
Ponderosity (kg/m^3)	1.54 (1.21 – 1.88) ‡	2.06 (1.70, 2.43) ‡	1.55 (1.22 – 1.89) ‡	2.05 (1.70 – 2.40) ‡
School glazing				
Single	-1.85 (-5.78 – 2.09)	-0.86 (-4.54 , 2.81)		-0.53 (-4.25 – 3.19)
Single and double	-3.32 (-9.38 – 2.73)	-2.03 (-7.63, 3.58)		-1.68 (-7.38 – 4.02)
Double	-1.99 (-5.92 – 1.94)	-1.58 (-5.19, 2.03)		-1.27 (-4.94 – 2.40)
Triple	*Ref*	*Ref*		*Ref*
Double glazing at home		-1.00 (-2.49, 0.48)	-0.58 (-2.08 – 0.93)	-1.03 (-2.52 – 0.46)
Employed		0.84 (-1.28, 2.96)		0.94 (-1.18 – 3.06)
Crowded		0.42 (-1.06, 1.89)		0.47 (-1.00 – 1.94)
Home owner		1.21 (-0.43, 2.85)		1.31 (-0.34 – 2.96)
Mother's education		-1.26 (-3.68, 1.16)		-1.18 (-3.61 – 1.25)
White British/Dutch		1.06 (-0.79, 2.91)		1.26 (-0.60 – 3.12)
Small cuff size		-8.19 (-10.63, -5.74) ‡		-8.06 (-10.51 - -5.61) ‡
Birth weight < 2,500 gr.		-2.35 (-5.25, 0.54)		-2.38 (-5.28 – 0.52)
Parental hypertension		1.64 (0.19, 3.09) ‡		1.57 (0.12 – 3.02) ‡
Premature		2.61 (-0.41, 5.63)		2.76 (-0.26 – 5.78)
Room temperature (°C)		-0.23 (-0.64, 0.18)		-0.18 (-0.59 – 0.23)
Random parameters				
Level 2: school	4.45 (0.53 – 8.37)	2.72 (-0.57 – 6.01)	3.71 (0.14 – 7.28)	3.07 (-0.30 – 6.44)
Level 1: pupil	91.44 (82.46 –100.42)	86.83 (78.46 – 95.20)	91.53 (82.55 – 100.51)	86.76 (79.19 – 95.33)

* B: Estimated change in systolic blood pressure (mmHg) per dB(A). 95% CI: 95% Confidence interval calculated by means of the standard error. † The models are additionally evaluated against a model with the noise term excluded. ‡ χ^2-test was statistically significant $\alpha < 0.05$.

TABLE 3.3 *The association between noise exposure and blood pressure and heart rate changes, after adjustment for confounders (only children visiting their school for at least 1 year)(n = 853)* *

Source	Location	Exposure metric	Outcome	Pooled sample (n = 853)	UK-sample (n=351)	NL-sample (n=502)
				B (95%CI) (p)*	B (95%CI) (p)*	B (95%CI) (p)*
Aircraft noise	At school†	$L_{Aeq,\ 7\text{-}23hrs}$	Systolic blood pressure	0.08 (-0.02 – 0.18) (0.10)	0.02 (-0.12 – 0.15) (0.77)	0.17 (0.01 – 0.33) (0.02)
			Diastolic blood pressure	0.05 (-0.04 – 0.14) (0.22)	0.01 (-0.09 – 0.12) (0.83)	0.20 (0.06 – 0.34) (0.00)
			Heart rate	0.05 (-0.06 – 0.15) (0.33)	0.01 (-0.13 – 0.16) (0.86)	0.08 (-0.11 – 0.27) (0.45)
	At home‡	$L_{Aeq,\ 7\text{-}23hrs}$	Systolic blood pressure	0.10 (0.00 – 0.20) (0.04)	0.03 (-0.10 – 0.17) (0.57)	0.17 (0.01 – 0.33) (0.03)
			Diastolic blood pressure	0.08 (-0.01 – 0.17) (0.05)	0.04 (-0.07 – 0.14) (0.43)	0.19 (0.05 – 0.32) (0.00)
			Heart rate	0.02 (-0.08 – 0.13) (0.61)	0.00 (-0.15 – 0.14) (0.95)	0.06 (-0.12 – 0.23) (0.51)
	At home‡	$L_{Aeq,\ 23\text{-}7\ hrs}$	Systolic blood pressure	0.09 (0.00 – 0.18) (0.03)	-0.01 (-0.13 – 0.12) (0.97)	0.19 (0.07 – 0.31) (0.00)
			Diastolic blood pressure	0.07 (-0.01 – 0.14) (0.08)	0.04 (-0.06 – 0.14) (0.35)	0.13 (0.01 – 0.24) (0.02)
			Heart rate	0.03 (-0.07 – 0.12) (0.50)	0.01 (-0.13 – 0.16) (0.84)	0.04 (-0.11 – 0.19) (0.55)
Road traffic noise	At school†	$L_{Aeq,\ 7\text{-}23hrs}$	Systolic blood pressure	-0.11 (-0.21 – 0.00) (0.03)	-0.09 (-0.25 – 0.08) (0.22)	-0.14 (-0.27 - -0.01) (0.02)
			Diastolic blood pressure	-0.04 (-0.13 – 0.06) (0.40)	0.02 (-0.11 – 0.15) (0.76)	-0.09 (-0.20 – 0.03) (0.09)
			Heart rate	-0.02 (-0.13 – 0.08) (0.62)	-0.11 (-0.28 – 0.07) (0.22)	0.02 (-0.14 – 0.17) (0.80)
	At home‡	$L_{Aeq,\ 7\text{-}23hrs}$	Systolic blood pressure		NA*	-0.09 (-0.22 – 0.04) (0.16)
			Diastolic blood pressure		NA*	-0.07 (-0.18 – 0.04) (0.17)
			Heart rate		NA*	0.06 (-0.08 – 0.20) (0.39)

* Abbreviations: B: estimated change in blood pressure or heart rate per dB(A); 95% CI: 95 percent confidence intervals calculated by means of the standard error; n: sample size, p: p-value for association $\alpha < 0.05$, tested by means of a χ^2-test; NA: Data not available; † The model is adjusted for either aircraft or road traffic noise at school, centre (only for the pooled analysis), age, gender, ponderosity, school glazing, double glazing at home, employment status, crowding, home ownership, mother's education, ethnicity, cuff size, birth weight, parental high blood pressure, prematurity, and room temperature. ‡ The model is adjusted for either aircraft or road traffic noise at home, centre (only for the pooled analysis), age, gender, ponderosity, double glazing at home, school glazing, employment status, crowding, home ownership, mother's education, ethnicity, cuff size, birth weight, parental high blood pressure, prematurity, and room temperature

Road traffic noise exposure
After pooling the data, chronic road traffic noise exposure at school ($L_{Aeq,\ 7\text{-}23\ hrs}$) was related to a decrease in systolic and diastolic blood pressure. For systolic blood pressure this association was statistically significant: A decrease of –0.11 (95% CI: -0.21, 0.00) mmHg/dB(A) was estimated. A negative association was found between chronic road traffic noise exposure and heart rate: chronic road traffic noise exposure was related to a decrease in heart rate; this was not statistically significant. The effect of road traffic noise on blood pressure did not differ between the samples. The effects of road traffic noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at home were only investigated in the Dutch sample: road traffic noise at home was related to a statistically non-significant decrease in systolic and diastolic blood pressure.

Comparison with other studies
In Figures 3.2 and 3.3, the results of the RANCH study are compared with other recent studies investigating the effects of noise on children's blood pressure. The figures show that small differences in blood pressure can be observed and that the effect of noise exposure on children's blood pressure differs among the studies.

3.1.4 Discussion

Aircraft noise
In this study indications were found for a possible association between chronic aircraft noise and blood pressure. However, the effect of chronic aircraft noise on the blood pressure differed between the samples: in the Dutch sample aircraft noise exposure was related to increased blood pressure; this was not the case in the British sample. Due to the difference in exposure metrics and adjustment for confounders, comparison of the results of the RANCH study with other studies was difficult. Figures 3.2 and 3.3 show that for aircraft noise exposure no consistent findings can be seen. The Los Angeles Airport Study (LAAS) showed that both systolic and diastolic blood pressure were higher in the children attending aircraft noise exposed schools than in children attending control schools [13, 14]. Blood pressure differences of 2.9 mmHg for systolic blood pressure and 2.6 mmHg for diastolic blood pressure were found, while the difference in noise exposure levels ($L_{Aeq,\ 1\ hr\ indoor}$) between the exposed and the control group was 18 dB(A). Comparison of the blood pressure between two groups of children living around the old Munich Airport, exposed to high noise levels ($L_{Aeq,\ 24hr}$=68.1 dB(A)) or lower noise levels (($L_{Aeq,\ 24hr}$=59.2 dB(A)) showed that there was an increase of 1.92 mmHg for systolic blood pressure and a decrease of 0.17 mmHg for diastolic blood pressure [16, 17]. Morrell et al. investigated the effects of aircraft noise exposure both at school and at home [19]. After adjustment for confounders, they found that both school and

residential aircraft noise levels were negatively but statistically not significantly associated with systolic and diastolic blood pressure; for school exposure, regression coefficients of -0.017 and -0.043 for systolic and diastolic blood pressure were found, corresponding with mean blood pressure differences of 0.5 – 1.3 mmHg across the whole noise range (15-45 ANEI).

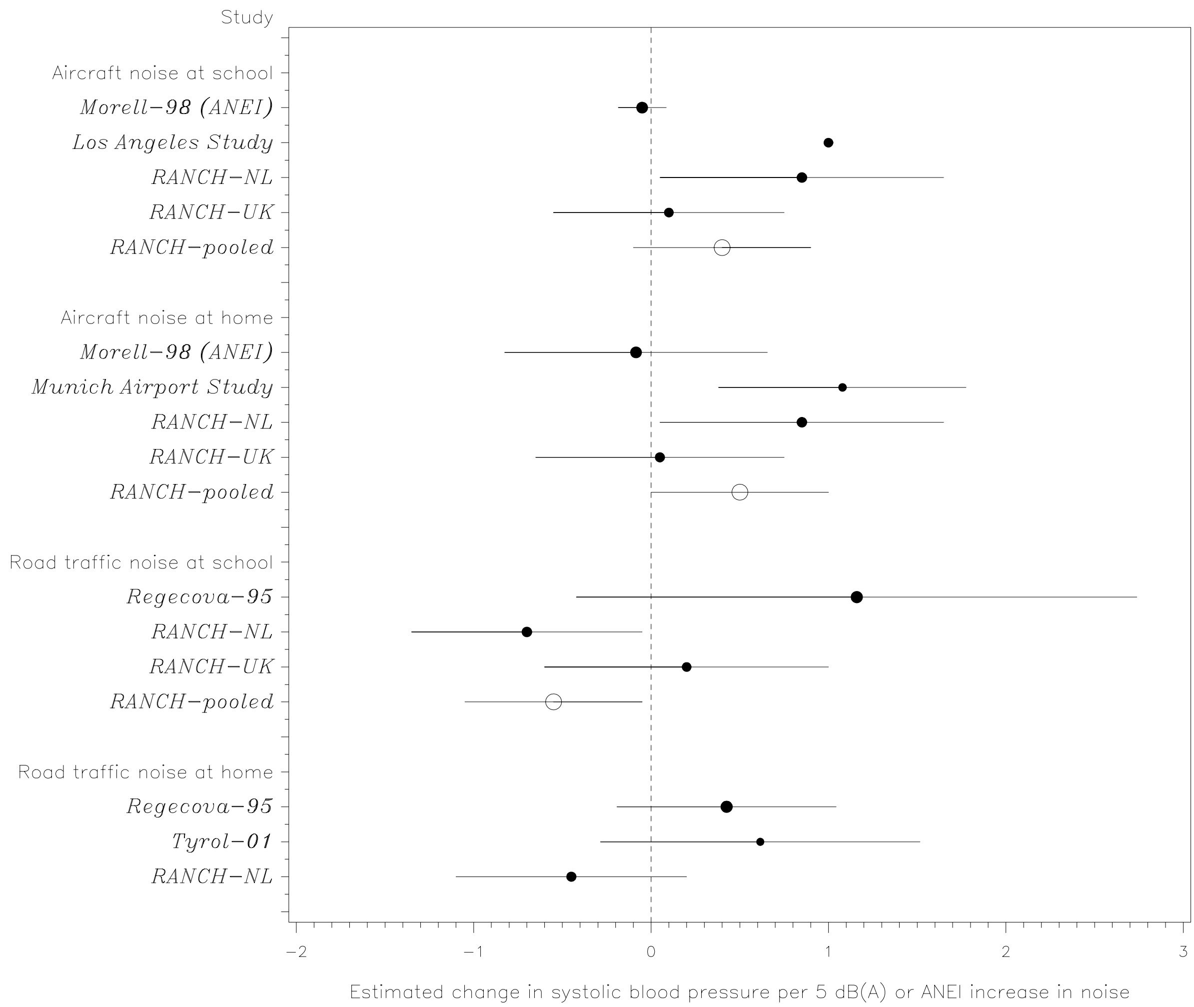

FIGURE 3.2 *The association between noise exposure and systolic blood pressure in children. The dotted vertical line corresponds to no effect of noise exposure; with the exception of Morell-98 [19] the circles and horizontal lines corresponds to the estimated change in blood pressure per 5 dB(A) increase in noise and 95% confidence interval. For Morell-98 [19] the circles and horizontal lines correspond to the estimated change in blood pressure per 5 ANEI increase and 95% confidence interval. With the exception of the results of the RANCH study and Morell-98 [19], the presented estimates of the other studies were not adjusted for confounders due to the fact that data were not available.*

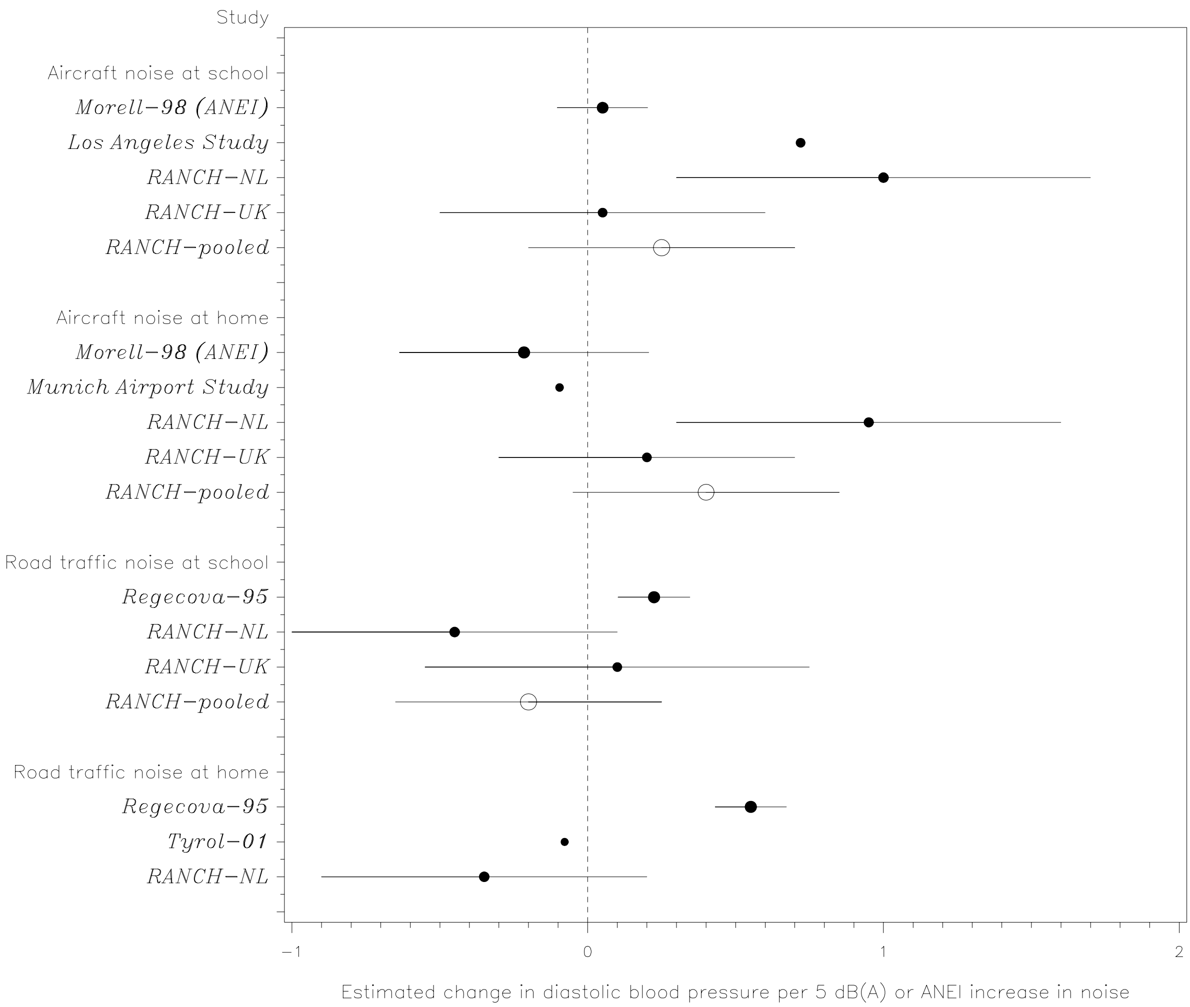

FIGURE 3.3 *The association between noise exposure and diastolic blood pressure in children. The dotted vertical line corresponds to no effect of noise exposure; with the exception of Morell-98 [19] the circles and horizontal lines corresponds to the estimated change in blood pressure per 5 dB(A) increase in noise and 95% CI. For Morell-98 [19] the circles and horizontal lines correspond to the estimated change in blood pressure per 5 ANEI increase and 95% CI. With the exception of the results of the RANCH study and Morell-98 [19], the presented estimates of the other studies were not adjusted for confounders due to the fact that data were not available.*

Until now the effects of long-term night-time noise exposure on the cardiovascular system were only investigated in adults: In a recent German study the associations between night-time road traffic noise and several cardiovascular outcomes were found to be stronger than the associations for daytime noise [20]. Because the correlations between aircraft noise metrics were high in the RANCH-study, it was not possible to disentangle the effects of school and home exposure (including the night period).

Road traffic noise

In the RANCH-study negative associations were found between chronic road traffic noise exposure and blood pressure. The results of previous studies investigating the effects of road traffic noise were not consistent (see also Figures 3.2 and 3.3). Regecová and Kellerová (1995) found that children attending kindergartens situated in areas with traffic noise levels higher than 60 dB(A) had higher mean blood pressure than children in quiet areas [15]. Mean heart rate values tended to decrease with increasing traffic noise recorded at kindergartens, which was consistent with the findings in the UK-sample. In the Tyrol Mountains Study (TMS), children exposed to higher levels of road and rail traffic noise (L_{dn}>60 dB(A)) had an elevated systolic blood pressure and only slightly elevated heart rate compared to children exposed to noise levels below L_{dn} 50 dB(A) [18]. For diastolic blood pressure a decrease was found. Karsdorf and Klappach (1968) found a maximal difference of 16 mmHg for both systolic and diastolic blood pressure in girls, when comparing the blood pressure of children attending a quiet school with that of children attending a noisy school [21].

A possible explanation for the unexpected road traffic noise effects might be the estimation of exposure to road traffic noise. Since children move to a different classroom each year during their time at school, road traffic noise exposure change. Thus, the road traffic noise levels at the façade of their current classroom might not reflect the average level of exposure during their time at school [10].

Differences between the samples

As already mentioned, the effect of aircraft noise on the blood pressure differed between the samples. It is not possible to give an unequivocal explanation for these differences. Although noise levels in both samples were calculated according to a standardized protocol, differences in variations in flight patterns and differences in availability of the aircraft- and road traffic fleet between the countries might have played a role. These could have lead to systematic biases and unexpected differences in the outcome [22 – 26]. There might be differences in frequency and type of insulation of both schools and homes, which could result in differences in the effect of noise on blood pressure, even though both design and analysis accounted for the influence of insulation [10]. Differences in schooling system and teachers' attitudes towards noise might have differential effects on the children's reactions to noise.

The British sample contained relatively more non-white children than the Dutch sample; the Dutch non-white group included Turkish and Moroccan children and children with a mixed background, while the British non-white sample included Pakistani and Indian children. Winkelby showed strong differences in blood pressure among different ethnic groups [27]. It appears that hypertension is very common in African cities and in black populations in Britain and the United States [28]. According to the Dutch Heart Foundation the prevalence of high blood pressure among young foreigners (Turkish and Moroccans) varies from 2 to 10%; the variation among Dutch natives is 4 to 7% [29]. Due to these differences in ethnic composition of the samples, it is possible that statistical adjustment did not lead to a complete comparison. Because of differences in the ethnic composition between the samples, the impact of ethnicity on the association between noise exposure and blood pressure might differ between the British and Dutch samples. This might be a possible explanation for the differences found in the effect of aircraft noise on blood pressure between both samples. Furthermore, life-style factors such as salt intake and body exercise were not measured but might have played a role. None of the explanations mentioned in this section, can be further investigated on the data available in the RANCH study.

Study strengths and limitations

This study had a relative large sample size; the participants were distributed over a broad exposure range by using a continuous noise exposure measure. To date, most studies investigating the impact of noise exposure have involved between-group comparisons (high vs low) or they have tended to create noise categories (e.g. high, medium, low) by using indicator terms for ordered polytomuous exposure categories. However, it is recognized that the results may be sensitive to decisions about cut-off points used to categorize continuous exposure variables and the method used to assign scores to exposure categories [30]. Furthermore, we were able to take into account a broad range of potential confounders and determinants which were gathered in a uniform way. Unlike previous studies, we took into account the hierarchical structure of the data. Finally, the current study investigated the effects of both school- and home noise exposure, including night-time noise exposure. Despite the availability of these data, it was not possible to disentangle the effects of school- and home exposure due to the high correlation between the aircraft noise metrics. Because the main objective of RANCH was to investigate the effects of noise exposure at school on children’s cognition, noise exposure at home was not taken into account during the selection. Based on our study it is therefore not possible to draw definite conclusions about the relative importance of noise exposure at home and at school and possible interactions between home and school noise exposure. The cross-sectional design of our study limits causal interpretations of the possible relation between noise exposure and blood pressure. The road traffic noise levels at the façade of the children’s school, might not reflect the average level exposure during their time at school. This might have biased the outcomes of our results [10].

Interpretation of the findings
Due to the fact that the results of this study are not fully consistent and the inconsistency in the scientific literature, it is not possible to derive an exposure-response relation between noise exposure and children's blood pressure.

Additionally, it is unknown whether the effects of noise on blood pressure are reversible if exposure to noise ceases; in the MAS differences in reading score between the two exposure groups disappeared after removing the differences in noise exposure [31]. Finally, it is difficult to indicate whether and to what extent slight increases in children's blood pressure can cause possible health risks in later life. The degrees of blood pressure elevations found in relation to noise exposure were small and the clinical significance of such minor changes in childhood blood pressure is difficult to determine. Findings could be due to chance. The extent of blood pressure elevations found are probably not significant for children during their youth, but could portend elevations later in life that might be health damaging [32]. In the literature it is suggested that increased blood pressure in children strongly predicts hypertension in young adults; essential hypertension and the precursors of cardiovascular disease might originate in childhood [33 – 37]. Some studies, investigating the effects of noise exposure on children's blood pressure interpret such findings as indicator of psychophysiological arousal [16, 17]. However, another possibility is that the observed blood pressure elevations are vegetative responses. Since we found significant associations with night-time exposure, blood pressure elevations might also be seen as an effect of sleep disturbance [20].

3.1.5 Conclusion
The relationship between aircraft noise and blood pressure was not fully consistent: in the Dutch sample, blood pressure increased statistically significantly as aircraft noise exposure increased; this was not the case in the British sample. These findings, taken together with those from previous studies, suggest that no univocal conclusions about the association between aircraft noise exposure and blood pressure can be drawn.

The findings for road traffic noise were difficult to interpret, since negative associations were found between chronic road traffic noise exposure and blood pressure. Furthermore, the results of previous studies investigating the effects of road traffic noise were not consistent. Based on our study it is not possible to draw definite conclusions about the relative importance of noise exposure at home and at school and possible interactions. For a better understanding of the underlying mechanisms, more research is necessary to disentangle the effects of home and school noise exposure.

3.2 The association between noise exposure and blood pressure and ischemic heart disease: *A meta-analysis*

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ABSTRACT

Objectives: It has been suggested that noise exposure is associated with blood pressure changes and ischemic heart disease risk, but epidemiological evidence is still limited. Furthermore, most reviews investigating these relations were not carried out in a systematic way, which makes them more prone to bias.

Methods: A meta-analysis of 43 epidemiological studies published between 1970-1999 and investigating the relation between noise exposure (both occupational and community), blood pressure and/or ischemic heart disease (ICD-9: 410-414) was conducted.

Results: A wide range of effects, varying from blood pressure changes to a myocardial infarction, was studied. With respect to the association between noise exposure and blood pressure, small blood pressure differences were noticed. Our meta-analysis showed a significant association for both occupational noise exposure and air traffic noise exposure and hypertension: RRs of 1.14 (95%CI: 1.01 – 1.29) and 1.26 (95%CI: 1.14 – 1.39) per 5 dB(A) noise increase were estimated, respectively. Air traffic noise exposure was positively associated with the consultation of a GP or specialist, the use of cardiovascular medicines and angina pectoris. In cross-sectional studies, road traffic noise exposure increases the risk of myocardial infarction and total ischemic heart disease.

Conclusion: Although we can conclude that there are indications that noise exposure can contribute to the prevalence of cardiovascular disease, the evidence for a relation between noise exposure and ischemic heart disease is still inconclusive, because of the limitations in exposure characterisation, adjustment for important confounders and the occurrence of publication bias.

Introduction

Noise is a persistent environmental problem. It appears that in Europe, about 450 million persons are exposed daily to equivalent noise levels of at least 55 dB(A); 113 million persons are exposed to equivalent noise levels of at least 65 dB(A), and 9.7 million persons are even exposed to equivalent noise levels of 75 dB(A) or more [38].

Noise exposure is associated with a number of health effects. We can distinguish (i) socio-psychological responses, such as annoyance, sleep disturbance, disturbance of daily activities and performance; (ii) physical responses, such as hearing loss, hypertension and ischemic heart disease [39]. At the moment a lot of discussion is going on how noise can affect human health and well being. Stress is supposed to play an important role in this. It can be seen as an effect of the appraisal of noise or as a (coping) reaction of the body (fight-flight): the so-called vegetative responses [39]. One of the models on noise and health that are being used at the moment is presented in Figure 1.3 in Section 1.3.1. It is an adapted version of the schematic presented by the Dutch Health Council [39] and assumes that health effects are determined by a combination of endogenous and exogenous factors, such as the physical and social environment and life style. Noise exposure is only one of these exogenous factors. This process may be modified by personal characteristics such as attitude and coping style. According to this model, noise exposure can induce biochemical, physiological or (socio-) psychological changes such as disturbance of sleep and daily activities, stress, and annoyance. These changes fall more or less within the normal range of biological variation. Whether these changes are of any significance to health depends above all on the degree to which the function of organ systems or social-psychological functioning is affected, the reversibility and duration of the changes and the possibilities for recovery or compensation, and on the possible loss of resilience [39]. Noise-induced sleeping problems and their influence on mood and performance the next day are part of every normal life. However, at some point sleeping problems or sleep disturbance may become clinically significant as normal physical, mental and social functioning is hampered. An effect such as the elevation of blood pressure due to noise exposure might fall largely within normal homeostasis. However, given a certain population distribution of for instance systolic blood pressure, even a small shift due to environmental exposure may yield a substantial increase in the prevalence and mortality of cardiovascular disease [39].

With this model keeping in mind, the present study focuses on the physical responses to noise exposure: blood pressure changes and cardiovascular disease risk. Although many observational studies and reviews on noise exposure and cardiovascular effects have been carried out, epidemiological evidence is still limited [4, 40-58]. Due to the preponderant influences of factors such as life style and genetic predisposition, it is difficult to gain insight in the (potential) contribution of noise to cardiovascular disease [39]. As a result, the results presented in these observational studies are not consistent. Most of the previous reviews were not carried out in a systematic way, which makes them more prone to bias [59]. Only two of the reviews have quantified the association between noise and cardiovascular disease [40, 60]. In the review of Duncan et al. (1993) the results of different noise exposure situations were combined. However, the situation in which people are exposed, may influence their response. The second study reviewed only occupational studies [40].

To gain more insight into the relation between noise exposure and its potential health impact, we performed a meta-analysis on observational studies investigating the relation between noise and blood pressure and/or ischemic heart disease. A meta-analysis or quantitative overview is a systematic review that employs statistical methods to combine and summarise data from several studies [59]. By means of a meta-analysis we can also gain more insight into the sources of heterogeneity among study results: the findings of observational studies are often distorted by different sources of bias [61], causing a fair amount of heterogeneous variation on study level [62]. This variation between various research results may be explained by differences in individual study characteristics with respect to the study population or design [62].

3.2.1 Materials and methods

Data-collection

Observational studies involving the association between noise exposure and blood pressure and/or ischemic heart disease, published between 1970 and 1999 in English, German or Dutch, were identified in MEDLINE, EMBASE, BIOSIS, SCISEARCH, as well as in literature files at the National Institute of Public Health and the Environment (see also Appendix 3.1 for search strategy). To make sure that most of the studies carried out could be identified, journals, reports and proceedings in the area of epidemiology, noise, cardiovascular disease and (public) health, were manually scanned. From relevant literature in the field of noise and health, references were checked for additional studies. Overall, more than 500 publications were identified.

Studies meeting the following criteria, were included for data-extraction:

- Title and/or abstract of the given survey had to involve occupational noise exposure or community noise exposure in relation to blood pressure or ischemic heart disease (or both blood pressure and ischemic heart disease). In the given studies, the relation between noise exposure and blood pressure and/or ischemic heart disease had to be studied in a study population of adults, who were not defined as a population with a certain illness or disorder.

- The survey had to quantify and/or describe the relation between objective noise exposure (in dB(A)) and blood pressure (mmHg) and/or the relation between objective noise exposure (in dB(A)) and ischemic heart disease (ICD-9: 410-414).

Only adults were studied, because the findings in children are difficult to interpret with regard to possible health risks in their later life [45]. The equivalent sound level ($L_{Aeq,}$ in dB(A)) was chosen as a measure of exposure because it is the measure that is most commonly used. Studies published before 1970 were excluded for several reasons: (i) they contained little quantitative information, necessary for a meta-analysis, (ii) they were often (quasi)-experimental and (iii) the epidemiological and methodological quality is relatively poor with respect to the current scientific standards [55]. Studies using hearing loss or defective hearing as a proxy for (previous) noise exposure were also excluded. The reasons were that (i) it is impossible to differentiate between hearing loss due to noise exposure and hearing loss due to other reasons; it is difficult to detect differences in exposure (level) in case noise exposure is based on defective hearing compared to other measures of exposure. Furthermore, (iii) it is possible that atherosclerosis and/or hypertension increase the risk for hearing loss [48]. In addition, surveys assessing noise exposure on the basis of subjective ratings, as given by the study subjects in a questionnaire, were excluded. Subjective indicators are susceptible to observation bias (due to over-reporting) and recall bias [50].

Data-extraction

From studies, that met the above-mentioned criteria [63-110], the following data were extracted via a structured data-extraction form: data about study characteristics (authors, year of publication, study -period and study -location, design), population characteristics (number of respondents, gender, age, inclusion- and exclusion criteria), exposure assessment and effect measurement were extracted. For each study, the data-extraction was done by at least two persons, working in the field of noise-research and/or statistics, and was discussed afterwards. Furthermore, a noise expert looked at the noise measurements presented in the studies. He checked whether the presented sound levels in the article were realistic given the presented methods of noise assessment.

The main effects under investigation were blood pressure, hypertension, and the use of anti-hypertensive and/or cardiovascular medication, angina pectoris, myocardial infarction and ischemic heart disease. In order to make a comparison between the studies, the following outcome variables were calculated:

- *Blood pressure*

Based on the extracted average blood pressure values, presented in the studies and noise levels (dB(A)), blood pressure change (mmHg) per noise level increase of 5 dB(A) (β_{BP}) and its variance for both systolic and diastolic blood pressure, were calculated.

- *Hypertension, use of antihypertensives, and/or cardiovascular medication, angina pectoris, myocardial infarction and ischemic heart diseases.*

Based on all the extracted prevalences (incidences) and/or relative risks and noise levels (dB(A)), the natural logarithm of the relative risk (ln (RR)) and its variance per 5 dB(A) was calculated. For studies comparing two exposure groups, the following equations were used:

(a) $\beta_i = \ln(RR) * (\frac{5}{\Delta dB(A)})$

(b) $\sigma_i = (\frac{(\ln RR_{hi}) - (\ln RR_{lo})}{3.92}) * (\frac{5}{\Delta dB(A)})$

Where:

β_i:	Estimated ln(RR) per 5 dB(A);
RR:	Relative risk extracted from study or calculated with Epi-info
ΔdB(A):	The difference in noise levels between the index and reference group;
σ_i:	Estimated standard error of β_i
RR_{hi}:	Upper level of RR of the 95% confidence interval;
RR_{lo}:	Lower level of RR of the 95% confidence interval;

(see also Appendix 3.2)

In studies where two or more exposure groups were compared, betas were estimated with the SAS procedure PROC REG. In this case, each group was compared to the lowest exposure group. From each participating study, one or more estimates of the above mentioned outcome variables and their variance were extracted. Because not all the required data were directly available, recalculations were done. Equations and methods used are presented in Appendix 3.3.

Data-aggregation

The extracted estimates had to be unconfounded by age and gender. Also they had to refer to a homogeneous study population: white collar workers are not a good control group for blue collar workers [50], because the difference in noise at work, might be associated with other factors of the work place, which are also related to the health outcome. Furthermore, there may be differences with regard to life -style, social status and psychosocial factors. Therefore, for the occupational studies researched in this paper, only estimates from studies investigating the association between noise and ischemic heart disease and/or blood pressure, well matched with regards to control (referent) groups, are included. Since the populations in the community noise studies were considered relatively homogeneous, no extra criteria were applied. These adjusted estimates were aggregated, taking into account the variance. The 'true value' was assumed to be normally distributed (mean (μ_{true}) and have a standard error (σ_{true})). By means of a meta-analysis, μ_{true} and σ_{true} is estimated, given a number of outcome measures y_i (i=1,….,n) with standard error σ_i. To estimate these parameters, a Random Effects Model (REM) was used. A Random effects model (REM) acknowledges the occurrence of variation of true effects between studies, but regards them as unknown effects to be estimated, by assuming that the effects observed in the sample of studies analysed, are drawn from a population of studies [62].

To summarise the data, summary estimates of the selected estimates were calculated. Because the effects of noise sources might differ, the summary estimates for occupational noise exposure, road traffic noise exposure, and air traffic noise exposure will be presented separately. Afterwards, the estimated betas for hypertension, use of antihypertensive and/or cardiovascular medication, angina pectoris, myocardial infarction and ischemic heart diseases, were transformed into a $RR_{5\ dB(A)}$ and 95% confidence interval.

Subgroup-analysis

In order to investigate how these summary estimates might be affected by heterogeneity, subgroup analyses were carried out (see Table 3.4). For the association between occupational noise exposure and blood pressure, as well as hypertension, we also calculated a summary estimate for those selected estimates that adjusted for body mass index (BMI).

Sensitivity analysis and publication bias

The sensitivity of the results to any single estimate was also examined for occupational noise exposure and blood pressure as well as hypertension. This was done by removing the estimate one by one, from the analysis, and recalculating the summary estimate.

One of the most important problems of a meta-analysis is, that some studies do not get published. If the reasons that studies remain unpublished are associated with their outcome (publication bias), the validity of meta-analysis can be seriously threatened. In order to indicate the extent of publication bias in the present study, funnel plots were made. A funnel plot is a scatter plot of the studies' effect estimates against the inverse of the standard error. It is based on the fact that the precision in estimating the underlying effect will increase as the sample size of studies increases. In the absence of bias, the plot should resemble a symmetrical funnel [111].

TABLE 3.4 *Subgroup-analyses*

Factor under study	Subgroup of studies
Measurement of exposure	sound level meters (SLM) both a personal doses meter (PDM) and a sound level meter (SLM) job-titles exposure measurement was not reported
Blood pressure measurement	1 time > 1 time
Definition of hypertension used	systolic blood pressure ≥ 95 mmHg and/or diastolic blood pressure ≥ 160 mmHg and/or use of antihypertensives systolic blood pressure ≥ 95 mmHg and/or diastolic blood pressure ≥ 160 mmHg
Inclusion of treated hypertensives	including treated hypertensives excluding treated hypertensives
Gender of study population	Males females both sexes
Age of study population	18-35 years 35-65 years 18-65 years
Study-location	Asia North-America Europe (including Israel) South-Africa
Publication-period	Nineties Eighties Seventies*
Study-design†	longitudinal studies, presenting 10-years incidences cross-sectional studies, presenting prevalences

*This subgroup was included for hypertension; †This subgroup-analysis was only carried out for the association between myocardial infarction and ischemic heart disease (IHD).

3.2.2 Results

Descriptives

Tables 3.5 and 3.6 show some characteristics of the studies involved in the data-extraction. The occupational studies were all cross-sectional; from the cohort studies [66, 69, 86, 88], only baseline results were available. The occupational studies were carried out among a great variety of industries throughout the world, within a broad exposure range: the $L_{Aeq,\,8h}$ varied from 48 to 116 dB(A). Next to cross-sectional studies, the community studies encompassed two case-control studies [100, 101] and two cohort studies [102 - 107]. They were carried out among equivalent sound levels (6-22 h and 7-19 h) of 38-80 dB(A) in Europe. In community noise studies, noise exposure is usually calculated, while occupational studies mainly tried to measure the noise exposure. The sample sizes of the studies varied from 46 persons [65] to 35,150 [109].

TABLE 3.5 *Study characteristics of the occupational studies included for data-extraction*

Study	Country	Design	Pop [**]	N	Industry	Exp levels (dB(A))[§§]	Exp measmnt	Effect[††]	Adjustm [‡‡]
Parvizpoor, ‘76 [63]	Iran	Cross	M, 19-59	1233	Textile mill	≤ 96	Not reported	B	1, 2, 3
Malchaire, ‘79 [64]	Belgium	Cross	M, > 20	2111	[†††]	93-100; 93-97	Dosimetry	B	1, 2
Ising, ‘80 [65]	Germany	Cross	M, 25-51	46	Brewery	95 +/- 0,7; 82 +/- 1,2	SLM & PDM	A	2, 4
Lees, ‘80 [66]	Canada	Cohort	M&F	140	[‡‡‡]	≤ 85 , > 90	Company records	B, C	-
Kornhuber, ‘81[67]	Germany	Cross	M&F	97	Motor works	97-111	SLM	A	-
Singh, ‘82 [68]	India	Cross	M&F?, 30-35	111	Army	88-107	Job-hist. & SLM	A	2
Aro, ’84 [69]	Finland	Cohort	M&F, 21-61	388	Metal industry	64,8 +/- 15,8	SLM	A	2, 3, 22
Belli, ‘84 [70]	Italy	Cross	M ?, 35-56	940	Textile mill	78-105	SLM	B	2
Verbeek, ‘84 [89]	NL	Cross	M, ≤ 65	238	Various [a]	78-98	[***]	A, B	2, 5
Van Dijk, ‘84 [90]	NL	Cross	M, 18-63	257	Shipyard	82-91; 91-111	SLM & PDM	A, D	2, 4, 5
Van Dijk, ‘87 [91]	NL	Cross	M, 17-61	421	Various [b]	≤ 80; 81-85; 86-90; 91-95; >95	SLM & PDM	A, D	2, 4, 6, 7, 8
Korotkov, ‘85 [71]	Russia	Cross	M, 33-36	207	Seamen	93; 65	Acoustic data	A, B	2, 5
Talbott, ‘85 [72]	U.S.A.	Cross	M, 40-63	350	Various [§]	89; 81	SLM &PDM	A, B	2, 9-13
Wu, ’87 [84]	Taiwan	[##]	M, 30-59	2730	Shipyard comp.	> 85; < 80	SLM	A, B	1, 2, 4, 5
Idzior-W, ‘87 [74]	Poland	Cross	M, 20-55	784	Riveters, farmers	105-116	Not reported	A, B, C	1, 2, 12, 14, 15
Tarter, ‘90 [80]	U.S.A.	Cross	M, 35-65	269	Automobile plant	≥ 85	Dosimetry	B, D	2, 16
Hiraii, ‘91 [76]	Japan	Cross	M, 20-59	1756		85-115; < 85; Quiet office	Not reported	A, B	2, 3
Green, ‘91 [77]	Israel	Cross	M, 25-65	162		74-102	PDM	A	2, 4, 13, 17
Zhao, ‘91 [87]	China	Cross	F, 18-50	1101	Textile mill	75-104	SLM & noise survey	B	2, 3, 5
Tomei, ‘91 [73]	Italy	Cross	M, 25-55	300		80 – 92; 70	Not reported	A, B	2, 5, 18
Lang, ‘92 [77]	France	Cross	M, 18-60	1986	Various [#]	85-100;≤ 80	SLM & interview	A, B	2, 4
Hessel, 1994 [86]	S-Africa	Cohort	M, 27-40	973	Mine	80-111	Jobtitles	A	2, 4, 11, 12, 16
Fog1-2, ‘94/95 [78, 79]	Italy	Cross	M&F, 18-60	8811	Metal company	≤ 55;56-80; >80	SLM	A, B	2, 3, 4, 5, 19, 22
Krist, ’95 [87]	Israel	Cohort	M&F, 20-65	3106	Various [#]	≤65 - >90	SLM	A	2, 3, 11, 12, 20, 22
Wu, ‘96[82]	Taiwan	Cross	M&F, 81-71	222	[§§§]	67 and 96	PDM	A	2, 4, 22 – 25
Saha, ‘96 [81]	India	Cross	M, 20-55	156	Therm pow. stat.	48-66; 90 – 113	SLM	A, B	2, 4
Zhao, ‘98 [83]	China	Cross	M&F, 18-58	1593	Chem fertil. Fact.	53,0 – 96,7	SLM	B	2, 3, 22
Talbott, ‘99 [85]	U.S.A.	Cross	M, 40-63	643	[###]	57,0 –100,1	SLM	A, B, D	4, 11, 12, 21

[*] Production divisions of a Livestock Company, chocolate factory, engineering shop, printing office, mechanical woodworking, metalworking company. [†] Metal company, Livestock Company, synthetic-processing company, metal processing company, chemical industry. [‡] Fabricage and production of metal parts and heating elements. [§] Mechanical or chemical industry, offices, garages and restaurants. [#] Metal work, textile sector, light industry, electronics, foodstuffs and plywood. [**] M: male, F: female; age in years. [††] A: Blood pressure; B: Hypertension; C: Cardiovascular disease; D: Use of medication for heart diseases. [‡‡] 1: socio-economic status; 2: age; 3: jobtype; 4: body mass index/quetelet index; 5: duration of exposure/number of working years; 6: shift work; 7: stress symptoms; 8: annoyance-index; 9: education level; 10: marital status; 11: alcohol consumption; 12: smoking (behaviour); 13: hearing loss; 14: residence; 15: physical activity at work; 16: ethnicity; 17: heart-rate; 18: suffering from hypertension; 19: cholesterol level; 20: coffee consumption; 21: medical history of hypertension; 22: sex; 23: blood lead level; 24: ambient lead concentration; 25: working history; [§§] $L_{Aeq,8h}$ this is the measurement-range of the study. [##] Cross & Case-referent study design. [***] SLM & noise exp. anamneses. [†††] Car assembly and wire mill. [‡‡‡] Production and handling areas. [§§§] Lead battery manufacturing factory. [###] Stamping and assembly plant

TABLE 3.6 *Study characteristics of the community studies included for data-extraction.*

Study	Country	Design	Population ††	N	Exposure			Effects Investigated *	Adjustments †
					Source	Level (dB(A))#	Measurement §		
Knip, ‘76 [92, 93]	NL	Cross	F, 40-49	1741	Road	55-60, 65-70	?	B, C, E, G	1, 2, 3, 4, 5, 6, 7, 8, 9
Eiff, ‘80 [94]	Germany	Cross	M&F, 20-59	931	Road	>50, 66-73	Calc	B, C	1, 10, 11, 12, 13, 14, 15
Neus, ‘83 [95]	Germany	Cross	M&F,	117	Road	< 57, > 66	?	A,	1, 11, 16
Schulze, ‘83[96]	Germany	Cross	M&F, 20-75	700	Road	64-67, 72-75	SLM ?	B, H	17, 18, 19, 20
Wölke, ‘83[97]	Germany	Before-after study	M&F, >18	350	Road	76, 60	?	B ‡	1, 11, 16
Knip, ‘84[98]	NL	Cross	M&F, 41-43	2878	Road	<55 – 80	SLM	A, B	11
Brederode, ‘89-a[99]	NL	Cross	M&F, 18-55	396	Road	40-75	Calc	A, H	1, 2, 10, 11, 21, 22
Berlin-a, ‘94[100, 101]	Germany	Case-control	M, 41-70	243	Road	60-80	Calc	F	1, 2, 17, 23, 24, 25
Berlin-b, ‘94[100, 101]	Germany	Case-control	M, 31-70	4035	Road	60-80	Calc	F	1, 2, 23, 24, 25
Berlin-c, ‘94[101]	Germany	Cross	M, 31-70	2169	Road	60-80	Calc	F	1
Cear, ‘93-‘99[102-104, 106, 107]	U.K	Cohort	M, 45-59	2512	Road	51-70	SLM & PDM	A, B, E, F, H	1, 2, 3, 4, 10, 16, 26
Speed, ‘93-‘99[102, 103, 105-107]	U.K.	Cohort	M, 45-63	2348	Road	51-70	SLM	A, E, F, H	1, 2, 3, 4, 10, 16, 26
Knip ‘76-a [108]	NL	Cross	M&F, 35-64	5828	Air	66-77, 55-66	Calc	B, D, E, G	1, 2, 3, 11
Knip, ‘76-b [109]	NL	Cross	M&F, < 99	35150	Air	55-72	Calc	B, C, D, G	1, 11
Brederode, ‘89-b [99]	NL	Cross	M&F, 18-55	432	Air **	< 63 - > 75	Calc	A, H	1, 2, 10, 11, 21, 22
RIVM/TNO, ‘98[110]	NL	Cross	M&F, > 18	11812	Air	38-75	Calc	D	1, 11

* A: Blood pressure change; B: Hypertension, C: use of antihypertensives, D: use of cardiovascular medication (incl. antihypertensives), E: angina pectoris, F: myocardial infarction, G: consultation GP/specialist, H: coronary heart diseases. † 1: age, 2: anthropometric data (BMI etc), 3: smoking, 4: physical activity at work; 5: shortness of breath at exert; 6: chronic cough; 7: lung pathology; 8: cholesterol; 9: diabetes; 10: alcohol consumption; 11: gender; 12: professional state; 13: income; 14: coffee consumption; 15: tea consumption; 16: social (economic) state; 17: education level; 18: professional activity; 19: working conditions; 20: living conditions; 21: hypertension in parents and siblings; 22: primary appraisal; 23: duration of living; 24: working; 25: noise in workplace; 26: family history; ‡ Incidence; § Calc: exposure assessment by means of calculations; SLM: Sound Level Meter; PDM: Personal Dosimeter. # For road traffic noise expressed as $L_{Aeq,\ 6\text{-}22\ h}$ and for air traffic noise expressed as $L_{Aeq,\ 7\text{-}19\ h}$; this is the measurement-range of the study. ** Military air traffic noise. †† M: Male; F: Female; age in years.

Exposure-response estimates

The influence of noise exposure on blood pressure was studied both for occupational, road and air traffic noise exposure (see Figures 3.4 and 3.5). A statistically significant increase in blood pressure level was only evident in studies for occupational noise exposure: for systolic blood pressure an increase of 0.51 (95%CI: 0.01 – 1.00) mmHg per 5 dB(A) was estimated (see Figure 3.4).

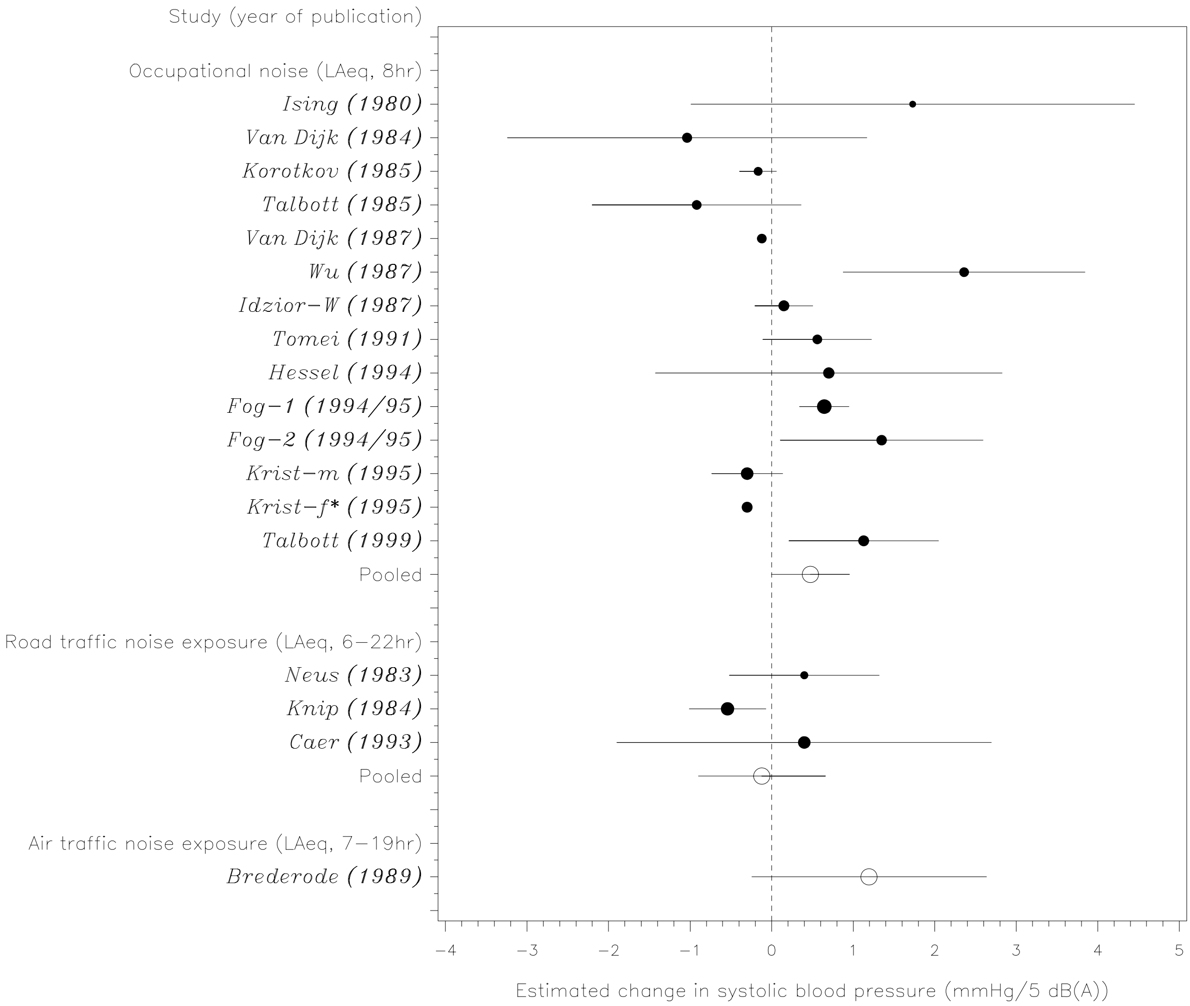

FIGURE 3.4 *The association between noise exposure and systolic blood pressure change, adjusted for sex, age and work type. The dotted vertical line corresponds to no effect of occupational, road traffic or air traffic noise exposure on systolic blood pressure. The black circles correspond to the estimated change in systolic blood pressure (mmHg) per 5 dB(A) increase of the occupational, road traffic or aircraft noise level and the horizontal lines correspond to the 95% confidence interval. The summary estimates are represented by the white circles. Measurement ranges of the studies included: occup. noise exp. $L_{Aeq,8h}$ 50-116 dB(A), road tr. noise exp. $L_{Aeq,6-22h}$ 51-80 dB(A), air tr. noise exp. $L_{Aeq,7-19h}$ 63- > 75 dB(A).* [*] *Estimate with a large variance of 3600.*

In the case of air traffic noise exposure and blood pressure increase, it refers only to military air traffic noise, and not to civilian air traffic noise [99]. Figures 3.4 and 3.5 show that the effect of occupational noise exposure on blood pressure differs between the studies. The association between occupational noise exposure and hypertension is statistically significant increased: a $RR_{5\ dB(A)}$ of 1.14 (95% CI: 1.01 – 1.29) was found (Figure 3.6 and Table 3.7).

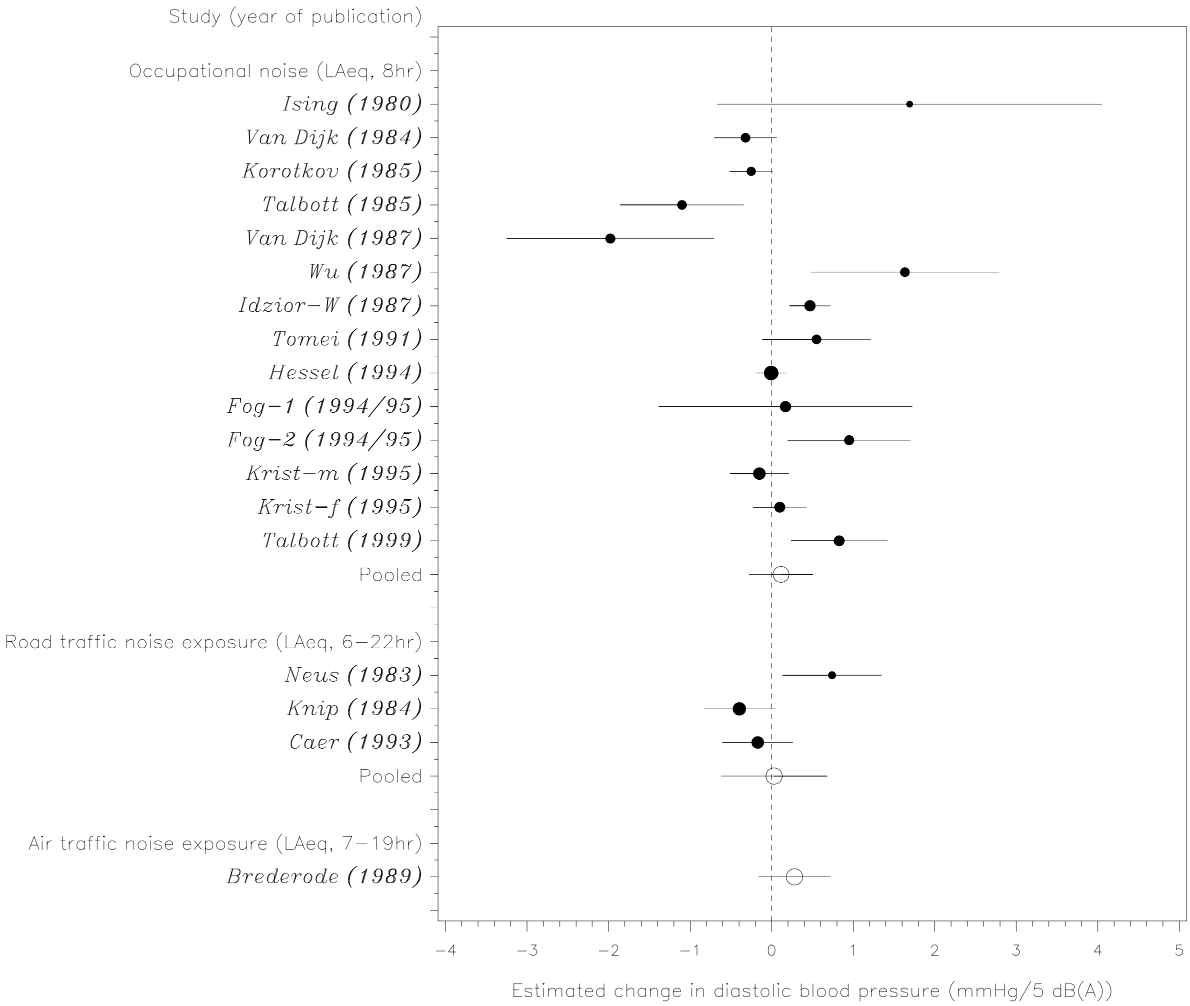

FIGURE 3.5 *The association between noise exposure and diastolic blood pressure change, adjusted for sex, age and work type. The dotted vertical line corresponds to no effect of occupational, road traffic or air traffic noise exposure on diastolic blood pressure. The black circles correspond to the estimated change in diastolic blood pressure (mmHg) per 5 dB(A) increase of the occupational, road traffic or aircraft noise level and the horizontal lines correspond to the 95% confidence interval. The summary estimates are represented by the white circles. Measurement ranges of the studies included: occup. noise exp.* $L_{Aeq,8h}$ *50-116 dB(A), road tr. noise exp.* $L_{Aeq,6\text{-}22hrs}$ *51-80 dB(A) and air tr. noise exp.* $L_{Aeq,7\text{-}19hrs}$ *63- > 75 dB(A).*

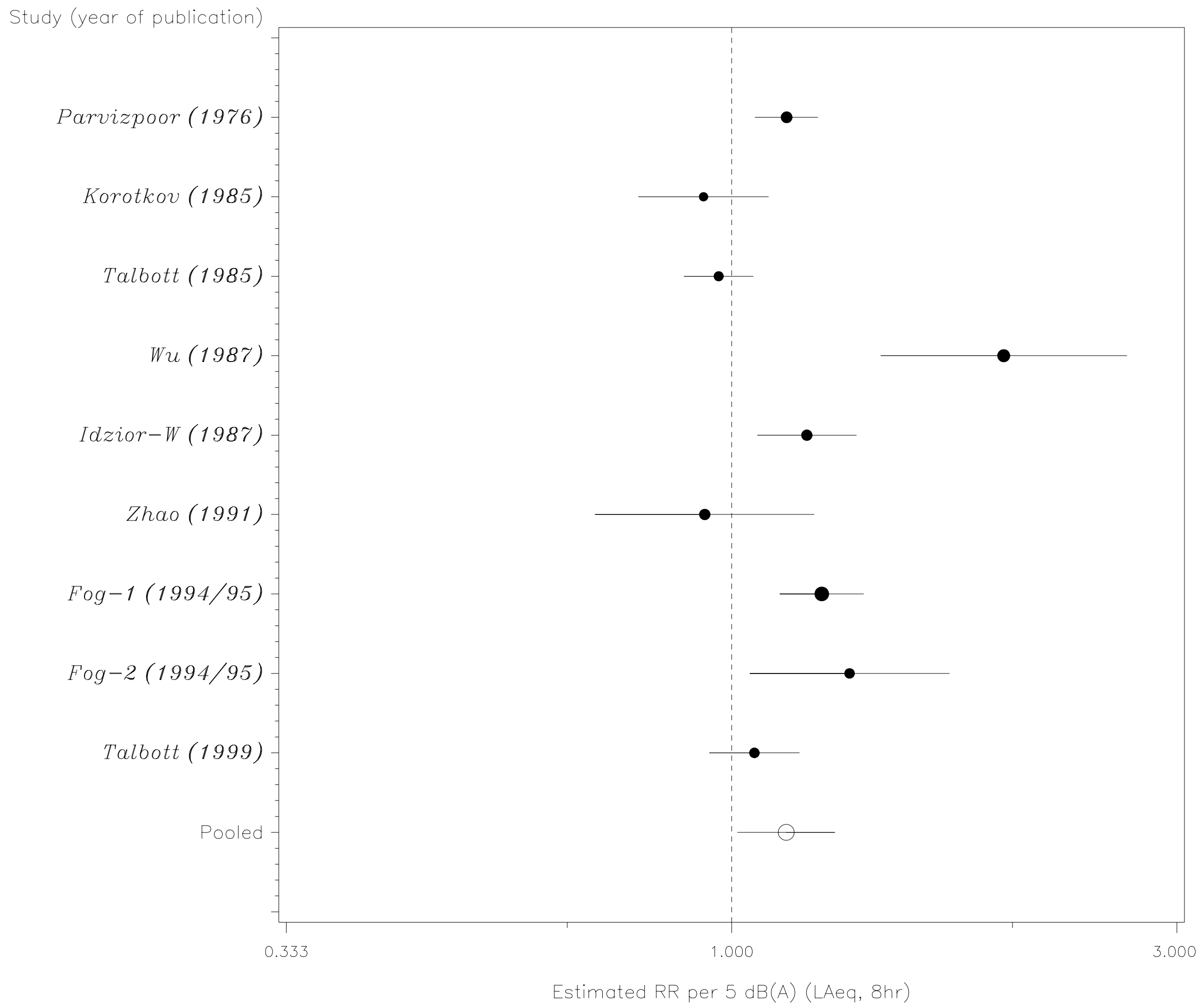

FIGURE 3.6 *The association between occupational noise exposure and hypertension, adjusted for age, sex and work type. The dotted vertical line corresponds to no effect of occupational noise exposure. The black circles correspond to the estimated $RR_{5\ dB(A)}$ and 95% confidence interval. The white circle represents the summary estimate and 95% confidence interval. Measurement range of the studies included: $L_{Aeq,\ 8h}$, 55-116 dB(A).*

In comparison with the occupational studies, the community studies contained relatively few estimates per effect (see Figures 3.7 and 3.8). Road traffic noise exposure is positively associated (non-significant) with myocardial infarction and ischemic heart diseases (Figure 3.7). Effects positively associated with air traffic noise exposure were hypertension, angina pectoris, and the use of cardiovascular medicines and consultation of a specialist and/or general practitioner (GP) (Figure 3.8). Only the association with air traffic noise exposure and hypertension was statistically significant: $RR_{5\ dB(A)}$ 1.26 (95%CI: 1.14 – 1.39) (Figure 3.8 and Table 3.7). However, these results were based on only one study [108].

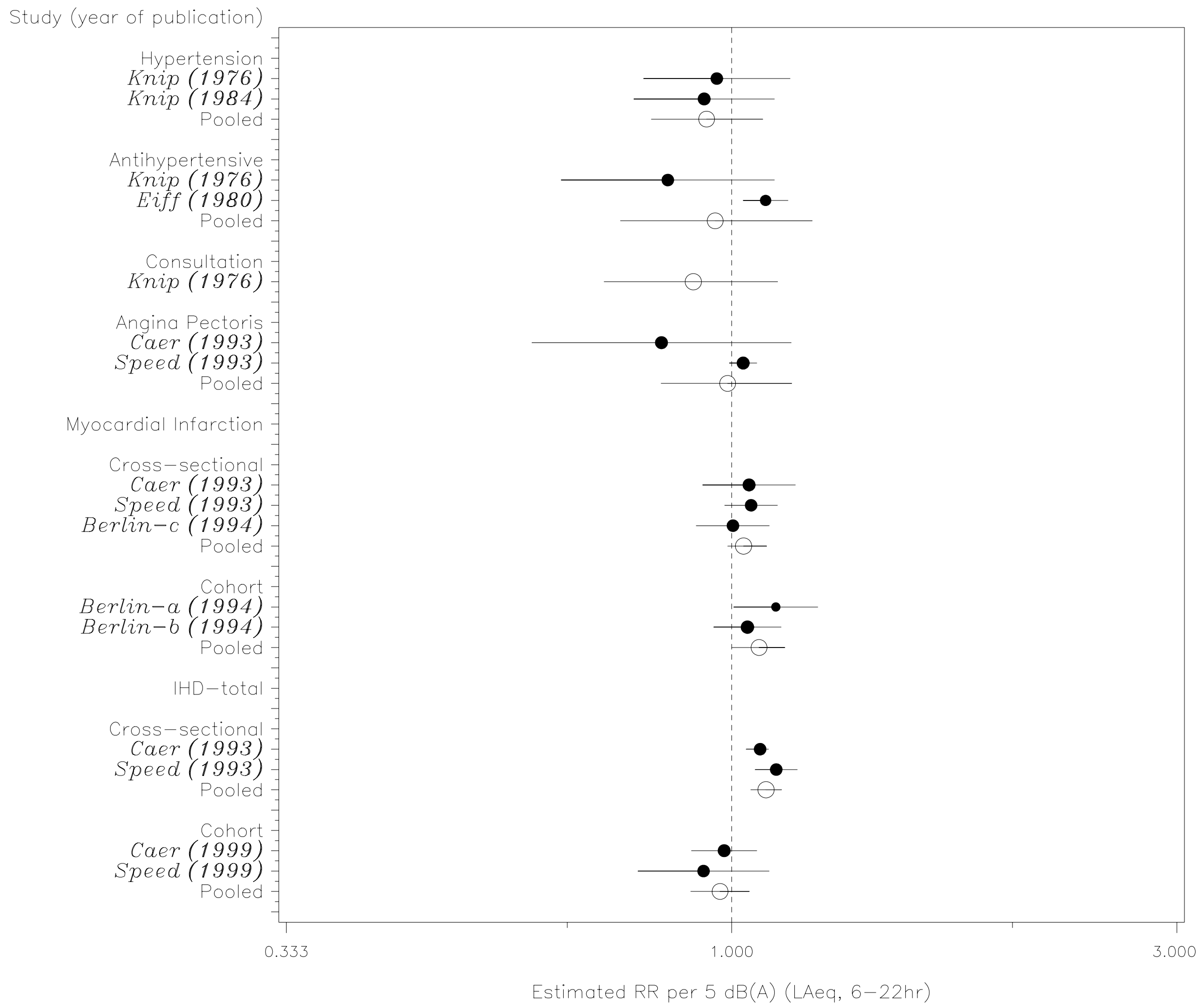

FIGURE 3.7 *The association between road traffic noise exposure ($L_{Aeq,\ 6\text{-}22hrs}$, in dB(A)) and hypertension or ischemic heart disease, adjusted for age and sex. The dotted vertical line corresponds to no effect of road traffic noise exposure. The black circles correspond to the estimated $RR_{5\ dB(A)}$ and 95% confidence interval. The white circles represent summary estimates and 95% confidence interval. Measurement ranges of the studies included: hypertension <55 – 80 dB(A), use of antihypertensives >50 – 73 dB(A), consultation of a GP/Specialist 55-70 dB(A), angina pectoris 51-70 dB(A), myocardial infarction 51-80 dB(A), and ischemic heart disease (IHD) 51-70 dB(A).*

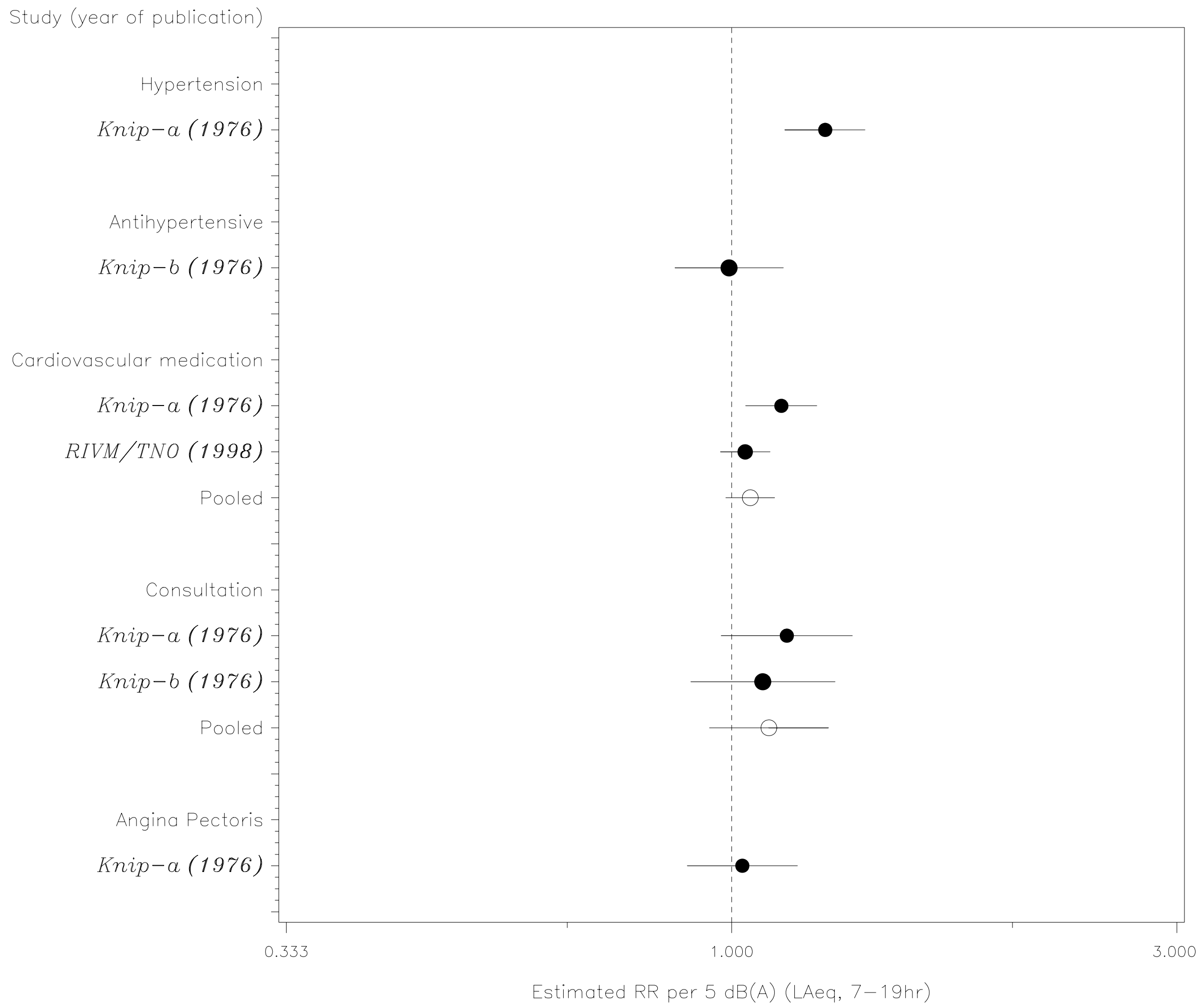

FIGURE 3.8 *The association between air traffic noise exposure ($L_{Aeq,\ 7\text{-}19}$, in dB(A)) and hypertension or ischemic heart disease, adjusted for age and sex. The dotted vertical line corresponds to no effect of air traffic noise exposure. The black circles correspond to the estimated $RR_{5\ dB(A)}$ and 95% confidence interval. The white circles represent summary estimates and 95% confidence interval. Measurement ranges for the studies included: hypertension 55 – 72 dB(A), use of antihypertensives 55 – 72 dB(A), the use of cardiovascular medicines 38-77 dB(A), consultation of a GP/Specialist 55-77 dB(A) and angina pectoris 55-72 dB(A).*

Subgroup-analyses

The results of the subgroup-analyses for the occupational studies are presented in Figures 3.9 and 3.10. These figures show that for the influence of occupational noise exposure on blood pressure change, a statistically significant increase in systolic blood pressure, could be distinguished for five subgroups: (i) studies adjusting for body mass index (BMI): 0.82 (95%CI: 0.00 – 1.65) mmHg/5 dB(A); (ii) studies investigating both males and females: 0.65 (95%CI: 0.34 – 0.95) mmHg/5 dB(A); (iii) studies including treated hypertensives: 0.67 (95%CI: 0.12 – 1.22) mmHg/5 dB(A);

(iv) studies carried out during the Nineties: 0.56 (95%CI: 0.04 – 1.08) mmHg/5 dB(A); and (v) studies using sound level meters (SLM) for exposure assessment: 0.87 (95%CI: 0.05 – 1.69) mmHg/5 dB(A). For diastolic blood pressure change, no subgroups that indicated a statistically significant change in blood pressure could be distinguished.

TABLE 3.7 *Summary estimates, expressed as $RR_{5\,dB(A)}$, for the association between noise exposure, hypertension, and ischemic heart diseases, adjusted for sex and age.*

Noise exposure [#]	**Outcome**	**$RR_{5\,dB(A)}$**	**95% CI** [§]	**N**[##]	**Measurement range (dB(A))**
Occupation	Hypertension [†]	1.14	1.01 – 1.29 *	9	55 – 116
Road traffic	Hypertension	0.95	0.84 – 1.08	2	<55 – 80
	Use of antihypertensives	0.96	0.76 – 1.22	2	> 50 – 73
	Consultation of GP/specialist	0.91	0.73 – 1.12	1	55 – 70
	Angina Pectoris	0.99	0.84 – 1.16	2	51 – 70
	Myocardial Infarction [c]	1.03	0.99 – 1.09	3	51 – 80
	IHD-total [‡]	1.09	1.05 – 1.13 *	2	51 – 70
Air traffic	Hypertension	1.26	1.14 – 1.39 *	1	55 – 72
	Use of antihypertensives	0.99	0.87 – 1.14	1	55 – 72
	Consultation of GP/specialist	1.10	0.95 – 1.27	2	55 – 77
	Use of cardiovascular medicines	1.05	0.99 – 1.11	2	38 – 77
	Angina Pectoris	1.03	0.90 – 1.18	1	55 – 72

[#] The noise exposure measures differed between the noise exposure sources: occupational noise exposure expressed in $L_{Aeq,\,8h}$, in dB(A), road traffic noise exposure expressed in $L_{Aeq,\,6\text{-}22h}$, in dB(A) and air traffic noise exposure expressed in $L_{Aeq,\,7\text{-}19h}$, in dB(A). [†] Adjusted for age, sex and work type. [‡] Only prevalence estimates. [§] CI: Confidence Interval. [##] N: Number of estimates * Significant, $p<0.05$

Looking at Figure 3.10, a statistically significant association between occupational noise exposure and hypertension could be identified for 6 sub groups: (a) studies adjusting for body mass index (BMI): $RR_{5\,dB(A)}$ 1.60 (95%CI: 1.10 – 2.32); (b) studies investigating populations aged 18-65 years: $RR_{5\,dB(A)}$ 1.18 (95%CI: 1.12 – 1.25). This differs from the $RR_{5\,dB(A)}$ estimated for studies investigating populations aged 18-35 years ($RR_{5\,dB(A)}$ 0.93 (95%CI: 0.79 – 1.10); (c) studies investigating both males and females: $RR_{5\,dB(A)}$ 1.25 (95%CI :1.13 – 1.39); (d) studies carried out in Europe: $RR_{5\,dB(A)}$ 1.60 (95%CI: 1.58 – 1.62); (e) studies using sound level meters (SLM) for exposure assessment: $RR_{5\,dB(A)}$ 1.32 (95%CI: 1.05 – 1.67); (f) studies carried out during the Nineties ($RR_{5\,dB(A)}$ 1.14 (95%CI: 1.00 – 1.31)), and Seventies ($RR_{5\,dB(A)}$ 1.15 (95%CI: 1.06 – 1.24)).

For the association between road traffic noise exposure and ischemic heart diseases (IHD) (Figure 3.7), data-aggregation resulted in statistically significant summary estimates for the cross-sectional studies [70] ($RR_{5\,dB(A)}$ 1.09 (95%CI: 1.05 – 1.13)). After combining the results of the reported 10-years incidence, the effect of road traffic exposure on IHD was eliminated [107] ($RR_{5\,dB(A)}$ 0.97 (95%CI: 0.90 – 1.04)). With respect to the association between road traffic noise and myocardial infraction, no significant differences between prevalence and incidence could be noticed.

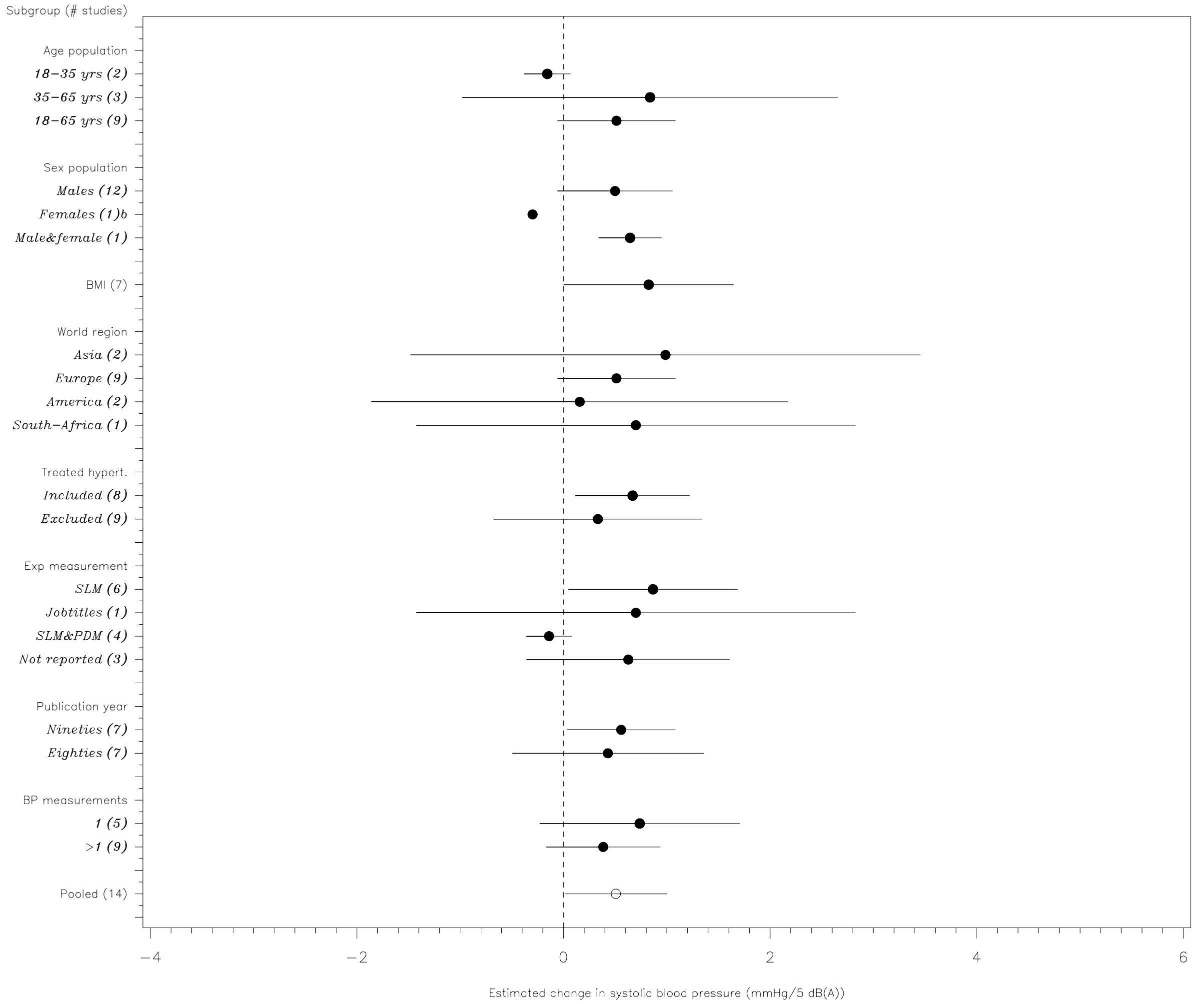

FIGURE 3.9a *Subgroup-analysis for the association between occupational noise exposure ($L_{Aeq,\,8h}$, in dB(A)) and systolic blood pressure, adjusted for age, sex and work type. The dotted vertical line corresponds to no effect of occupational noise exposure on systolic blood pressure. The black circles correspond to the estimated change in systolic blood pressure (mmHg) per 5 dB(A) increase of the occupational noise level and the horizontal lines correspond to the 95% confidence interval. The white circles represent summary estimates and 95% confidence interval. [b] This estimate has a standard error of 60.*

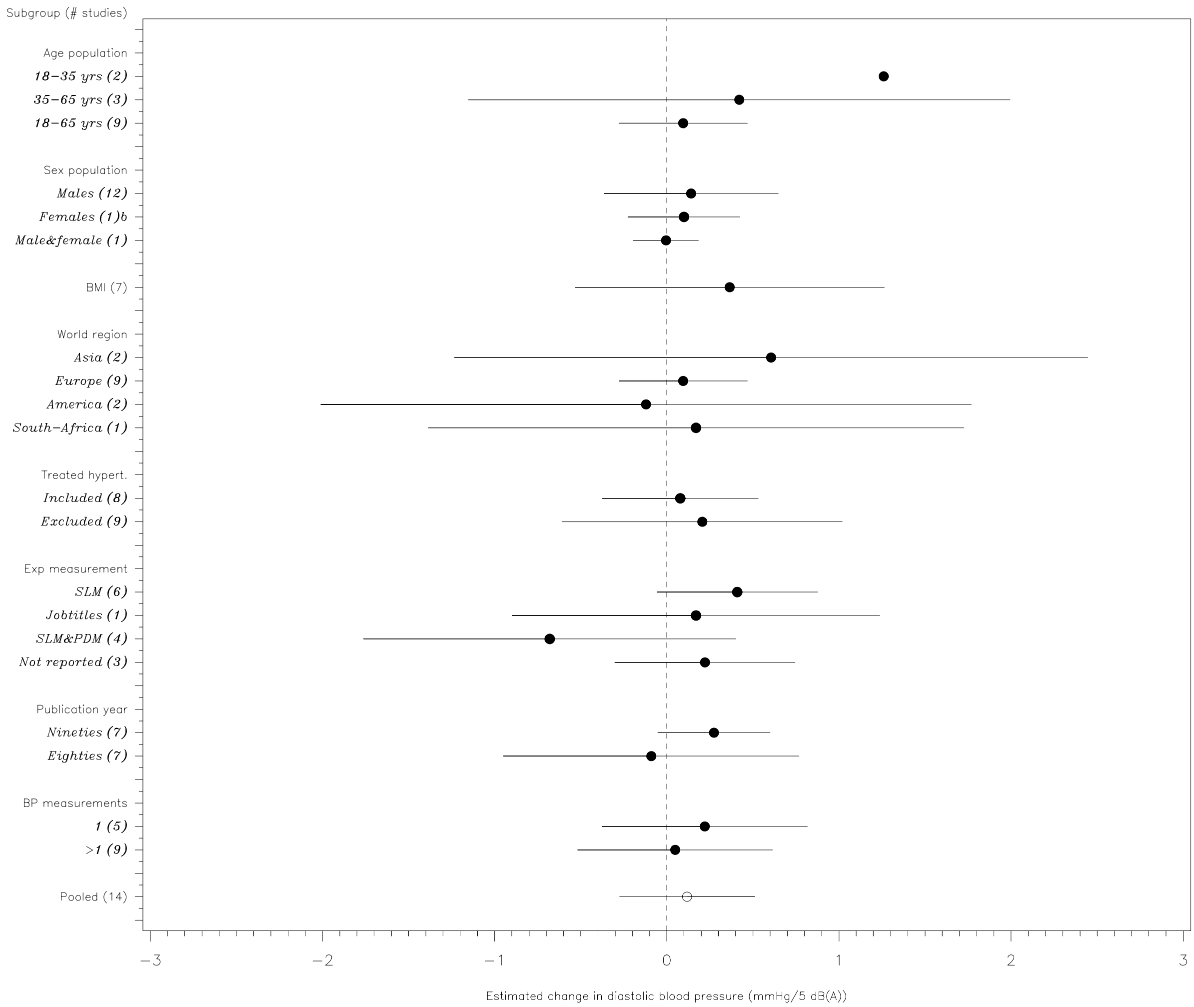

FIGURE 3.9b *Subgroup-analysis for the association between occupational noise exposure ($L_{Aeq,\ 8h}$, in dB(A)) and diastolic blood pressure, adjusted for age, sex and work type. The dotted vertical line corresponds to no effect of occupational noise exposure on diastolic blood pressure. The black circles correspond to the estimated change in diastolic blood pressure (mmHg) per 5 dB(A) increase of the occupational noise level and the horizontal lines correspond to the 95% confidence interval. The white circles represent summary estimates and 95% confidence interval.*

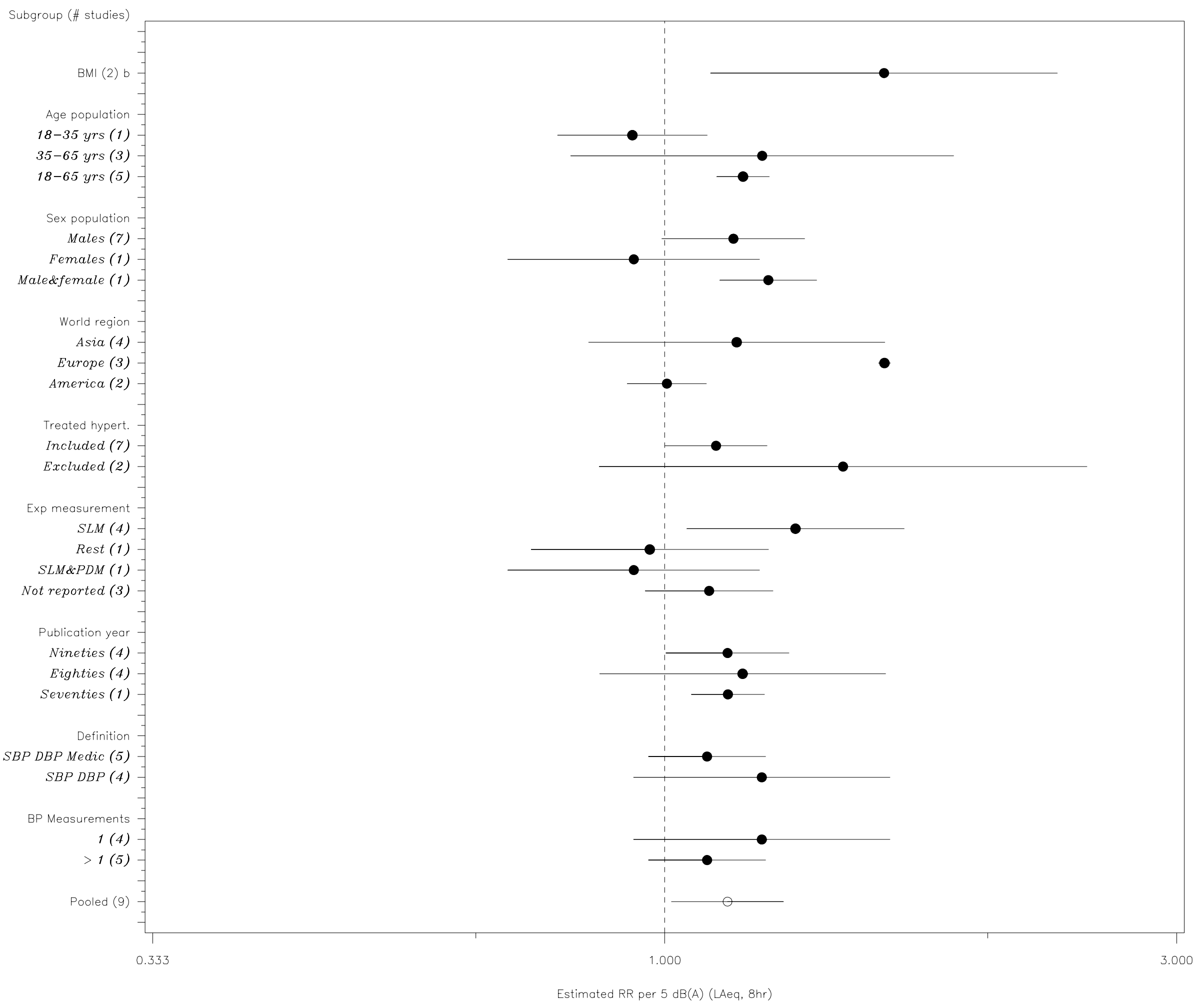

FIGURE 3.10 *Subgroup-analysis for the association between occupational noise exposure ($L_{Aeq,\ 8h}$, in dB(A)) and hypertension, adjusted for age, sex and work type. The dotted vertical line corresponds to no effect of road traffic noise exposure. The black circles correspond to the estimated $RR_{5\ dB(A)}$ and 95% confidence interval. The white circles represent summary estimates and 95% confidence interval. [b] BMI: adjusted for sex, age, blue collar workers and body mass index; SLM: Sound Level Meter; PDM; Personal dosimeter; SBP DBP Medic: Studies defining hypertension as systolic blood pressure ≥ 95 mmHg and/or diastolic blood pressure ≥ 160 mmHg and/or use of antihypertensives. SBP DBP: Studies defining hypertension as systolic blood pressure ≥ 95 mmHg and/or diastolic blood pressure ≥ 160 mmHg.*

Sensitivity analysis and publication bias

Sensitivity analysis through one by one exclusion of studies revealed that the results of the meta-analysis for occupational noise exposure and blood pressure as well as for occupational noise exposure and hypertension were not significantly affected by separate studies.

Because only few estimates were available for most of the studied effects, it was only possible to make funnel plots for blood pressure changes and hypertension associated with occupational noise exposure. Figure 3.11 presents the results for hypertension. The figure shows that studies finding a relatively small effect have been published less often.

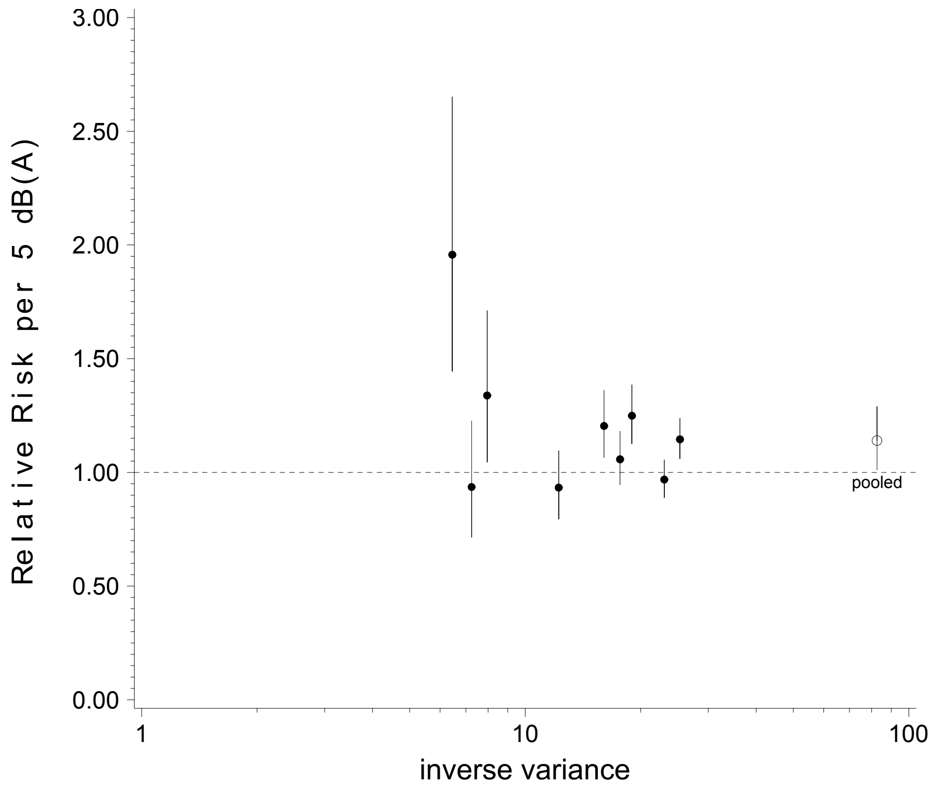

FIGURE 3.11 *Funnel plot of the results of occupational studies investigating the relation between occupational noise exposure ((*$L_{Aeq, 8h}$*, in dB(A)) and the risk of hypertension, adjusted for age, sex and work type*

3.2.3 Discussion

Main results

For this meta-analysis, 43 occupational and community studies with a wide range of effects, varying from blood pressure changes to a myocardial infarction, were studied. With respect to the association between noise exposure and blood pressure, small blood pressure differences were noticed. A significant increase in systolic blood pressure was evident for occupational noise exposure. The results of the occupational studies tally with the results of an earlier review, evaluating 21 occupational studies, that presented increases of the mean systolic and diastolic blood pressure of 3.9 and 1.7 mmHg for persons in exposed groups as compared to persons in reference groups, respectively [40]. Our results concerning community noise studies, correspond to the results of a research review by Babisch (1998), in which it was concluded that no consistent findings can be seen and that there was little epidemiological evidence of an increase in blood pressure in subjects exposed to traffic noise [45]. Furthermore, it can be concluded that the results of the occupational studies, investigating blood pressure, are contradictory (see also Figures 3.4 and 3.5). From the results with respect to the subgroup analyses for blood pressure, no sources of heterogeneity could be identified, however. The finding that road traffic noise exposure is not associated with the risk on hypertension agrees with Babisch (1998), who concluded that there was little epidemiological evidence of an increased risk of hypertension in subjects exposed to traffic noise [45]. In the present study a statistically significant association for occupational noise exposure with hypertension was recorded: a $RR_{5\ dB(A),\ occup}$= 1.14 (95%CI: 1.01 – 1.29). Passchier-Vermeer (1993) also found a significant risk increase of hypertension; a RR of 1.7 for noise levels exceeding 85 dB(A) was recorded [40]. Duncan et al. (1993) found an increase in the odds of developing hypertension as a function of increasing noise levels above 20 Kosten units (equivalent to $L_{Aeq,7\text{-}19hrs}$ 55 dB(A)) [60]. However, there is a difficulty in the comparison of these results, because the results of the different exposure situations were combined.

The use of anti-hypertensives (an indirect indicator for hypertension) was not associated with community noise exposure. Air traffic noise exposure was positively associated with the consultation of a GP or specialist, the use of cardiovascular medicines and angina pectoris. In cross-sectional studies, road traffic noise exposure increases the risk of myocardial infarction and ischemic heart diseases (IHD-total). However, for ischemic heart disease (IHD-total), this was in contradiction with the results of the follow-up studies, in which this effect was not evident.

The hypothesis that the association between noise exposure and ischemic heart disease might differ between the different noise sources is not confirmed with our results: Comparing the random effect estimates per effect between air traffic noise and road traffic noise (Table 3.7), shows that air traffic noise exposure is more strongly associated with blood pressure and/or ischemic heart disease than road traffic noise exposure. However, these differences are not statistically significant. A possible explanation of the observed differences might be found in the study of Miedema & Oudshoorn (2001). Recently, they published the results of a pooled analysis on noise exposure and annoyance. These results indicated that air traffic noise is more annoying than road traffic noise [112].

Studies included

From the above, it can be concluded that epidemiological evidence on noise exposure, blood pressure, and ischemic heart diseases is still limited: with respect to blood pressure and hypertension, results were contradictory, and for ischemic heart diseases, only a few studies are available. One can raise some criticism of the individual studies: first, the studies are mainly cross-sectional. This aggravates both the determination of the direction of the causation and the accurate estimation of noise-exposure [4]. To have persistent effects such as coronary heart disease, noise may have to be of certain intensity and to be present for a certain length of time. Another problem when investigating chronic diseases in cross-sectional studies, is the problem of self-selection in community studies and the healthy worker effect in occupational studies. In community studies, somewhat sensitive subjects may tend to move out of the polluted areas, diluting the effect of interest [45]. In occupational study subjects may have left the job because of cardiovascular diseases due to noise or because of the noise itself at the time when the study is started. These effects tend to diminish the magnitudes of the effect estimates [50].

Furthermore, noise exposure was often poorly characterised: in the occupational studies noise exposure was mainly assessed by means of fixed measurements with sound level meters. Also data on the use of ear protection were largely missing. In community studies, exposure was often calculated. From the literature it was not possible to derive whether these models were validated. While noise exposure was assessed at people's home, the fact that people are working during the day was not taken into account. However, the characterisation of personal exposure is a general problem in environmental epidemiological studies, especially concerning long-term effects. In general, the reporting of noise-related factors, such as fluctuation of noise levels, duration of exposure, frequency (Hz) [115], and peak or continuous noise, was incomplete. Other reviewers also concluded this [40, 45, 60]. Adjustments for the position of the living and/or sleeping room(s) were often not made. Also the blood pressure was not always measured in a standard way and often only a single blood pressure measurement was done. The definition of hypertension was often based on this single measurement. In addition, studies did not always adjust for important modifying factors, such as BMI, smoking, and alcohol consumption. The aspects mentioned in the above section might have lead to misclassification on both exposure and effect, which will bias the effect in the direction of no effect.

Bias meta-analysis

As compared to earlier reviews on noise exposure and cardiovascular effects, our study was carried out in a more systematic way: inclusion and exclusion criteria were defined, and to be able to compare study results, one consistent measure of association was used. Furthermore, this study provided estimates based on more recent studies, stratified analyses by various study characteristics (sub-group analyses), and analyses for publication bias.

However, some aspects have to be kept in mind by interpreting our results: A number of studies contained exposure groups that had no clear-cut noise range (e.g.

people exposed to < 80 dB(A)). In order to calculate an effect estimate, a L_{Aeq} value was defined by a noise expert as a ‘best guess’. These choices might have influenced the strength of the calculated associations.

For the meta-analysis, we presented the results of an exponential model, which meant that a constant RR per noise unit is assumed which implicates an exponential relation between noise exposure and the effect concerned. It was not possible to indicate a threshold value (see Appendix 3.2). This is not consistent with studies that state that there is a threshold value of 70 dB(A) [114].

A serious threat for the validity of a meta-analysis is publication bias. With respect to occupational noise exposure and hypertension, the funnel plot shows (Figure 3.11) that studies with negative results are sometimes missing because they were not available. For this association, we concluded that there is an indication for publication bias. Another possible explanation is that there are some poor studies (e.g. with misclassification of exposure), reporting a false positive association. For the other effects under study, it was not possible to make funnel plots, because of the few studies that were available.

The results of the occupational studies were not consistent. From the subgroup analyses, it appeared that for the association of occupational noise exposure, with blood pressure, and hypertension, no sources of heterogeneity could be identified, despite the fact that the occupational studies were carried out among a great variety of industries. Our results show that with respect to the association between traffic noise exposure and ischemic heart diseases (IHD-total), study-design might be a possible source of heterogeneity.

Biological mechanisms

From literature it is suggested that noise-induced cardiovascular effects have to be seen as the consequence of stress. Stress can arise in several ways in relation to noise. We can distinguish a physiological and a psychological pathway. In experimental studies that studied the effects of short-term noise exposure, acute biochemical, physiological, cardiovascular changes have been found. These mark a common, physiological stress-reaction of short duration that occurs as a consequence of the activation of the autonomous nervous and hormone system. It appeared that the acute effects referred to, were the same as the effects caused by an ordinary stress reaction.

Some authors assume that the effect of noise on the auditory system is transmitted to the Reticular Arousal System and the hypothalamus, where both neuronal and hormonal (hypothalamus pituitary-adrenal axis) may be activated [4, 40]. Like mentioned in the introduction, stress can also be the consequence of the appraisal of noise [39].

Once there is a stress-situation, this can lead to the following effects, which are primary risk factors for cardiovascular disease: (i) Directly: as a result of stress the body secretes adrenal medullary hormones (catecholamines) such as noradrenaline. The effects of these hormones will be the raise of peripheral resistance and the increase of blood pressure and heart rate [4]; (ii) Indirectly: stress may affect human behaviour. In that way it can contribute to cardiovascular disease. For example by increased smoking, alcohol consumption, and use of medicines [40]. According to Morrell et al. (1997), heart diseases caused by noise exposure may occur more often in susceptible subgroups within populations through physiologically mediated aggravation of existing physical or mental conditions, or precipitation of complications. For example, triggering of dysrhythmias in persons with heart disease. We can conclude that the biologic mechanism of the relation between noise exposure and cardiovascular effects seems plausible, but is very complex [41].

3.2.4 Conclusions

The results of this meta-analysis are consistent with a slight increase of cardiovascular disease risk in populations exposed to air traffic and/or road traffic noise. We feel it is especially important that a range of observed endpoints is consistent with known cardiovascular disease progression. Small, transient, stress-related hemodynamic responses that are harmless on the individual level may result in slight, but relevant shifts in blood pressure on the level of populations. In a smaller, susceptible proportion of the population this shift may lead to an increase of diagnosed hypertension, medication use, visits to the general practitioner, and eventually the prevalence of ischemic heart disease, including angina pectoris and myocardial infarction (Figure 1.3 in Section 1.3.1). In this perspective, additional cases of myocardial infarction attributable to noise exposure can be regarded as the tip of the Iceberg.

The evidence for a relation between noise and cardiovascular disease is still inconclusive. Not only because of the complexity with regard to noise and health outlined here, but also because of limitations in exposure characterisation, blood pressure measurement and/or definition of hypertension, adjustment for important confounders, and the occurrence of publication bias. Considering the above, we recommend to carry out more large follow-up studies. Exposure characterisation could be improved by repeated personal dose measurements in a representative sample of the study population and reporting more noise related factors such as exposure duration and intensity. Furthermore, we should not only study health end-points such as angina pectoris and myocardial infarction.

3.2.5 References and notes

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Appendix 3.1 Search profile

This is the search-profile that is used to identify studies on noise and blood pressure and/or ischemic heart disease.

```
BASE COMMAND ACCEPTED FOR ME66;MEDLINE;LAST-UPDATE=3.11.1998
*** MEDLINE reloaded using MeSH 98 *** Copyright NLM. For details of copyright,
liabilities and warranties see COPYRULES file: BASE ZC00
?
t hc
   1.00  852601 FIND CT D CARDIOVASCULAR DISEASES
   2.00    9236 FIND CT D NOISE
   3.00     330 FIND 1 AND 2
   4.00     298 FIND 3 AND PY>=1970
   5.00     200 FIND 4 AND LA=(EN;GE;DU)
   6.00  147130 FIND CT D BLOOD PRESSURE
   7.00     222 FIND 2 AND 6
   8.00     152 FIND 7 NOT 3
   9.00     138 FIND 8 AND PY>=1970
  10.00     106 FIND 9 AND LA=(EN;GE;DU)
  11.00     306 FIND 5 OR 10
  12.01       0 DUPLICATE CANDIDATES IN S= 11.00  (OUTPUT ONLY)
  12.02       0 DUPLICATES REMOVED FROM S= 11.00  (OUTPUT ONLY)
  13.00     306 UNIQUE              IN S= 11.00


BASE COMMAND ACCEPTED FOR EM74;Embase;LAST-UPDATE=30.10.1998
Copyright Elsevier Science B.V. 1998. All Rights Reserved.
For Menu driven search enter : CALL MENU
t hc
   1.00  717226 FIND CT D CARDIOVASCULAR DISEASES
   2.00   13186 FIND CT D NOISE
   3.00     415 FIND 1 AND 2
   4.00     415 FIND 3 AND PY>=1970
   5.00     369 FIND 4 AND LA=(EN;GE;DU)
   6.00  106923 FIND CT D BLOOD PRESSURE
   7.00     196 FIND 2 AND 6
   8.00     130 FIND 7 NOT 3
   9.00     130 FIND 8 AND PY>=1970
  10.00     116 FIND 9 AND LA=(EN;GE;DU)
  11.00     485 FIND 5 OR 10
  12.01     120 DUPLICATE CANDIDATES IN S= 11.00  (OUTPUT ONLY)
  12.02     119 DUPLICATES REMOVED FROM S= 11.00  (OUTPUT ONLY)
  13.00     366 UNIQUE              IN S= 11.00
  14.00    9321 FIND CT=(NOISE;NOISE EXPOSURE;NOISE INJURY;NOISE NUISANCE;NOISE
                POLLUTION;NOISE SOUND;NOISE,TRAFFIC;INDUSTRIAL NOISE)
  15.00    7355 FIND 14/IM=1
  16.00     299 FIND 5 AND 13
  17.00      80 FIND 16 AND 15
  18.00      67 FIND 10 AND 13
  19.00      36 FIND 18 AND 15
****END OF TAB*


POOLKEY            = BA93
DATABASE NAME      = Biosis Prev AB
NUMBER OF RECORDS  = 3.224.147
FIRST ENTRY        = 1.01.1993
LAST  UPDATE       = 26.10.1998 05:25
UPDATE PERIOD      = WEEKLY
?
t hc
   1.00    6796 FT=NOISE
   2.00  429631 FIND CARDIOVASCULAR OR ISCHAEM? OR ISCHEM? OR ANGINA PECTORIS
                OR MYOCARD? OR CORONARY OR VASCULAR DISEASE? OR CARDIAC OR
                BLOOD PRESSURE OR HYPERTENS?
   3.00  114159 FT=HEART
   4.00      92 FIND 1/(TI;UT;CT) AND (2 OR 3)/TI
```

```
  5.00    258 FIND 1/(TI;UT;CT) AND (2 OR 3)/(TI;UT;CT)
  6.00     40 FIND 5 AND (EXPOS? OR HAZARD? OR DISEASE? OR CARDIO?)/TI
  7.00    106 FIND 4 OR 6
  8.01     34 DUPLICATE CANDIDATES IN S=  7.00  (OUTPUT ONLY)
  8.02     34 DUPLICATES REMOVED FROM S=  7.00  (OUTPUT ONLY)
  9.00     72 UNIQUE              IN S=  7.00
****END OF TAB*


POOLKEY           = BA70
DATABASE NAME      = Biosis Prev AB Backfile
NUMBER OF RECORDS  = 8.123.668
FIRST ENTRY        = 1.01.1970
LAST  UPDATE       = 31.12.1992 23:59
UPDATE PERIOD      = NONE
?
t hc
  1.00   15079 FT=NOISE
  2.00  449557 FIND CARDIOVASCULAR OR ISCHAEM? OR ISCHEM? OR ANGINA PECTORIS
               OR MYOCARD? OR CORONARY OR VASCULAR DISEASE? OR CARDIAC OR
               BLOOD PRESSURE OR HYPERTENS?
  3.00  188779 FT=HEART
  4.00    241 FIND 1/(TI;UT;CT) AND (2 OR 3)/TI
  5.00    527 FIND 1/(TI;UT;CT) AND (2 OR 3)/(TI;UT;CT)
  6.00    139 FIND 5 AND (EXPOS? OR HAZARD? OR DISEASE? OR CARDIO?)/TI
  7.00    288 FIND 4 OR 6
  8.01     76 DUPLICATE CANDIDATES IN S=  7.00  (OUTPUT ONLY)
  8.02     76 DUPLICATES REMOVED FROM S=  7.00  (OUTPUT ONLY)
  9.00    212 UNIQUE              IN S=  7.00
****END OF TAB*


POOLKEY           = IS74
DATABASE NAME      = SCISEARCH
NUMBER OF RECORDS  = 16.631.495
FIRST ENTRY        = 1.01.1974
LAST  UPDATE       = 6.11.1998 06:25
UPDATE PERIOD      = WEEKLY
?
t hc
  1.00   69704 FT=NOISE
  2.00  500007 FIND CARDIOVASCULAR OR ISCHAEM? OR ISCHEM? OR ANGINA PECTORIS
               OR MYOCARD? OR CORONARY OR VASCULAR DISEASE? OR CARDIAC OR
               BLOOD PRESSURE OR HYPERTENS?
  3.00  188999 FT=HEART
  4.00    261 FIND 1/(TI;UT;CT) AND (2 OR 3)/TI
  5.00    323 FIND 1/(TI;UT;CT) AND (2 OR 3)/(TI;UT;CT)
  6.00    107 FIND 5 AND (EXPOS? OR HAZARD? OR DISEASE? OR CARDIO?)/TI
  7.00    272 FIND 4 OR 6
  8.01    174 DUPLICATE CANDIDATES IN S=  7.00  (OUTPUT ONLY)
  8.02    174 DUPLICATES REMOVED FROM S=  7.00  (OUTPUT ONLY)
  9.00     98 UNIQUE              IN S=  7.00
****END OF TAB*

0 DUPLICATES REMOVED FROM S= 11.00  (OUTPUT ONLY)
 13.00


 15.00    7355 FIND 14/IM=1
 16.00     299 FIND 5 AND 13
 17.00
```

Appendix 3.2 Why the exponential model

When we started this study, the shape of the relation between noise exposure and coronary heart disease was not clear: linear, exponential, with or without threshold value? In order to get an idea of the shape we plotted the noise exposure levels (as extracted from the studies) against the prevalence of the effect in question. These plots showed that it was not possible to indicate a threshold value. This is not consistent with studies that state that there is a threshold value of 70 dB(A)) [114]. Furthermore, the plots showed that the shapes of the dose-response relations were not specific. Therefore we decided to use two models for the meta-analysis: an exponential model (as presented in the article) and an additive model defined as:

(a) $$\beta_{i,Additive} = \left(\frac{RR-1}{\Delta dB(A)}\right) * 5$$

(b) $$\sigma_{i,additive} = \left(\frac{RR_{hi}-RR_{lo}}{3.92}\right) * \left(\frac{5}{\Delta dB(A)}\right)$$

Where

ΔdB(A):	the difference in noise levels between the index and reference group;
RR:	Relative risk extracted from study or calculated with Epi-info
RR_{lo}:	Lower level of RR;
RR_{hi}:	Upper level of RR;
$\beta_{i,additive}$:	Estimated change in risk per 5 dB(A);
$\sigma_{additive}$:	Estimated standard error of β_i

The additive model assumes that the increase in prevalence per unit of noise (dB(A)) is constant. The exponential model assumes a constant RR per unit of noise, which implicates an exponential relation between noise exposure and the prevalence of the effect concerned. The results of the meta-analysis showed that the associations found per 5 dB(A) with the additive model were stronger as compared with the exponential model, but that both models lead to the same conclusions. To find out whether the models were valid, we plotted the noise levels of the reference groups (as extracted from the studies) against the beta per 5 dB(A) of the different exposure groups. These plots showed that neither of the models show clear dependence on the background levels. Therefore both models seem to be fit the data. Because the exponential model is most commonly used, we only present the results of the exponential model.

Appendix 3.3 Equations used for recalculations

(a) $$\beta_{i,bloodpressure} = (\frac{\Delta Bloodpressure}{\Delta dB(A)}) * 5$$

(b) $$SE_i = \frac{SD_i}{\sqrt{N}}$$

(c) $$\sigma_{i,bloodpressure} = ((\frac{\sqrt{(SE_i^2 + SE_{ii}^2)}}{\Delta dB(A)}) * 5)^2$$

(i) $$L_{Aeq,7-19h} = 0.555 * B_{GL} + 44$$ *(74)*

Where

Δ*Bloodpressure* :	the difference in systolic or diastolic blood pressure;
ΔdB(A):	the difference in noise levels;
SE_i:	Standard error of systolic or diastolic blood pressure in group i;
SE_{ii}:	Standard error of systolic or diastolic blood pressure in group ii;
SD_i:	Standard deviation of systolic or diastolic blood pressure;
N:	Population
β_i:	Estimated change in blood pressure or risk per 5 dB(A);
σ_i:	Estimated standard error of β_i
B_{GL}:	Traffic noise exposure in Kosten units. In The Netherlands, air traffic noise exposure (B_{GL}) is expressed in Kosten units (KE). Kosten developed this measure in 1963. Modifying factors are: maximum noise levels ($L_{A,max}$) during the overflights, the total number of overflights and the overflight-times, averaged over one year with adjustment for the number of night overflights [113]
$L_{Aeq, 7-19h}$:	Equivalent noise exposure level during day-time in dB(A)

3.3 Addendum: The association between noise exposure and ischemic heart disease: update of the results with studies published between 2000 and 2007

BACKGROUND

Since the publication of this meta-analysis in 2002, several new studies were published. For the purpose of this thesis, the meta-analysis was extended with observational studies investigating the association between community noise exposure and blood pressure and ischemic heart disease that were published after 2000. The aim was to investigate whether the conclusions that were drawn in 2002 with regard to the effects of road and aircraft noise exposure had changed. To this end, observational studies involving the association between road traffic and/or aircraft noise exposure and blood pressure and ischemic heart disease investigating adults, published between 1970 and 2007 in English, German or Dutch were identified and processed according to the methods and criteria that were described Section 3.2.2. The results for blood pressure are presented in Section 3.4

RESULTS

Descriptives

Since 2000, 16 studies were published that investigated the possible impact of road traffic and aircraft noise exposure on the cardiovascular system and that were involved in the data-extraction [116 - 133]; from some other studies that were already included into the meta-analysis, updated and/or new results came available [107, 134 - 136]. Table 3.8 shows some characteristics of the studies that were published since 2000. They encompassed 11 cross-sectional studies, two case-control studies, two follow-up studies and a time-series study. Sample sizes ranged from 366 to 28,781 persons; eight studies investigated the effects of road traffic noise, six studies investigated the effects of aircraft noise and one study investigated the effects of both road traffic and aircraft noise exposure. Noise exposure was mainly estimated by means of noise models. The studies investigating the effects of road traffic noise exposure were carried out among equivalent sound levels ($L_{Aeq,\ 6\text{-}22hrs}$) of about 40 to 75 dB(A); the studies investigating the effects of aircraft noise were carried out among equivalent sound levels (L_{den}) of about 35 to 70 dB(A). Within the studies, a wide range of effects was investigated: blood pressure changes, hypertension, use of antihypertensives and/or cardiovascular medicines, angina pectoris, myocardial infarction and hospital admissions. The most important effects and changes that were observed in comparison with the results presented in 2002 (see also Section 3.2) will be presented below.

Road traffic noise

Since 2000, seven cross-sectional studies investigating the effect of road traffic noise exposure ($L_{Aeq,\ 6\text{-}22hrs}$) on hypertension have been identified [124, 125, 127, 128, 131]. In most of these studies, the prevalence of hypertension was assessed by means of one or more questions about doctor diagnosed hypertension that were part of a social survey questionnaire (indicated as self-reported hypertension). The results of the separate studies are presented in Figures 3.12a and b.

For completeness, the results of studies published before 2000 were also included, regardless of the adjustment of confounding factors. After including the results of the new studies [119, 124, 127, 128, 130], a positive but statistically non-significant association was found: an $RR_{5dB(A)}$ 1.12 (95%CI: 0.97 – 1.30) was estimated.

Road traffic noise is positively, but non-significantly associated with the prevalence of angina pectoris. After including the results of studies that have been published after 2000 [119, 124], an $RR_{5dB(A)}$ of 1.05 (95%CI: 0.95 – 1.17) (N = 5) was estimated (see also Table 3.9).

The relation between road traffic noise and myocardial infarction was investigated in eight studies [95, 101 – 108, 116 – 119]. In these studies, myocardial infarction was based on information that was obtained from a clinical interview, or was assessed by means of one or more questions about doctor diagnosed myocardial infarction that were part of a social survey questionnaire (also indicated as self-reported myocardial infarction) (see also Figure 3.12b). Table 3.9 shows that road traffic noise exposure remains positively associated with the prevalence of myocardial infarction.

TABLE 3.8 *Observational studies that investigated the association between community noise exposure and blood pressure and ischemic heart disease published between 2000 and 2007.*

Study	Ctry [*]	Design [§]	Population		Exposure			Effects Invest [†]	Adjustments [‡]
			Sex, age	**N**	**Src [#]**	**Level (L_{16hr} or L_{den})**	**Assessment**		
NaRoMi[116-118]	Ger	CC	M&F, 20-69	4,115	R	<60, 61-65, 66-70, >70	Calc	F	1 – 13
Spandau[119]	Ger	Cr	M&F, 18-90	1,718	R	<55, 55-60, 60-65, > 65	Calc	B, E, F	1, 2, 6, 7, 14-18
					A	<60, 61-65, 66-70	Calc	B, E, F	1, 2, 6, 7, 14-18
Okinawa[120]	Jap	Cr	M&F, ≥ 40	28,781	A	<60, 60-64, 65-69, >70	Calc ?	A, B	1, 2, 7
ROOM[121]	Swed	CC	M&F, 45-70	3,500	R	< 50 vs > 50	Calc	F	1, 2, 19
Tobias-01[122]	Sp	Ts			C	62.5 -71	M	I	20 – 22
Yosh-97[123]	Jap	Cr	F, 20-60	366	R	<55, 56-60, 61-65, 66-70, 71-75		B	NR
Tyrol-1[124]	O	Cr	M&F, 25-64	1989	R&T	<60 - ≥65	M&Calc	A, B, E, F	NR
Tyrol-2[125]	O	Cr	M&F, 20-75	572	R&T	<50, 50-55, 55-60, >60	M&Calc	A,B	NR
Sweden-1[126]	Swed	Cr	M&F, 18-90	2,959	A	<50, 50-55, 55-60, >60	Calc	B	1, 2, 6, 23
Sweden-2[121]	Swed	Ch	M	2,037	A	≤ 50 vs > 50	Calc	B	1, 2, 7
Sweden-3 [127, 128]	Swed	Cr	M&F, 19-80	667	R	39.5-44.5; 45.5-49.5; 50.5-54.5; 55.5-64.5	Calc	B	(1), 2, 6, 19, 23, 24
Sweden-4[129]	Swed	Ch	M, 45-65	417	A	< 55 vs > 55	Calc	B, E, F	NR
Lerum[130]	Swed	Cr	M&V, 18-75	1953	R	44.5-49.5; 50.5-54.5; 55.5-59.5; 60.5-69.5	Calc	B, C	1, 2, 5, 6, 23, 28
Skåne[131]	Swed	Cr	M&V	13,557	R	<51.1; 51.1-55.1; ≥ 56.1	Calc	B	1, 2, 7
GES02[132]	NL	Cr	M&V, ≥ 18	5,873	A	44-70	Calc	B, D	1, 2, 14, 17, 25-27
GES05[133]	NL	Cr	M&V, ≥ 18	6,091	A	35-65	Calc	B, D	1, 2, 14, 17, 25-27

[*] Ger: Germany, Jap: Japan, Swed: Sweden, Sp: Spain, O: Ostria, NL: The Netherlands [†] A: blood pressure change; B: hypertension; C: Use of antihypertensives; D: Use of cardiovascular medication (incl. antihypertensives); E: angina pectoris; F: myocardial infarction; G: consultation GP/Specialist; H: coronary heart diseases; I: hospital admission/emergency room. [‡] 1: sex; 2: age; 3: diabetes mellitus; 4: hypertension; 5: family history of MI and/or hypertension; 6: smoking status or smoking; 7: Body Mass Index or Quetelet Index; 8: employment status; 9: living with(out) partner; 10: duration of education; 11: noise sensitivity; 12: aircraft noise level; 13: rail traffic noise; 14: alcohol consumption, drinking habits; 15: physical activity; 16: hearing loss; 17: socio-economic status; 18: season; 19: living duration; 20: temperature; 21: humidity; 22: influenza epidemics; 23: education level; 24: type of dwelling; 25: ethnicity; 26: family size; 27: urbanisation; 28: occupational noise exposure [§] Cr: Cross-sectional study, CC: Case-control study, TS: Time series, Ch: Cohort study. [#] R: Road traffic noise, A: Aircraft noise, T: Rail traffic noise, C: Community noise

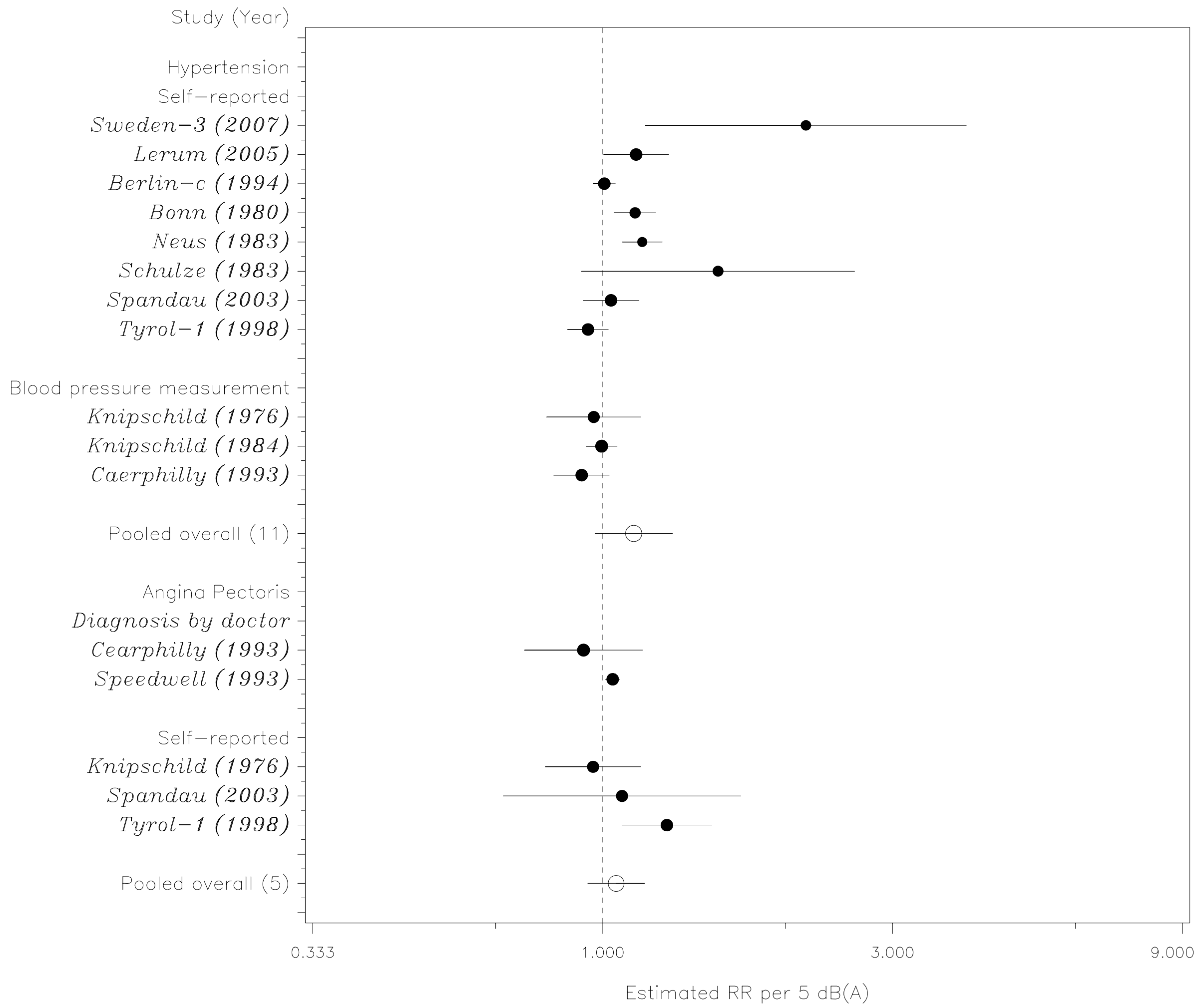

FIGURE 3.12a *The association between road traffic noise exposure ($L_{Aeq,\ 6\text{-}22hrs}$ or $L_{Aeq,\ 22\text{-}6hrs}$ in dB(A)) and hypertension, and angina pectoris. The dotted vertical line corresponds to no effect of road traffic noise exposure.*

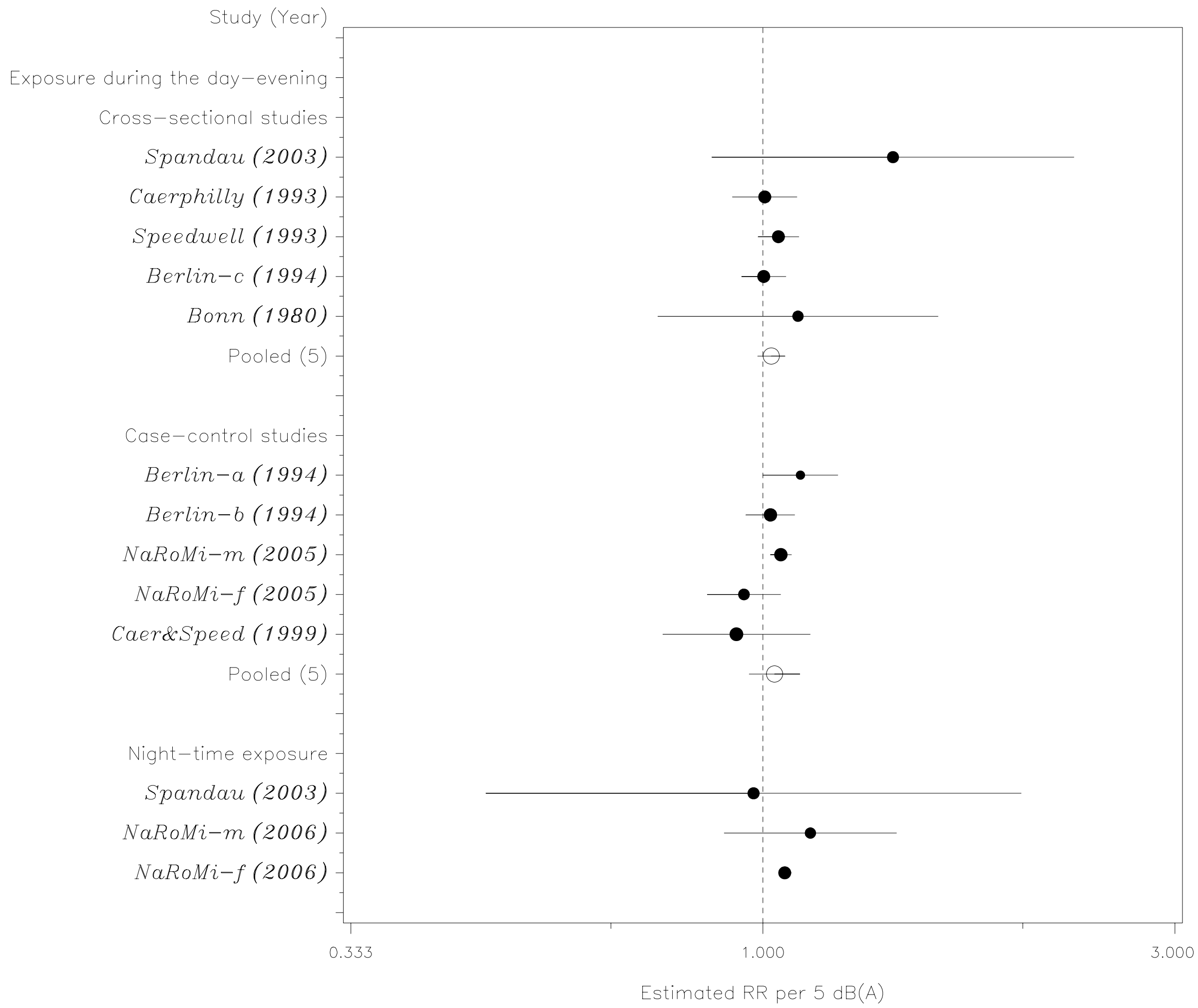

FIGURE 3.12b *The association between road traffic noise exposure ($L_{Aeq,\ 6\text{-}22hrs}$ or $L_{Aeq,\ 22\text{-}6hrs}$ in dB(A)) and myocardial infarction. The dotted vertical line corresponds to no effect of road traffic noise exposure.*

Aircraft noise exposure

In relation to aircraft noise exposure (L_{den}), seven studies came available since 2000 [119 - 121, 126, 129, 132, 133]: they involved five cross-sectional studies [119, 121, 126, 132, 133] and two follow-up studies [121, 129]. In four studies hypertension was measured by means of questions about doctor diagnosed hypertension that were part of a questionnaire [119, 126, 132, 133]. The results of the separate studies are presented in Figure 3.13; for completeness, the results of the study published before 2000 was also included [108]. After including the results of the new studies the association between aircraft noise exposure (L_{den}) and hypertension remained statistically significant [$RR_{5dB(A)}$ 1.13 (95%CI: 1.00 – 1.26)].

The relation between aircraft noise exposure and the use of cardiovascular medicines was investigated in four cross-sectional studies [108, 110, 132, 133] among adults living in the neighbourhood of Schiphol Airport. A statistically significant association was found [$RR_{5dB(A)}$ 1.12 (95%CI: 1.01 – 1.24)]. In addition, a statistically significant association between night-time aircraft noise exposure (L_{night}) and the use of cardiovascular medicines was found: $RR_{5dB(A)}$ 1.10 (95%CI: 1.02 – 1.20). However, in all studies, the use of cardiovascular medicines was measured by means of self-report. A positive but non-significant association was found between aircraft noise exposure and the prevalence of angina pectoris.

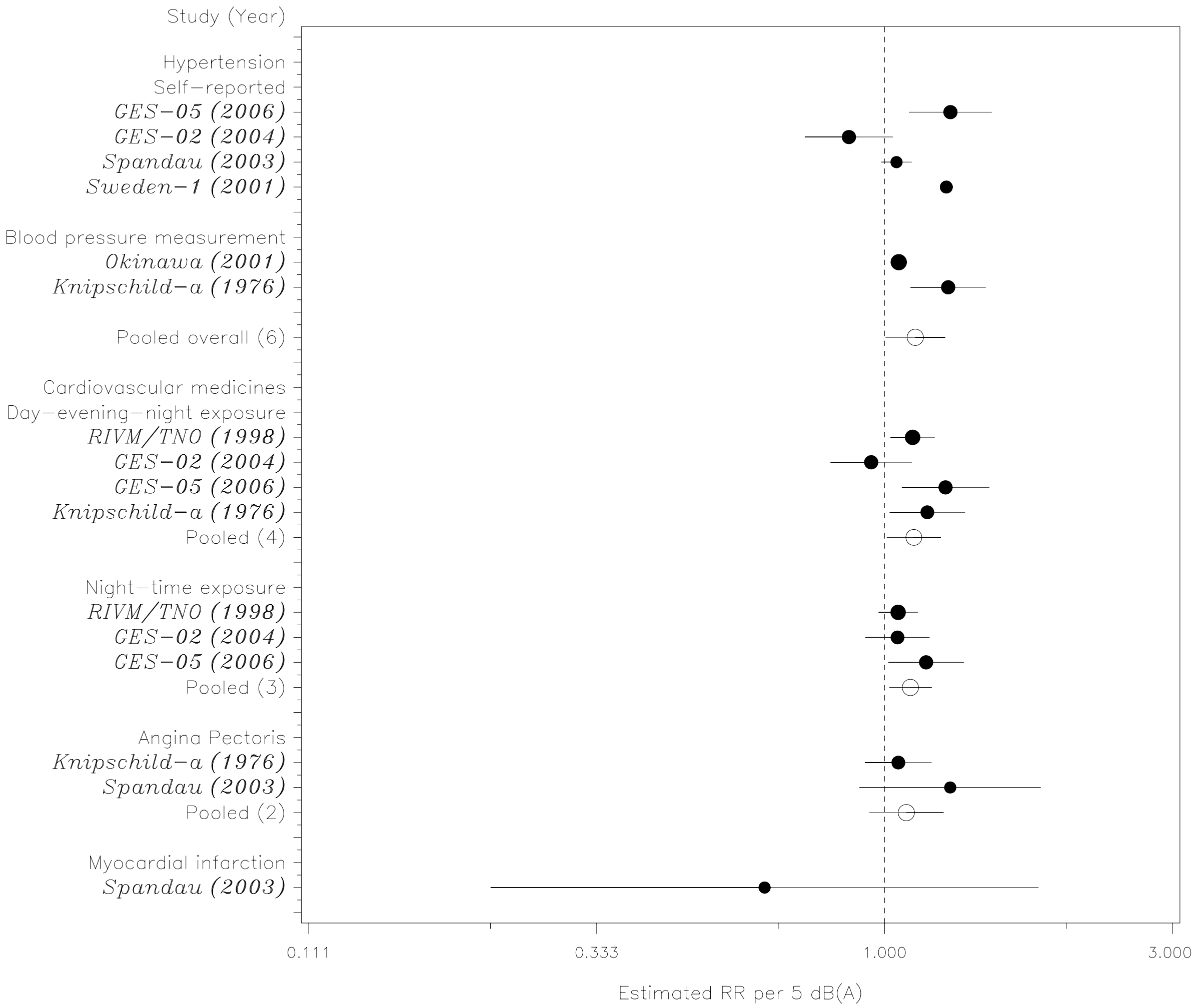

FIGURE 3.13 *The association between aircraft noise exposure (L_{den} or L_{night} in dB(A)) and hypertension, the use of cardiovascular medicines, angina pectoris and myocardial infarction. The dotted vertical line corresponds to no effect of aircraft noise exposure.*

TABLE 3.9 *Updated and original summary estimates, expressed as $RR_{5dB(A)}$ for the association between noise exposure, hypertension, and ischemic heart disease.*

Noise exposure *	Outcome	Original estimate † $RR_{5dB(A)}$ (95%CI)	Updated estimate $RR_{5dB(A)}$ (95%CI)
Road traffic	Hypertension	0.95 (0.84 – 1.08)	1.12 (0.97 – 1.30)
	Angina Pectoris	0.99 (0.84 – 1.16)	1.05 (0.95 - 1.17)
	Myocardial_cross ‡	1.03 (0.99 – 1.09)	1.02 (0.99 – 1.06)
	Myocardial_incid §	-	1.03 (0.96 – 1.10)
Air traffic	Hypertension	1.26 (1.14 – 1.39)#	1.13 (1.00 – 1.26)#
	Use of cardiovascular medicines	1.05 (0.99 – 1.11)	1.12 (1.01 – 1.24)#

95%CI, 95 percent confidence interval. * The noise exposure measures differed between the noise exposure sources: road traffic noise exposure expressed in $L_{Aeq6\text{-}22\ hrs}$ in dB(A); air traffic noise exposure expressed in $L_{Aeq\ 7\text{-}19\ hrs}$ (original estimates) and in L_{den} (updated estimates) in dB(A). † estimates presented in 2002 (see also Table 3.7) ‡ prevalence estimate. § incidence estimate. # $p < 0.05$

Subgroup analyses

The results of the subgroup analyses were published in Figures 3.12 and 3.13. For the association between road traffic noise exposure and hypertension, data aggregation produced a positive but non-significant summary estimate for the studies (n=8) measuring hypertension by means of a questionnaire [$RR_{5dB(A)}$ 1.20 (95%CI: 0.99 – 1.45)] [95, 97, 98, 102, 119, 124, 128, 130]. After the results of the three studies, in which hypertension was assessed by means of blood pressure measurements [93, 94, 99, 103, 105, 107, 108], were combined, the effect of road traffic noise exposure on hypertension was eliminated [$RR_{5dB(A)}$ 0.96 (95%CI: 0.92 – 1.00)].

With respect to the association between road traffic noise and the prevalence of angina pectoris, only small differences were observed between studies assessing the prevalence of angina pectoris by means of a question about doctor diagnosed angina pectoris as part of a social survey questionnaire [$RR_{5dB(A)}$ 1.11 (95%CI: 0.90 – 1.36)] [103 – 108] and studies in which the diagnosis was made by a medical doctor [$RR_{5dB(A)}$ 1.04 (95%CI: 1.01 – 1.07)] [93, 119, 124]. For the association between road traffic noise exposure and the prevalence of myocardial infarction, data aggregation produced a positive, but non-significant estimate [$RR_{5dB(A)}$ 1.02 (95%CI: 0.99 – 1.06)]; the effect did not change after the results of the reported 1-year incidence were combined [$RR_{5dB(A)}$ 1.03 (95%CI: 0.96 – 1.10)]. Since the studies investigating the effect of night-time noise exposure (L_{night}) on myocardial infarction involved a cross-sectional [119] and a case-control study [116, 117], no effect estimate was produced. After the results of studies investigating the association between aircraft noise exposure and the prevalence of hypertension were combined [73, 90, 96, 97, 83, 84], a positive statistically significant association was found. When looking at the association between aircraft noise exposure and self-reported hypertension a positive but non-significant association was found [$RR_{5dB(A)}$ 1.11 (95%CI: 0.94 – 1.32)]; data-aggregation of the aircraft noise studies measuring hypertension by means of blood pressure measurements produced also a non-significant summary estimate [$RR_{5dB(A)}$ 1.14 (95%CI: 0.95 – 1.37)].

DISCUSSION AND CONCLUSIONS

In this addendum, the associations between road traffic and aircraft noise exposure and hypertension, angina pectoris, myocardial infarction and the use of cardiovascular medicines, were updated with the results of studies that were published after 2000. Data-aggregation of the road traffic noise studies produced positive but non-significant associations for hypertension, angina pectoris and myocardial infarction. Data-aggregation of the aircraft noise studies produced significant associations for hypertension and the use of cardiovascular medicines.

Recently, Babisch (2006) has published the results of a systematic review; for the relation between road traffic noise and the incidence of myocardial infarction he pooled the results of three case-control studies and one follow-up study [100, 101, 107, 116]. Per 5 dB(A) noise exposure category, Babisch estimated an Odds Ratio (OR). Persons exposed to road traffic noise levels equal or less than 60 dB(A) ($L_{Aeq,\ 6\text{-}22hrs}$) were considered as reference group. By doing this, he implicitly assumed that no effects of noise will occur below these levels [141]. In addition, a function was fitted to the pooled data points (see also Figure 3.14). In the meta-analysis of Babisch only men were included.

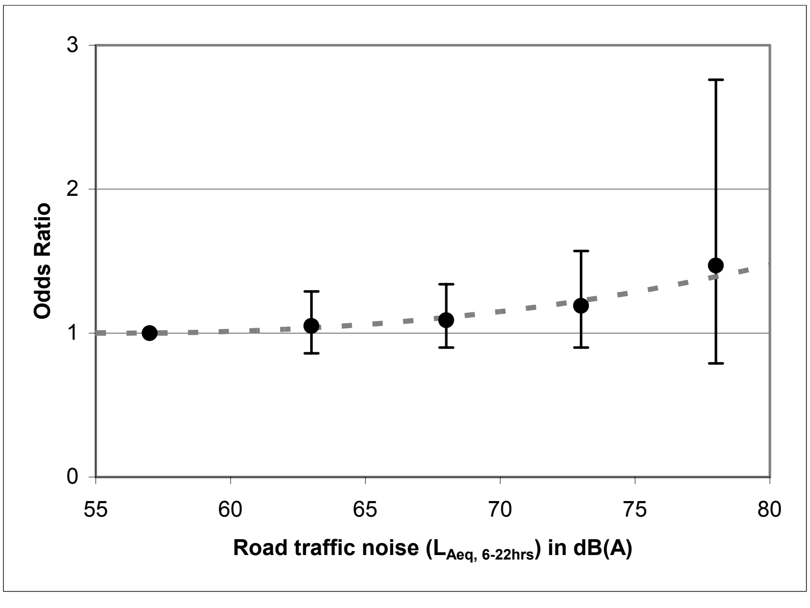

FIGURE 3.14 The association between road traffic noise ($L_{Aeq,\ 6\text{-}22hrs}$ in dB(A))) exposure and the incidence of myocardial infarction, derived by Babisch (2006) [141].

A direct comparison with the results of the meta-analysis that is presented here, is difficult. As opposed to Babisch (2006) [141], the outcome measure was the Relative

Risk on the incidence of myocardial infarction per 5 dB(A) increase of the noise level, assuming that there is a linear relation between road traffic noise exposure and the incidence of myocardial infarction. In case the results of our meta-analysis are applied from noise levels of 60 dB(A) ($L_{Aeq,\ 6\text{-}22hrs}$) and higher, it appears that our Relative Risks differ from the Odds Ratios that were estimated by Babisch [141].

Since 2000 more case-control and cohort studies have been carried out. In comparison with cross-sectional studies, the design of case-control and cohort studies is usually considered as having a higher validity and credibility. This is a positive development.

However, some methodological weaknesses can be observed in the individual studies. The most important have to do with (i) the measurement of the cardiovascular outcomes and (ii) exposure characterisation. There is concern with regard to the measurement of the different cardiovascular outcomes in the studies that were included in the meta-analysis. Outcomes such as the prevalence of hypertension and the use of cardiovascular medicines were often measured by means of questions about doctor diagnosed hypertension and medication use that were part of a questionnaire. However, the reliability of such a method is questionable. E.g. since a person does not always notice whether he or she suffers from hypertension, it is possible that a part of the hypertensive persons may have classified themselves as having a normal blood pressure (normotensive). Over-reporting is also possible: Studies investigating adults' health have suggested that persons with poorer perceived health often attribute the cause of their symptoms to external conditions such as their living environment [133, 141]; subjects may be more prone to blame their environment for their health problems, or may even tend to exaggerate adverse effects of exposure in order to influence noise policy. It can be envisaged that reporting bias becomes less a problem if (i) outcomes become 'harder' such as is the case with myocardial infarction: a very definite and severe outcome which subjects would clearly remember if they had experience it [141]; and (ii) in case outcomes such as hypertension are assessed objectively (e.g. measurement of blood pressure or a structured clinical interview instead of self-reported hypertension in a self-administered questionnaire).

As was also the case in studies that were published before 2000, most studies investigating the impacts of transportation noise exposure on blood pressure and cardiovascular disease have still involved between-group comparisons. It is recognised that the results of these studies may be sensitive to decisions about cut-off points used to categorise continuous exposure variables and the method used to assign scores to exposure categories [140]: the exposure assessment and the inability to apply individual exposure estimates (if available) to larger study populations might have caused exposure misclassification.

Although the results of this update are suggestive for a slight increase of cardiovascular risk in populations exposed to aircraft and road traffic noise, they are limited because of possible exposure misclassification and reporting bias due to the fact that the cardiovascular outcomes of the participating studies were usually measured by means of self-report.

3.4 Addendum: Noise exposure and blood pressure: comparison between children and adults

BACKGROUND

Since children behave differently, and their coping mechanisms are not fully developed, children are suspected of being more susceptible to noise exposure than adults [137]. However, scientific evidence from studies investigating the susceptibility of children to noise in a systematic way is scarce. For the purpose of this thesis, the meta-analysis was extended with observational studies, investigating the association between road traffic and aircraft noise exposure and children's blood pressure. The aim was to investigate how the effects of noise on blood pressure that were found in children relate to what was found in adults. To this end, observational studies involving the association between road traffic and/or aircraft noise exposure and blood pressure investigating children and/or adults, published between 1970 and 2007 in English, German, or Dutch were identified and processed according to the methods and criteria that were described in Section 3.2.2 of this chapter.

RESULTS

Descriptives

Seven studies, investigating the effects of road and rail traffic and aircraft noise exposure on children's blood pressure met the criteria for data-extraction. They encompassed two follow-up studies [5, 138], one before-after study [17] and four cross-sectional studies [15, 18, 125, 139]. Table 3.10 shows some characteristics of these studies. The sample sizes of the studies varied from 115 children to 1230 children. Across the studies, different noise metrics were used: $L_{Aeq,\ 1hr}$, $L_{Aeq,\ 24\ hr}$, ANEI, L_{dn}, $L_{Aeq,\ 7\text{-}23\ hrs}$. Noise exposure was usually estimated by means of noise models.

Exposure-response estimates

The influence of noise exposure on children's blood pressure was studied for both road and air traffic noise exposure at home and at school. Figures 3.15 and 3.16 show that the effect of transportation noise exposure on children's blood pressure differs between the studies. Since only one study met the criteria for data-aggregation and because of the observed heterogeneity, it was not possible to pool the results of the child studies.

Subgroup-analyses

In Figures 3.15 and 3.16 the results of both the child studies and adult studies investigating the effects of noise exposure on blood pressure were presented.

Comparison of the estimates derived from child studies with the estimates derived from adult studies, is difficult due to the heterogeneous results of the studies. It can be observed that the effect estimates derived from the child studies do not appear to be different from those derived from the adult studies. However, this evaluation is not based on statistical significance but on an approximate estimation of the effect estimates.

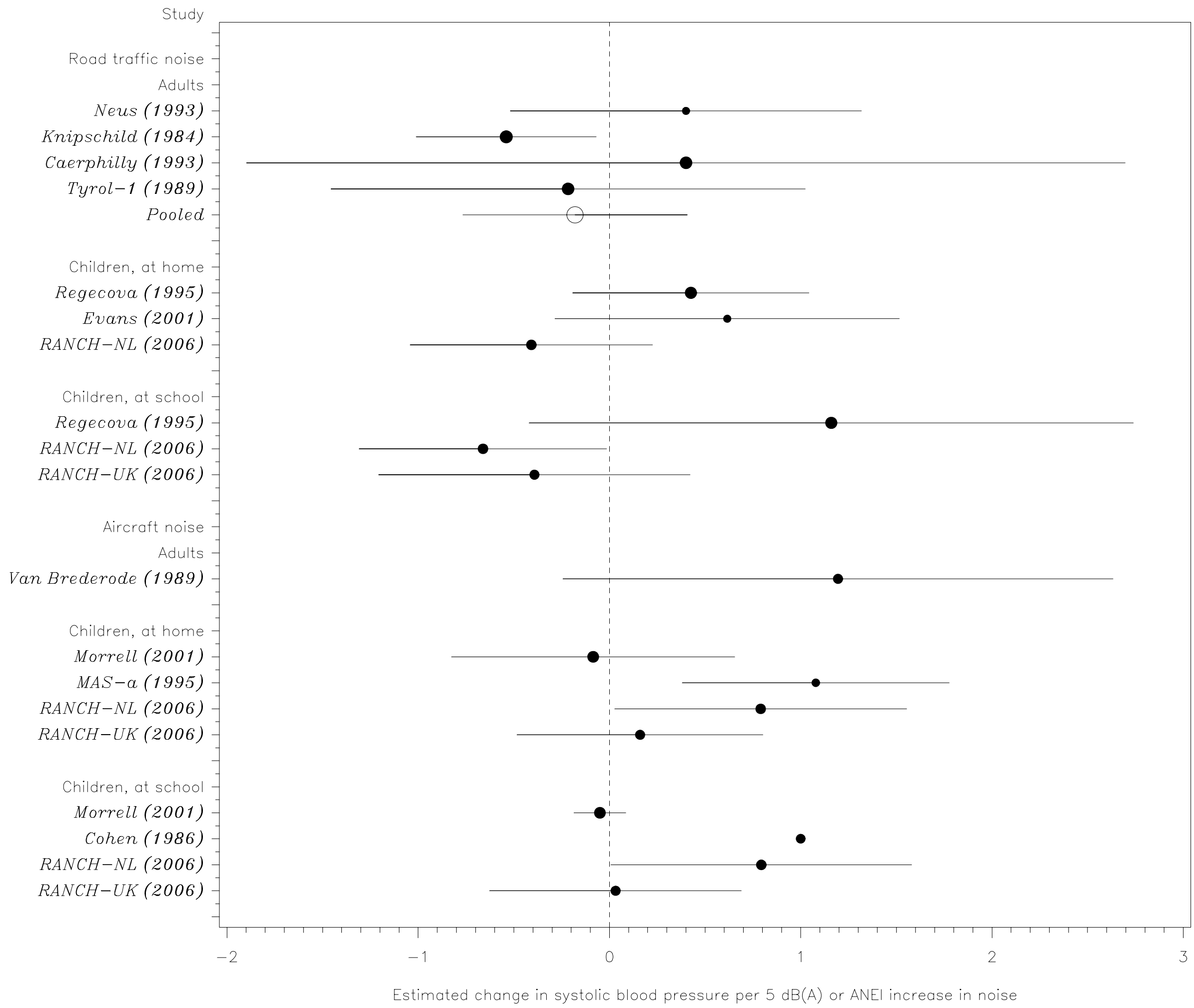

FIGURE 3.15 *The association between aircraft or road traffic noise exposure and systolic blood pressure in adult and child populations. The dotted vertical line corresponds to no effect of noise exposure on systolic blood pressure. The circles correspond to the estimated difference in blood pressure (mmHg) per 5 dB(A) increase of the noise. The horizontal lines correspond to the 95 percent confidence interval.*

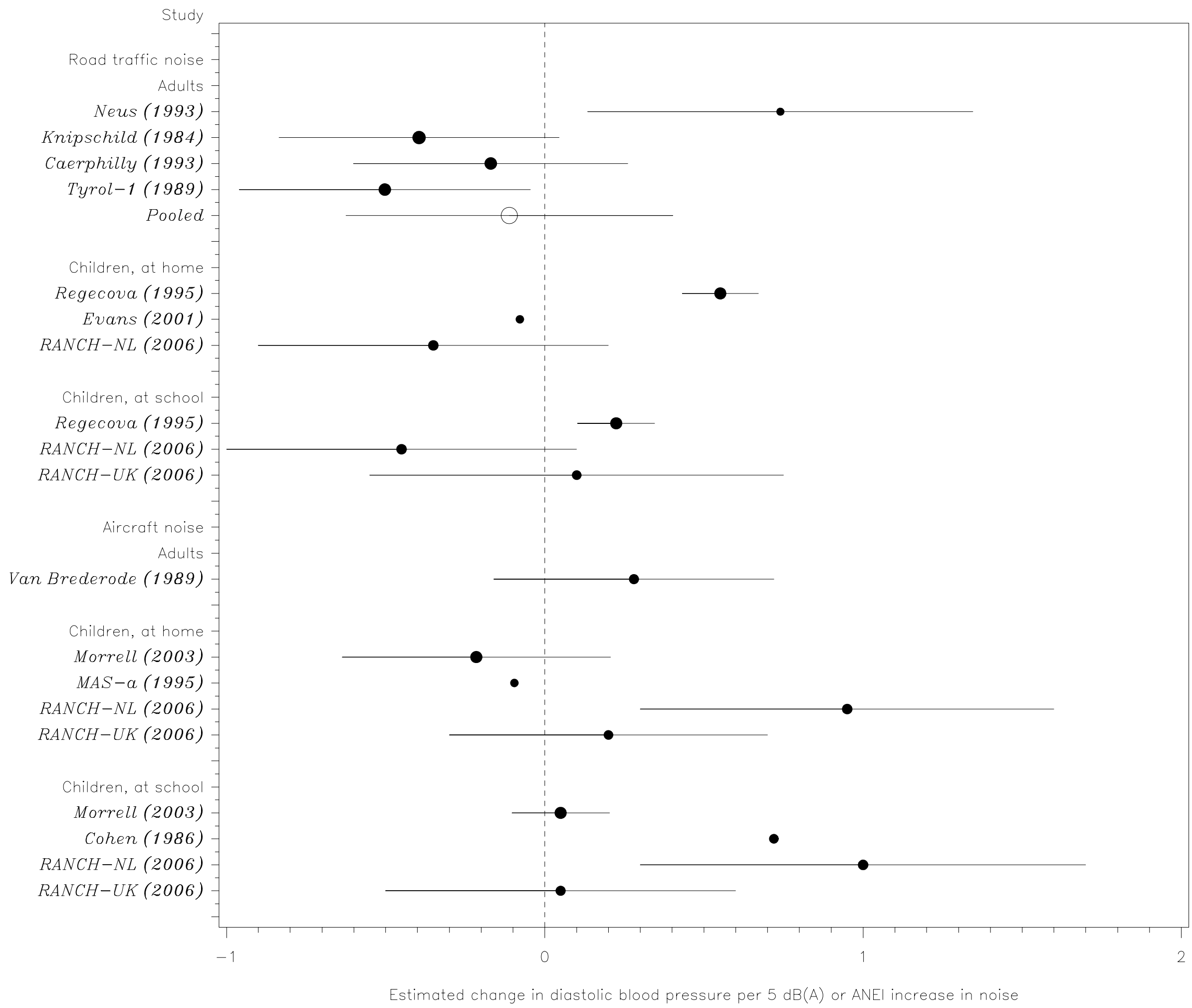

FIGURE 3.16 *The association between aircraft or road traffic noise exposure and diastolic blood pressure in adult and child populations. The dotted vertical line corresponds to no effect of noise exposure on diastolic blood pressure. The circles correspond to the estimated difference in blood pressure (mmHg) per 5 dB(A) increase of the noise. The horizontal lines correspond to the 95 percent confidence interval.*

CONCLUSION

For the purpose of this thesis, the meta-analysis was extended with studies investigating the effects of transportation noise on children's blood pressure. Comparison of the estimates derived from child studies with the estimates derived from adult studies, is difficult due to the heterogeneous results of the studies. Based on our findings no conclusions can be drawn with regard to the hypothesis that children do not appear to react differently on noise exposure than adults do.

TABLE 3.10 *Study characteristics of the community studies investigating children's blood pressure included for data-extraction*

Study	Country	Design	Population *	N (#)†	Exposure				Adjustments #
					Source	Noise metric	Level (dB(A))‡	Measurement §	
LA-Study-a [5]	USA	Cohort	B&G, 3-4 gr	262 (7)	Air	$L_{Aeq, 1hr}$	70.3; 62.8; 65.1; 62.1	SLM	1, 2, 3, 4, 5, 6
LA-Study-b [5]	USA	Cross	B&G, 3 gr	163	Air	$L_{Aeq, 1hr}$	66.1; 63.8; 65.3; 57.0	SLM	1, 2, 3, 4, 5, 6
Tyrol-1 [18]	Austria	Cross	B&G, 8-12 yr	796	Road	$L_{Aeq, 24hr}$	< 45; 45-49; 50-54; 55-59; 60-64; 65-69; >70	SLM & Calc	-
MAS-a [17]	Germany	Cross	B&G	135	Air	$L_{Aeq, 24hr}$	59; 68		6, 7, 22 **
MAS-b [17]	Germany	Before-after	B&G, 9-11 yr	217	Air	$L_{Aeq, 24hr}$	53; 62		1, 22, 30, 31
Regecová-1995 [15]	Slowakia	Cross	B&G, 3-7 yr	1542	Road	$L_{Aeq, 24hr}$	≤ 60; 61-69; ≥ 70	SLM	7
Morrell-2003 [138]	Australia	Cohort	B&G, 3 gr	1230 (75)	Air	ANEI	15-45	SLM & Calc	3, 5, 7, 8, 11, 12, 14-29
Tyrol-2 [125]	Austria	Cross	B&G, 9-10 yr	115	Road, rail	L_{dn}	< 50; > 60	SLM & Calc	6, 7, 8, 9, 10 **
RANCH-a [139]	NL, UK	Cross	B&G, 9-11 yr	1283 (62)	Air	$L_{Aeq, 7\text{-}23hrs}$	34-73	Calc	4, 6-9, 11, 32-40
RANCH-b [139]	NL, UK	Cross	B&G, 9-11 yr	1283 (62)	Road	$L_{Aeq, 7\text{-}23hrs}$	34-67	Calc	4, 6-9, 32-41

* B: Boy; G: Girl, gr: grade in school, yr: years of age; † N: Number of participants; #: number of schools; ‡ this is the measurement range of the study; § Calc: exposure assessment by means of model calculations; SLM: exposure assessment by means of measurements with sound level meters; # 1: family size, 2: grade in school, 3: months enrolled in school, 4: race, 5: height, 6: ponderosity or body mass index, 7: age, 8: sex, 9: mother's education, 10: family situation, 11: road traffic noise exposure, 12: rail traffic noise exposure, 14: weight, 15: subscapular skinfold, 16: eating before school (y/n), 17: salt used on food, 18: parent history of high blood pressure, 19: family history of high blood pressure, 20: child history of high blood pressure, 21: non-English speaking background, 22: SES, 23: blood pressure measurer, 24: blood pressure machine, 25: child activity, 26: home insulation, 27: house characteristics, 28: school insulation, 29: ambient temperature, 30: occupation, 31: parental education; 32: country; 33: type of glazing; 34: employment status parent; 35: child lives in crowded house (y/n); 36: parents are home owner (y/n); 37: cuff size; 38: birth weight; 39: prematurity; 40: room temperature; 41: aircraft noise.** exposure groups were comparable on these factors

4 Does transportation noise exposure cause neurobehavioural effects in primary schoolchildren? Results from the RANCH study

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Submitted for publication

ABSTRACT

Cognitive performance in 553 primary schoolchildren living around Schiphol Amsterdam Airport with different aircraft and road traffic noise exposure levels was examined cross-sectional. Selected tests from the Neurobehavioral Evaluation System (NES), a computerised battery, were used.

Effects of road traffic and aircraft noise exposure at school were observed in the more difficult parts of the Switching Attention Test (SAT). No definite conclusions can be drawn about the relative importance of noise exposure at home and at school and possible interactions.

4.1 Backgrounds

Transportation noise
Transportation is an activity that is responsible for a large and growing proportion of environment and health effects in Europe. Noise is generally perceived as one of the problems associated with transportation. It has been estimated that approximately 40% of the European Union's population is exposed road traffic noise at levels exceeding 55 dB(A) and 20% is exposed to levels exceeding 65 dB(A) during daytime [1]. Despite numerous measures in the field of noise abatement at European, national and local levels, the noise-problem does not become smaller. Without additional policy measures, more people will be exposed to higher noise levels in the coming decades.

Effects of noise in children
Long-term noise exposure is associated with a number of effects on health and well-being. These include community responses such as annoyance, sleep disturbance, disturbance of daily activities, and physiological responses such as hearing loss, hypertension and ischemic heart disease [1]. This paper focuses on the effects of noise on children. Although it is not investigated systematically yet, children are suspected of being more susceptible to noise exposure for a number of reasons: since they spend their time at other settings and because they behave differently, children’s exposure can differ from adults’ exposure; children often cannot escape from exposure, where adults can; and children have not (fully) developed coping mechanisms and cannot always change their situation, whereas adults may have the power and/or resources to do so. These factors combine to generate or trigger a wide range of negative effects [2].

Studies investigating the effects of noise on cognitive functioning in children
Among children, effects on cognitive functioning were studied the most. However, with the preponderant influence of factors such as socio-economic status, the child's living conditions, other environmental exposures and genetic predisposition, it is difficult to gain insight into the contribution of noise to cognitive functioning. This is probably one of the reasons that the results from observational studies are limited since they cannot provide complete answers about the underlying mechanisms as how noise affects children’s cognitive functioning and do not generate exposure-response relations that can be applied for risk assessment. Secondly, a number of methodological problems emerge from earlier studies investigating the impact of noise on cognitive functioning (e.g. small differences in noise levels between the exposure groups, potential selection bias). Thirdly, most studies usually only focus on noise exposure at school although it is questionable whether the effects of noise on children should exclusively be attributed to noise exposure at school [3]. Finally, it is

difficult to select appropriate tests that are sensitive to the effects of noise at specific stages of development, because of the many developmental stages through which children progress [4]. Reliance upon insensitive developmental outcomes (simple cognitive tasks) may cause underestimation of the effect of noise [5]. Most observational studies [6 – 15] have investigated the effects of noise on cognitive performance by means of selected paper-and-pencil tests measuring reading comprehension, sustained attention, and long-term memory, assuming that noise directly or indirectly affects the ability to think and reason (including concentration and memory). But how about behaviour and learning? Therefore, it would be interesting to investigate the effects of noise on cognitive performance by means of neurobehavioural tests that evaluate these different aspects of central nervous system functioning.

Aims and objectives

The aim of this paper is to investigate the possible relation between aircraft and road traffic noise exposure and cognitive performance in primary schoolchildren. Since we wanted to expand the traditional paper-and-pencil tests, cognitive performance was operationalised by means of a selection of computerised neurobehavioural tests from the Neurobehavioral Evaluation System (NES) [16]. Figure 4.1 gives an overview of the tests all the tests that were applied in our study. The objectives of our paper were (i) to study the external validity of the NES towards commonly used paper-and-pencil tests, and to find out the added value of NES tests in comparison to paper-and-pencil tests; (ii) to analyse the relations between road and aircraft noise exposure and the different outcomes of the NES for the school situation, and (iii) to analyse the relations between road and aircraft noise exposure and the different outcomes of the NES for the home situation. We acquired data from a Dutch sub-sample of schoolchildren living around Schiphol Amsterdam Airport that were gathered during the European 5th Framework project RANCH (Road traffic and Aircraft Noise exposure and children's Cognition and Health) [17].

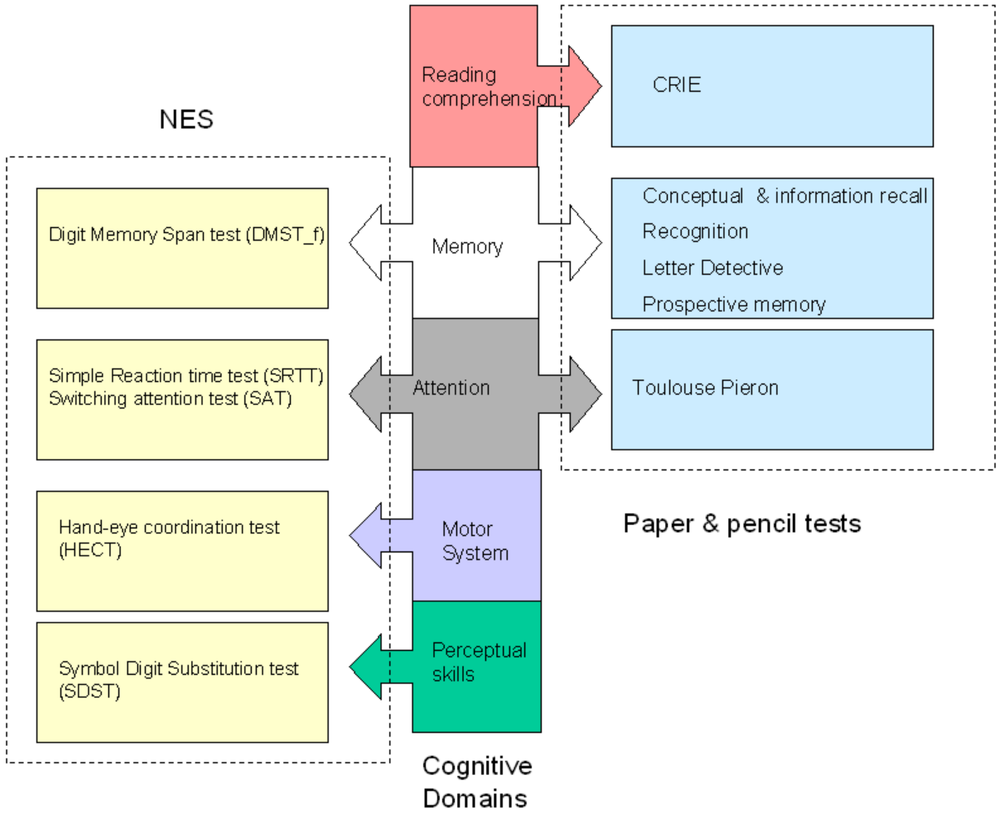

FIGURE 4.1 *Cognitive test batteries applied*

The Neurobehavioral Evaluation System

The NES, the application of which is relatively new in the field of noise and health, is designed to evaluate different aspects of cognitive functioning [18]. Originally, the NES was developed to facilitate the conduct of epidemiologic studies of populations at risk for or suffering from central nervous system dysfunction due to environmental agents [16]. The test was developed for adults but later adapted for use in children [19]. The feasibility of measuring a range of neurobehavioural parameters by (computerised) performance tests and questionnaires in relation to community noise in the school environment, was tested and demonstrated before [18]. Less is known about the external validity of the NES towards paper-and-pencil tests that are more commonly used in studies investigating the effects of community noise on cognition. The correlational pattern and factor-structure might indicate how the NES complements such paper-and-pencil tests. Therefore it was recommended to investigate a sample of at least 500 children [18].

Location of exposure

Most studies investigating the effects of noise on children have only focused on exposure at school. This is a gap in the research, since the impact of noise on children can occur in different environments over 24hr period: Time use studies [20, 21] have shown that children aged 7-12 years spent about 71% of their time inside or directly outside their home. Most of the time children sleep (44%) while they spent only 13% of their time in school following courses and making homework.

4.2 Methods

Participants

Participants were 553 primary schoolchildren (48.5% girls; M = 10.5 years) that were recruited from 620 children of 24 primary schools in three Municipal Health Office areas around Schiphol Airport (see also Figure 4.2).

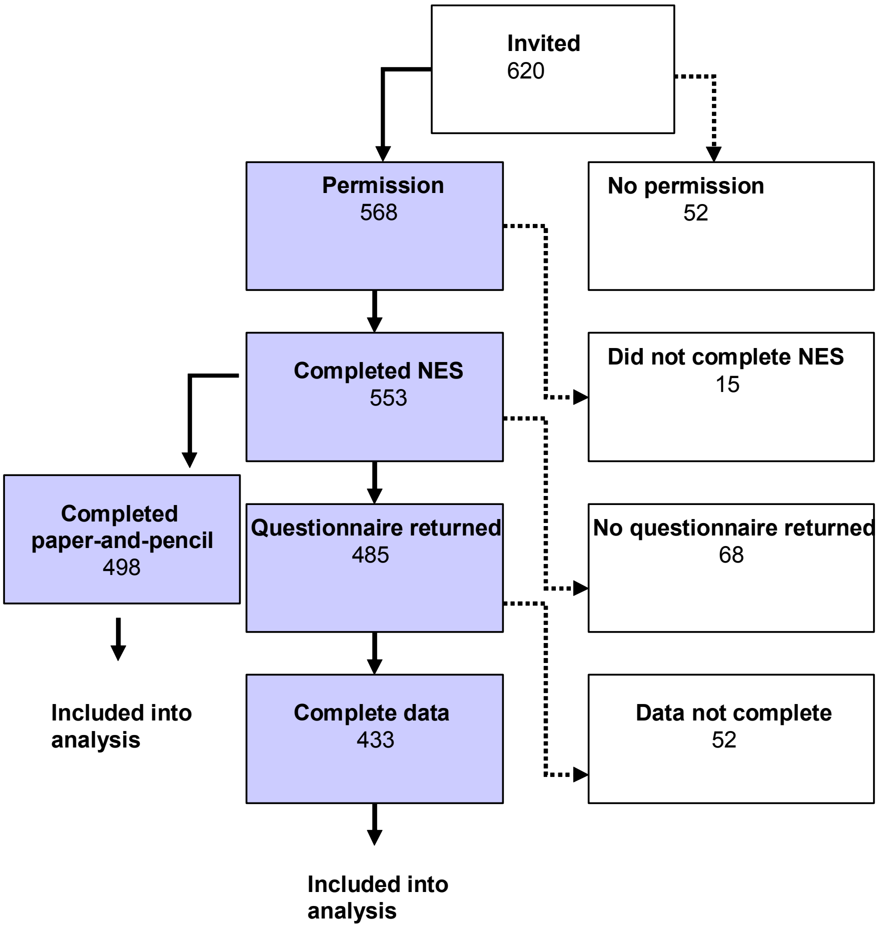

FIGURE 4.2 *Flowchart indicating the completeness of response and loss of information for the participating children.*

The schools were selected according to the modelled aircraft and road traffic noise exposure levels of the school area, and were matched on a neighbourhood-level indicator of property value and the percentage of non-western foreigners [17]. More than 80% of the children lived in a house that was owned by their parents; 44% of the houses had double glass. Nearly all parents of the children did paid work for at least 19 hrs per week. About 27% of the children suffered from a longstanding illness. Table 4.1 presents the most important characteristics of these children and the schools they visit.

TABLE 4.1 *Characteristics of the children that completed the NES and whose parents returned their questionnaire (n = 485) and the schools they visit (n = 24).*

	%	Mean +/- Std	Range[††]
Age (yrs)		10.5 +/- 0.6	8.8 – 12.8
Girls, %	48.8		
Socio-economic status			
Employed parents, %[*]	91.9		
Crowding in the home, % [†]	32.9		
Parental home ownership, %	81.4		
Mother's education (index 0 -1)[‡]		0.5 +/- 0.3	0.0 – 1.0
Health			
Long-standing illness, %[§]	27.7		
ADHD, %	1.9		
Dyslexia, %	3.5		
Main language at home is Dutch, %	93.4		
Parental support (scale 1-12)[#]		8.6 +/- 1.9	3 – 12
Glazing at school, %			
Single	47.8		
Double	49.5		
Triple	2.7		
Double glazing at home, %	55.6		
Modelled noise exposure ($L_{Aeq,\ 7\text{-}23\ hr}$) in dB(A)			
Aircraft noise at school		48.6 +/- 7.1[**]	36.3 – 62.8
Aircraft noise at home		48.1 +/- 7.1[**]	34.5 – 63.4
Road traffic noise at school		48.7 +/- 8.6[**]	34.0 – 62.0
Road traffic noise at home		50.2 +/- 7.3[**]	28.0 – 67.0

[*] Measure of the highest employment status in the child's household. At least one of the parents has to do paid work for at least 19 hrs per week; [†] this is an objective measure of the number of people per room at home. If the number of people is smaller or equal to the number of rooms than the child's household is defined as crowded; [‡] Mother's education was measured using a ranked index of standard qualifications. A relative index was then calculated for this variable in order to make comparisons between different measures in each country. The index ranges from 0 to 1, with higher number indicating low educational attainment; [§] based on parental reports of the child having either attention deficit hyperactivity disorder (ADHD), asthma/bronchitis, eczema, epilepsy, depression, diabetes or dyslexia; [#] parental support for school work is assessed by a self-report scale in the children's questionnaire; [**] presented are the arithmetic mean and corresponding standard deviation; [††] the range runs from the minimum value to the maximum value; abbreviations: Std: Standard deviation, n: sample size.

Procedures

Cognitive performance measured by the Neurobehavioral Evaluation System (NES)
The NES was administered in groups of eight children in a quiet room in school with the help of a personal computer and additional hardware (joystick/push button). The duration of the test was approximately 30 minutes. The following tests were included in the NES (see also Figure 4.1):

- *Simple Reaction Time Test (SRTT)*: In the Simple Reaction Time Test (SRTT) the subject was asked to press a button as quickly as possible when a red square appears on the screen. The inter-trial interval (2.5 – 5.0 sec) was varied randomly to reduce effects of stimulus adaptation. Individual reaction times (in ms) were recorded.
- *Switching Attention Test (SAT):* The Switching Attention Test (SAT) was meant to test the ability of the subject to switch rapidly between responses to simple two-choice visual discriminations based on changing verbal cues. The SAT consisted of a series of three different testing conditions. In the first testing condition ("Block") the subject was asked to respond to each of a series of large rectangles (which appeared on one side of the screen) presented in succession on the screen. The subject had to press the button on the corresponding side of the push button box as quickly as possible. In the second testing condition ("Arrow") the subject was asked to respond to a large arrow presented in the middle of the screen that points either to the left or to the right by pressing the left or right button on the button box as quickly as possible. In the third condition ("Switch") the word "Side" or "Direction" appeared immediately before each stimulus. The stimulus was an arrow pointing either to the left or to the right, presented on either the left or right side of the screen. The subject was asked to respond to each stimulus on the basis of response criterion signified by the word presented immediately before it on each trial. The response latency and the number of switching errors were recorded.
- *Hand –Eye-Coordination Test (HECT):* In the Hand-Eye Coordination Test (HECT) the subject is asked to use a joystick to trace over a sine wave/saw tooth pattern on the computer screen. A cursor moved horizontally at a constant velocity, while the subject controls the vertical motion of the cursor with the joystick. Deviations from the line were recorded and constitute a measure of co-ordination ability. Per trial, the vertical distance (pixels) of the cursor from the setline were sampled.
- *Symbol-Digit Substitution Test (SDST)*: The Symbol-Digit Substitution Test (SDST) is a test of perceptual coding and attention. In the SDST nine symbols and nine digits were paired at the top of the screen. The subject had to press the digit keys corresponding to a test set of the nine symbols scrambled. Test measure was the time required to complete each set divided by the number of correct responses.
- *Digit Memory Span Test:* In the Digit Memory Span Test (DMST) subjects were instructed to memorise a list of visually presented digits which were presented one by one on the computer screen at a rate of one per second. The starting list length was four digits long and using an “up-and-down” procedure the subject's task was memorise as long as possible sequences

and to show this by correctly pressing the relevant numbers on the keyboard. Performance was scored as the mean sequence length memorised over trials.

Table 4.2 presents the mean scores and standard deviations of the outcomes of the NES. In this table, outcomes from the feasibility study [18], conducted in 1997 are also included. Comparison showed that the differences between the two samples fall within the range of the 95% confidence intervals.

TABLE 4.2 *Mean scores and variability parameters of the different NES tests for the children whose parents returned their questionnaire (n = 485) in comparison with the results of Emmen et al. (1997) [18].*

Domain	Test/condition	RANCH				Emmen [18]
		Mean +/- Std	**Min**	**Max**	**Med**	**Mean +/- Std**
Attention	Simple Reaction Time	357 +/- 51	256	572	350	303 +/- 57
	Switching Attention					
	Fault-block (#)	0.87 +/- 1.02	0	5	1	1 +/- 1.25
	React. time-block (ms)	401 +/- 79	244	685	391	377 +/- 104
	Fault-arrow (#)	1.71 +/- 1.59	0	8	1	1.25 +/- 1.36
	React. time-switch (ms)	557 +/- 108	245	949	546	499 +/- 95
	Fault-switch (#)	10.52 +/- 5.70	0	27	10	10.11 +/- 5.89
	React. time-switch (ms)	693 +/- 147	247	1075	700	794 +/- 203
Locomotion	Hand Eye Coordination					
	Deviation (pixels)	1.76 +/- 0.43	0.77	3.13	1.77	1.97 +/- 0.32
Perceptual	Symbol Digit Substitution					
Coding	Latency	3.31 +/- 0.56	2.11	5.95	3.23	3.28 +/- 0.71
Memory	Digit Memory Span					
	Span-length	4.78 +/- 0.63	3.30	7.60	4.70	4.9 +/- 0.7

Abbreviations: #: number, ms: millisecond, Std: Standard deviation, Min: minimum value, Max: maximum value, Med: median.

Cognitive performance measured by paper-and-pencil tests

The paper-and-pencil tests were administered on a separate day, during a three hour testing session under exam conditions [17]. The following paper-and-pencil tests were administered (see also Figure 4.1): Reading comprehension was measured by the Cito Readability Index for Elementary and Special Education (CRIE) [22], which is a nationally standardised and normed test. In association with this test, prospective memory was measured by asking the children to write their initials in the margin when they reached two predefined points in the reading comprehension test. Episodic memory (recognition and recall) were assessed by a task adapted from the Child Memory Scale [23]. This task assessed time delayed cued recall and delayed recognition of two stories presented on a compact disc. Working memory was tested using a modified version of the Search and Memory test [24, 25]. Sustained attention was measured using the Toulouse Pieron Test [26]. A more detailed description of the administration of the paper-and-pencil tests in RANCH can be found elsewhere [17].

Noise exposure assessment

Noise exposure was assessed for each child by linking the school and home addresses to modelled aircraft and road traffic noise levels. The noise levels were calculated, in accordance with a standardised noise protocol, which provided a procedure for determining outdoor noise exposure. Modelled school aircraft noise levels (expressed in $L_{Aeq\ 7\text{-}23\ hrs}$) with a resolution of 250x250 meter grids were obtained from nationally available noise contours from the Dutch National Aerospace Laboratory (NLR) for the year 2001. These predicted the average noise exposure from 7 to 23 hrs for a period of one year. School road traffic noise levels (expressed in $L_{Aeq\ 7\text{-}23\ hrs}$) were estimated from modelled composite data from 2000 and 2001, with a resolution of 25x25 meter grids using national standard methods [27]. Table 4.1 shows that the aircraft noise levels ($L_{Aeq,\ 7\text{-}23hrs}$) to which the children were exposed at school ranged from 36 to 63 dB(A); aircraft noise levels at home ranged from 34 to 63 dB(A). Aircraft noise levels were comparable with road traffic noise levels. High correlations between home and school aircraft noise levels ($L_{Aeq,\ 7\text{-}23hrs}$) were found ($r > 0.9$). The correlation between home and school road traffic noise levels was moderate ($r \sim 0.6$).

Potential confounding variables

The children were also given a questionnaire to take home for their caregiver (preferably the mother) to complete. The questionnaire requested information on the health and behaviour of the child, noise sources heard at home and noise annoyance, and potential confounding factors such as glazing of the child's home, length of residency, indicators for socio-economic status, country of birth and the main language spoken at home. These variables were only available for those children whose parents also completed the questionnaire (N = 485), so parent participation served as a selection criterion for inclusion in analysis. Before data-collection, all procedures and materials were tested in a pilot study in October 2001.

Data-analysis

In order to investigate the reliability and the dimensionality of the cognitive tests a principal component analysis (PCA) was carried out on the scores of both the NES and the paper-and-pencil tests using SPSS for Windows (version 12.0.1). In PCA, linear combinations of the observations were found. Only components with Eigenvalues greater than 1 were included. To make the components more interpretable, a rotation with the Varimax method was performed resulting in components that are uncorrelated. However, at the basis of age, gender etc. one would expect a certain correlation between the components. As kind of sensitivity analysis an oblique rotation (with Delta = 0) was performed in addition to Varimax rotation, assuming that the resulting components may be correlated. Cronbach's alphas were calculated, to test how reliable the components were in terms of internal consistency. Only children that completed both the computerised and paper-and-pencil tests were included in this part of the analysis (N = 498).

To investigate the impact of aircraft and road traffic noise on cognitive performance (operationalised by the NES), multilevel analyses were carried out using the MIXED procedure of SAS version 8.1. Multilevel modelling takes into account the hierarchical structure of the data (children grouped within schools) and enables effects at both the level of school and pupil to be included in the same model. Two-level (pupil and school) random intercept models were used. Coefficients (B) and standard errors (SE) were estimated under restricted maximum likelihood estimation (REML). Only children with complete data (N=433) were included into the analysis. In all models, aircraft or road traffic noise exposure (at school or at home) was the main independent variable and was included as a continuous variable. The models included age (yrs), sex, main language spoken at home (Dutch/non-Dutch), long-standing illness (based on parental reports of the child having either ADHD, asthma/bronchitis, eczema, epilepsy, depression, diabetes or dyslexia), parental support for school work (assessed by a self-report scale in the children's questionnaire), school glazing (single, double or triple), indicators for socio-economic status (crowding, home ownership, parental employment and mother's education), and the other noise source as potential confounders. Statistical significance of a coefficient was tested under full maximum likelihood (ML) estimation, using a Chi-square test of deviance. Further analyses were conducted, excluding children whose parents have reported that they suffered from ADHD and/or dyslexia.

4.3 Results

Coherence between the two cognitive test batteries

Principal component analysis on the two cognitive test batteries with Varimax rotation shows that for the 17 items a 4-factor solution appeared to be the most appropriate (see also Table 4.3). The total percentage of variance explained by these factors is 52.7 %. Four components could be derived: The first component consists of end points referring to episodic memory and included recognition, information and conceptual recall. The second component refers to response speed and includes simple reaction time and the three reaction time parameters of the Switching Attention Test (SAT); the third component includes the fault conditions of the SAT. A fourth component includes working memory and sustained attention. The oblique rotation resulted in the same grouping of variables as the Varimax rotation. The interpretation of the components did not change. Table 4.3 shows the factor structure and Cronbach's alphas of the derived cognitive components.

TABLE 4.3 *Factor loading matrix (n = 498)*[*]*.*

Test battery	Item	Factor I	Factor II	Factor III	Factor IV
NES	SRTT	0.743			
	Block_RT	0.764			
	Arrow_RT	0.769			
	Switch_RT	0.618			
	Block_f			0.631	
	Arrow_f			0.757	
	Switch_f			0.632	
	SDST			0.369	
	DMST				0.492
	HECT	0.538			
PP	Conceptual recall		0.922		
	Information recall		0.918		
	Recognition		0.675		
	CRIE		0.458		
	Working memory				0.682
	Sustained attention				0.608
	Prospective memory				0.469

Factor	Interpretation	Variance explained	Alpha[†]
I	Response speed and locomotion	20.3	0.76
II	Episodic memory and reading comprehension	15.1	0.77
III	Switching attention (# faults) and perceptual coding	10.8	0.58
IV	Memory and attention	6.5	0.42
Total		**52.7**	

[*] Per item only the highest loadings were presented; [†] Cronbach's alpha (standardized), based on the items given in the factor loading matrix; this is a function of the item-inter-correlation and of the number of items included in the scale. Abbreviations: NES: Neurobehavioral Evaluation System; PP: Paper-and-pencil test; SRTT: Simple Reaction Time Test; Block_RT: Switching Attention Test, block condition, reaction time; Arrow_RT: Switching Attention Test, arrow condition, reaction time; Switch_RT: Switching Attention Test, switch condition, reaction time; Block_f: Switching Attention Test, block condition, number of faults; Arrow_f: Switching Attention Test, arrow condition, number of faults; Switch_f: Switching Attention Test, switch condition, number of faults; SDST: Symbol Digit Substitution Test; DMST: Digit Memory Span Test; HECT: Hand-Eye Coordination Test; CRIE: Cito Readability Index for Elementary and Special Education; n: sample size.

Effects of aircraft noise exposure on cognitive performance

Figure 4.3 shows the fully adjusted associations between aircraft noise exposure at school and at home and the different scores of the NES tests. In order to be able to present the outcomes of the multilevel analyses in one figure, Z-scores were computed. No clear patterns could be distinguished: reaction speed did not increase with the complexity of the task and accuracy decreased in relation to noise. Only in the difficult part of the SAT a significant effect was observed: The results of the multilevel analysis show a statistically significant relation between aircraft noise exposure at school and the number of faults for the Switch condition of the SAT (χ^2 = 4.7, df = 1, p = 0.03): an increase of 0.96 (95%CI: 0.04 – 1.89) faults was found as aircraft noise exposure increased 10 dB(A) (see also Table 4.4).

Potential confounders that had a significant effect on the score of the SAT were parental support (children who received more parental support made more faults in the block condition), sex (boys made more faults in the arrow condition), mother's education (children of parents with a lower level of education made more faults in the switching condition), and main language spoken at home (children whose main language at home was Dutch, made less faults during the switching condition). The effects of aircraft noise exposure on the SAT did not change after exclusion of children suffering from ADHD and/or dyslexia

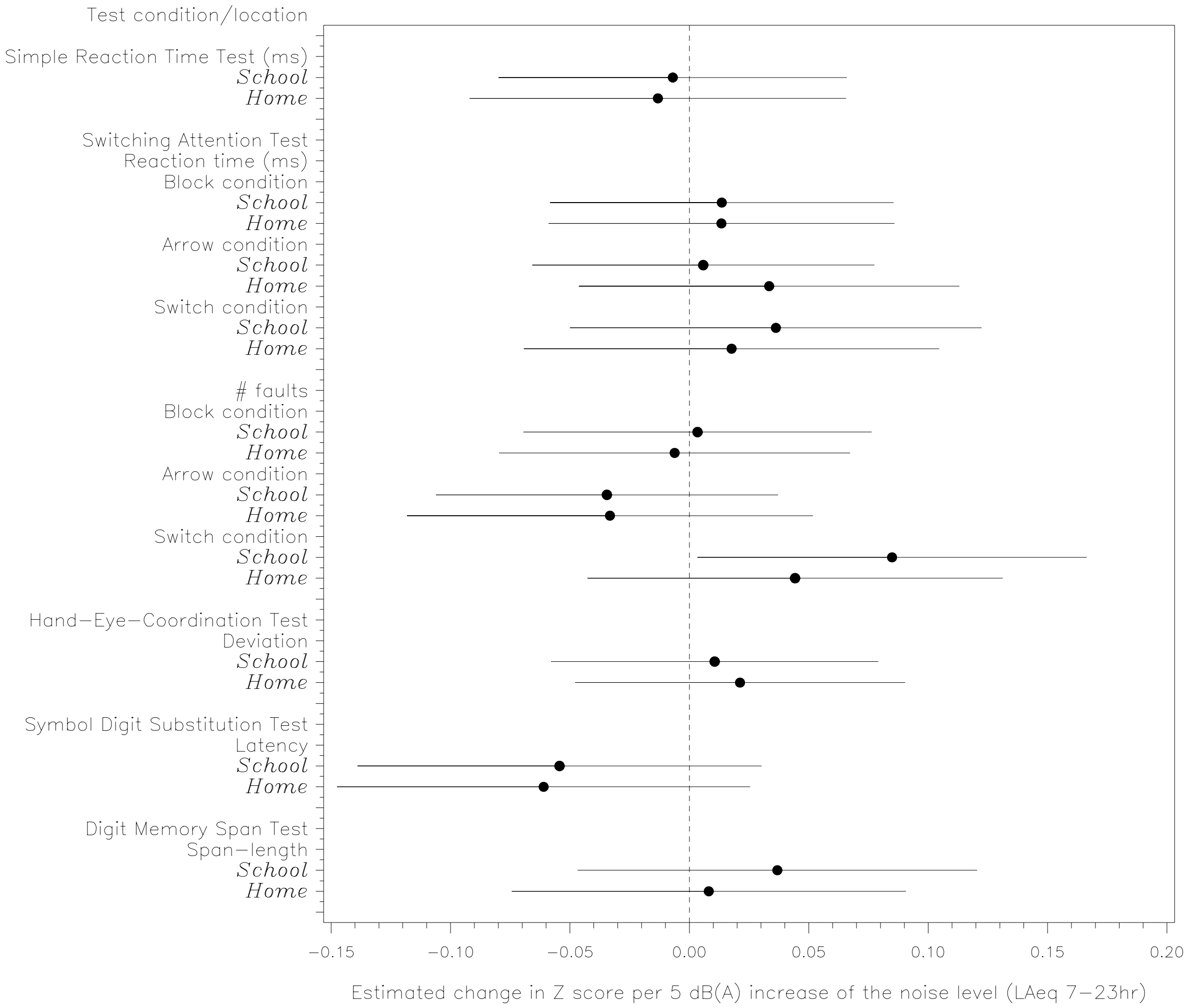

FIGURE 4.3 *The relation between aircraft noise exposure at school and at home ($L_{Aeq,\ 7\text{-}23hrs}$) and the scores of the different NES-tests, adjusted for road traffic noise exposure at school and/or at home, age, gender, socio-economic status, main language spoken at home, long-standing illness, parental support and classroom glazing or double glazing at home. The dotted vertical line corresponds to no effect of aircraft noise exposure. The circles correspond to the estimated change in Z-score per 5 dB(A) increase of the aircraft noise level and the horizontal lines correspond to the 95% CI.*

TABLE 4.4 *The fully adjusted multilevel models for noise exposure at school and at home and the Switching Attention Test (faults)*

Outcome →	**Block_f**		**Arrow_f**		**Switch_f**	
	B (SE)	**B(SE)**	**B (SE)**	**B (SE)**	**B (SE)**	**B (SE)**
Fixed coefficients ↓						
Intercept	1.713 (1.008)	1.687 (0.986)	2.604 (1.574)	2.848 (1.645)	10.098 (5.946)	11.725 (5.737)
Aircraft noise at school	0.001 (0.008)		-0.011 (0.012)		0.097 (0.047)*	
Road traffic noise at school	0.000 (0.006)		0.026 (0.010)*		0.057 (0.039)	
Aircraft noise at home		-0.001 (0.008)		-0.011 (0.014)		0.050 (0.046)
Road traffic noise at home		0.000 (0.007)		0.005 (0.012)		0.058 (0.042)
Age (yrs)	-0.176 (0.093)	-0.154 (0.092)	-0.170 (0.146)	-0.065 (0.150)	-0.515 (0.536)	-0.462 (0.531)
Boys	0.157 (0.099)	0.158 (0.099)	0.398 (0.154)*	0.388 (0.156)*	0.438 (0.556)	0.435 (0.560)
Employed	0.031 (0.186)	-0.014 (0.191)	-0.549 (0.290)	-0.532 (0.300)	-0.188 (1.045)	-0.183 (1.078)
Crowded	-0.175 (0.105)	-0.179 (0.106)	-0.095 (0.164)	-0.103 (0.167)	-0.421 (0.593)	-0.441 (0.600)
Home owner	0.008 (0.130)	-0.004 (0.132)	0.082 (0.203)	0.077 (0.210)	0.749 (0.743)	0.588 (0.750)
Mother’s education	0.094 (0.182)	0.100 (0.184)	0.247 (0.285)	0.202 (0.291)	2.176 (1.033)*	2.187 (1.042)*
Main language is Dutch	0.120 (0.236)	0.123 (0.233)	0.003 (0.368)	-0.065 (0.384)	-2.849 (1.368)*	-2.395 (1.350)
Long-standing illness	0.118 (0.110)	0.116 (0.111)	0.082 (0.172)	0.077 (0.174)	0.624 (0.620)	0.720 (0.626)
Parental support	0.071 (0.026)*	0.071 (0.027)*	-0.006 (0.041)	0.003 (0.042)	-0.195 (0.148)	-0.176 (0.150)
Classroom glazing						
Single	0.089 (0.308)		0.237 (0.481)		1.167 (1.815)	
Double	0.125 (0.308)		0.430 (0.481)		0.735 (1.812)	
Triple	*Ref*		*Ref*		*Ref*	
Double glazing at home		0.020 (0.098)		0.000 (0.156)		0.737 (0.559)
Random Parameters						
Level 2: School	0.000	0.000	0.000	0.0542	0.450	0.305
Level 1: Pupil	1.003	1.009	2.445	2.467	31.660	32.069

B: Estimated change in the test score per dB(A); SE: Standard Error; N: sample size; Block_f : Switching Attention Test, block condition, number of faults; Arrow_f : Switching Attention Test, arrow condition, number of faults; Switch_f : Switching Attention Test, switch condition, number of faults.

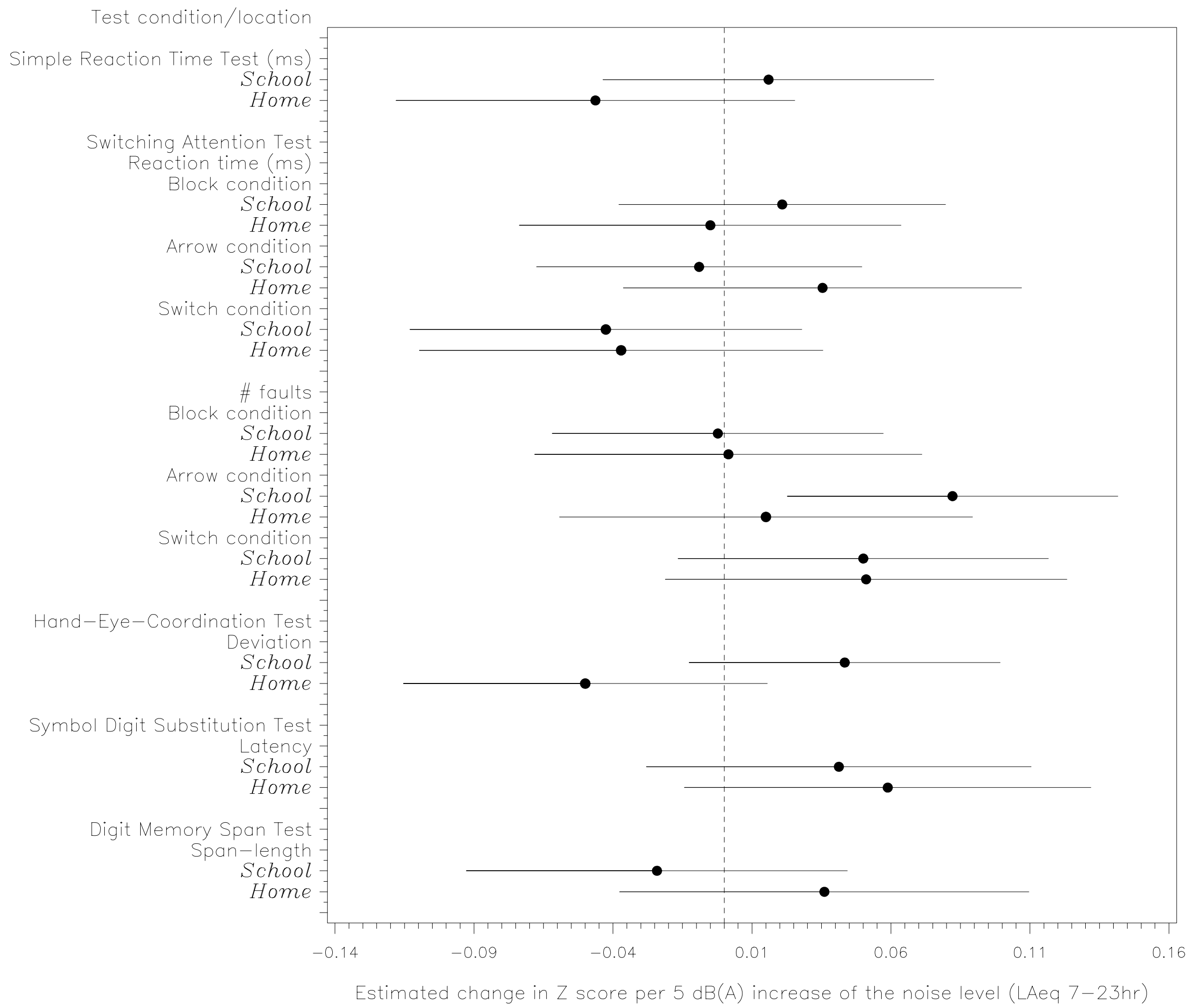

FIGURE 4.4 The relation between road traffic noise exposure at school and at home ($L_{Aeq,\ 7\text{-}23hrs}$) and the scores of the NES-tests, adjusted for aircraft noise exposure at school and/or at home, age, sex, socio-economic status, main language spoken at home, long-standing illness, parental support and classroom glazing or double glazing at home. The dotted vertical line corresponds to no effect of road traffic noise exposure. The circles correspond to the estimated change in Z-score per 5 dB(A) increase of the road traffic noise level and the horizontal lines correspond to the 95% CI.

The effects of road traffic noise exposure on cognitive performance

Figure 4.4 shows the fully adjusted associations between road traffic noise exposure at school and at home and the different scores of the NES tests. Looking at the figure, no patterns could be distinguished. Only the relation between road traffic noise at school and the number of faults during the Arrow-condition of the SAT was statistically significant (χ^2 = 8.2, df=1, p=0.004). A 10 dB(A) increase in road traffic noise at school resulted in an increase of 0.27 (95%CI: 0.08 – 0.46) faults (see also Table 4.4).

4.4 Discussion

In this study investigating the neurobehavioural effects of road traffic and aircraft noise exposure in 553 primary schoolchildren living around Schiphol Amsterdam Airport, effects of school noise exposure were observed in the more difficult parts of the Switching Attention Test (SAT): children attending schools with higher road or aircraft noise levels made more faults. This is in agreement with the results of recent other studies investigating the effects of transportation noise exposure at school on children's cognitive functioning. In the Munich Airport Study (MAS), Evans and colleagues (1995) found that children from noise exposed communities had more errors on a difficult subscale of a German standardised reading test than children from quiet communities; the two groups did not differ on the easy and intermediate portions of the test [9]. Meis and colleagues (1998) found similar adverse impacts on more complex memory tasks after comparing simulated and actual aircraft noise exposure in the lab and in the field [28]. In the West London Schools Study (WLSS) no significant difference on the score of the reading comprehension test was found between children in the noise and quiet groups. However, when the 15 most difficult items of the reading test were analysed separately, a significant difference was found between the two noise exposure conditions [29]. From this study and previous scientific literature it can be concluded that performance on simple tasks is less susceptible to the effects of noise than performance on more complex tasks [30], requesting increased mental performance.

Speed-accuracy

The descriptive results of the SAT (Table 4.2) indicate that response latency increased with the complexity of the task, while accuracy decreased. It was expected that with increasing noise levels accuracy decreased, assuming that the cognitive effects of noise may be the result of changed information strategies leading to faster processing of information, at the expense of the flexibility and efficiency of cognitive resources [8]. However, in our study, reaction speed did not increase with the complexity of the task while accuracy decreased in relation to noise. The findings in the literature are not consistent.

Neurobehavioral Evaluation System

By combining the NES with paper-and-pencil tests, we were able to investigate the external validity of the NES. Compared to the paper-and-pencil tests, the coherence between the different NES tests was relatively high: Two interpretable components could be derived. This supports the structure of the association between the separate NES-tests. From our results it can be concluded that the tests of the NES can complement the paper-and-pencil tests when investigating the effects of noise on children's cognitive functioning: in addition to the paper-and-pencil tests, the tests of the NES measure some different aspects of attention: response speed and switching attention.

In comparison with the paper-and-pencil tests, the NES offers some advantages: (i) it is a standardised method that gives test-leader independent results; during the test there is a minimal interaction between the test administrator and the child. This minimises observer bias and the results are not influenced by the observer's attention; (ii) data collection by means of the NES is highly efficient: both the administration, data handling and reporting of results are easy. As a consequence the sample size can be increased more easily, thus allowing for better modelling of covariates, reduction of sampling bias and increase of statistical power; (iii) the presentation of the test material is rather consistent and responses are exactly timed; furthermore, (iv) the computerised performance tests were well-accepted by the children; the game character of the tests usually stimulates motivation [31].

Location of exposure: school versus home

Our study found an effect of noise exposure at school on the SAT. No effects of home noise exposure were found. It is possible that exposure at school or home differently affected the outcomes of the SAT. In addition, it is possible that exposure to noise at home may have affected the outcomes of the tests by interacting with exposure at school. Such effects were already found in relation to annoyance where analyses indicated a carry-over effect: children in high aircraft noise areas report more annoyance from aircraft noise in high road traffic noise areas than children in low road traffic noise areas and *vice versa* [32]. Unfortunately, these hypotheses can not be further investigated on the data available in the RANCH study, because of the substantial co-linearity between school and home noise exposure. And since the main objective of RANCH was to investigate the effects of noise exposure at school on children's cognition, noise exposure at home was not taken into account during the selection.

Strengths and limitations

This study represents an improvement on previous studies due to its comprehensive inclusion of potential confounders and determinants. The hierarchical structure of the data (children within schools) has been taken into account, which was not the case in analyses of previous studies. The participants were distributed over a broad noise exposure range, and a continuous noise exposure measure was used in the statistical analysis, adding to the statistical power of the study. Most studies investigating the impact of noise exposure have involved between-group comparisons (high versus low): results of these studies may be sensitive to exposure misclassification. The current study investigated the effects of both school and home noise exposure. Due to the high correlation between the noise metrics it was not possible to disentangle the effects of school and home noise exposure. Another limitation of the study is its design. Furthermore, the estimation of exposure to road traffic noise remains problematic: During their time at school, road traffic noise exposure changes as children move to a different classroom each year. Thus, the road traffic noise levels at the façade of their current classroom might not reflect the average level of exposure during their time at school. An additional problem is that road traffic noise exposure is less uniformly distributed across classrooms as air traffic noise.

Interpretation of the results

In this study statistically significant associations were observed between aircraft and road traffic noise exposure at school ($L_{Aeq,\ 7\text{-}23hrs}$) and the number of faults made during the SAT. However, it is difficult to indicate what these effects mean. The elevations in the number of faults found in relation to noise exposure were small and the clinical significance of such minor changes is difficult to determine: there is insufficient specificity to employ the neurobehavioural tests to diagnose (neurotoxic) disorders in individuals [33]. Findings could be due to chance.

Due to the cross-sectional design of this study, it is unknown whether the neurobehavioural effects of noise are reversible if exposure to noise ceases; in the Munich Airport Study differences in reading score between the two exposure groups disappeared after removing the differences in noise exposure [10]. The individual tests that are included into the NES reflect the concerted action of many neurobehavioural mechanisms or brain systems affected [34]. It can be concluded that in addition to cognition (having to do with the ability to think and reason), neurobehavioral components (having to do with the way the brain affects emotion, behaviour and learning) play also a role in the relationship with noise.

4.5 Conclusions

On the basis of these analyses the authors conclude that neurobehavioural tests can complement paper-and-pencil tests when investigating the effects of noise on children's cognitive functioning. Factor analysis demonstrated that, in addition to commonly used paper-and-pencil tests, neurobehavioural tests measure some different aspects of attention: response speed and switching attention. Effects of school noise exposure were observed in the more difficult parts of the SAT. Based on this study and previous scientific literature it can be concluded that performance on simple tasks is less susceptible to the effects of noise than performance on more complex tasks. It is not possible to draw definite conclusions about the relative importance of noise exposure at home and at school and possible interactions.

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5 The role of annoyance in the relation between transportation noise and children's health and cognition

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ABSTRACT
On the basis of our findings it cannot be ruled out that the appraisal of the noise affects the association between aircraft-and road traffic noise exposure and children's health and cognition. However, our conclusion is limited due to the relatively small group of annoyed children, which may have influenced our group comparisons. Furthermore, the observed relation between annoyance and perceived health is possibly biased due to the fact that both were measured within the same questionnaire.

These are the main conclusions of a cross-sectional multi-centre study carried out among 2,844 schoolchildren (age 9-11 years) attending 89 primary schools around three European airports. The aim was to investigate how annoyance affects the relation between aircraft and road traffic noise exposure and children's health and cognition. Different, sometimes competing, working mechanisms of how noise affects children's health are suggested. Some effects are supposed to be precipitated through (chronic) stress, while others may arise directly. There is still no theory that can adequately account for the circumstances in which noise will affect cognitive performance.

5.1 Introduction

Transportation is responsible for a large and growing proportion of environmental and health effects in Europe – despite the major improvements that have been made in vehicle technologies. Approximately 30% of the European Union's population is exposed to levels of road traffic noise of more than 55 dB(A) [1].

Long-term noise exposure is associated with a number of effects on health and well-being [1]. It is assumed that noise acts as a stressor and as such has the potential of facilitating diseases which are partly caused by stress as a co-factor [2]. Children could be particularly vulnerable to the effects of noise because they have less capacity to anticipate, understand and cope with stressors [3].

At the moment, different, sometimes competing, working mechanisms of how noise affects children's health are suggested [1, 25, 37]. Some effects are supposed to be precipitated through (chronic) stress, while others may arise directly. Another problem is that previous studies investigating the effects of noise exposure on children, have not substantially investigated the underlying mechanisms by which noise can affect children's cognitive functioning. As a consequence there is still no theory that can adequately account for the circumstances in which noise will affect cognitive performance.

Appraisal can be considered as a process in which a person determines whether a situation poses a threat, challenge or potential harm or loss, on the basis of which they choose a response strategy to deal with the situation. In former research investigating adults, the appraisal of the stressor was found to be one of the essential factors predicting short- and long-term health effects of exposure to repetitive daily chronic stressors such as environmental noise [7]. It is unknown how this operates for children's health and cognition in relation to noise. An indicator that is often used for the appraisal of noise by adults is annoyance. Previous reported results make clear that annoyance in children pertains to the same construct as in adults: by means of a factor analysis including annoyance and interference of activities due to aircraft and road traffic noise, and subjective health symptoms, we demonstrated that interference and annoyance were highly related whilst perceived health formed a separate dimension [8]. And as in adults, noise exposure was related to a significant increase of the percentage annoyed children. The assumption is that a negative appraisal is manifest in a high annoyance score [7].

Aim

The aim of the current analysis is to find out whether annoyance might have played a role in the association between noise and cognitive functioning and health, using data collected in the framework of the European 5th Framework RANCH project (Road traffic and Aircraft Noise exposure and Children's cognition and Health). To reduce the risk of overestimating the true association with noise, children's health was operationalised by means of a subjective and an objective indicator of health:

perceived health as measured by a symptom list, and resting blood pressure measured as part of a physical examination. Cognitive functioning was measured by means of a selection of computerised neurobehavioural tests from the Neurobehavioral Evaluation System (NES) [9]. Our objectives were (i) to investigate the relation between aircraft and road traffic noise and perceived health; (ii) to investigate whether annoyance is an intermediate step in the relation between noise and cognitive functioning and health; (iii) to investigate whether annoyance confounds the association between noise and cognitive functioning and health; and (iv) to investigate whether the relation between noise and health and cognitive functioning differs between different annoyance groups (interaction effect). Recently, an inconsistent association between aircraft noise and children's blood pressure was already reported and a negative association with road traffic noise was found [6]. With regard to cognition, effects of noise exposure were only observed in the more difficult and demanding parts of the Switching Attention Test (SAT) [10]. The relation between aircraft noise and perceived health has not been reported yet.

5.2 Methods

Selection and recruitment

Children aged 9-11 years were recruited from primary schools in areas around Heathrow Airport (London, UK), Schiphol Airport (Amsterdam, The Netherlands) and Madrid-Barajas Airport (Spain). Schools were selected according to the modelled aircraft and road traffic noise exposure of the school area (expressed as $L_{Aeq,\ 7\text{-}23hrs}$), and were matched on indicators of socio-economic status (SES) and ethnicity. Out of 767 primary schools available in the three study areas, 134 were invited to participate and 89 agreed. Subsequently, the parents or caregivers of 3,207 children were approached through the schools by letter to give consent for their children to participate. Written consent was also obtained from the children. The final sample contained 2,844 children. For further details of selection and recruitment, see Stansfeld *et al.*, 2005 [3].

Procedure

The children completed a self-administered questionnaire as part of a two-hour group testing session. Blood pressure was measured in the United Kingdom and The Netherlands only (N = 1,283), in groups of 4-6 children in a quiet room in the school building during the afternoon. The NES was administered in The Netherlands only (N = 553), in groups of eight children in a quiet room in school with the help of a personal computer and additional hardware (joystick/push button). The duration of the test was approximately 30 minutes. The children of all three participating centres were also given a questionnaire to take home for their mother (preferably) or other caregiver to complete. The questionnaire requested information on health and behaviour of the child, noise annoyance, and potential confounding factors such as glazing, length of residency, country of birth, socio-economic factors such as home ownership, crowding, and the language primarily spoken at home. These variables were only available for those children whose parents also completed their questionnaire, so parents' participation served as a selection criterion for inclusion in the data-analysis. Table 5.1 indicates which questionnaires and tests were administered in the different participating centres.

TABLE 5.1 *Overview of instruments used and end-points measured in the different samples of RANCH*

Instrument	End point	United Kingdom	The Netherlands	Spain
Child's questionnaire	Perceived health	+	+	+
	Annoyance	+	+	+
Physical examination	Blood pressure	+	+	
NES	Neurobehavioural functioning		+	
Parent's questionnaire	Confounding factors	+	+	+

+: instrument is applied; NES: Neurobehavioral Evaluation System

Noise exposure assessment

In all centres, chronic aircraft noise levels ($L_{Aeq\ 7\text{-}23\ hrs}$) at school were obtained from nationally available noise contours. These predict the average noise exposure during a specified time interval for a specified period. In The Netherlands, modelled aircraft noise levels for the year 2001 were obtained from the Dutch National Aerospace Laboratory (NLR) [11]. In the UK, modelled aircraft noise levels for the year 2000 were based on the 16hr outdoor LAeq contours provided by the Civil Aviation Authority (CAA) for a three month period (July-September). In Spain, modelled aircraft noise levels were based on the 16-hour outdoor LAeq contours for a three month period (July-September) of 1999 provided by the Spanish Airports and Air Navigation.

Outdoor road traffic noise levels at school were measured in $L_{Aeq\ 7\text{-}23\ hrs}$. In the UK, school road traffic noise levels were estimated from a combination of data regarding proximity to motorways, major roads, minor roads and traffic flow [12]. In Spain, direct external measurements were taken of road noise during school visits. Taking into account factors such as traffic flows, speed limitations, distance to the street, these were transformed into 7-23h LAeq-values. In The Netherlands, modelled composite data from 2000 and 2001 adopted from national standard methods, with a resolution of 25x25 meter grids, were linked to school addresses using a Geographic Information System (GIS) [11].

Perceived health

The child's perceived health was operationalised by means of a list of self-reported health symptoms. As part of a self-administered questionnaire, we asked the children how often they had each of the following symptoms: headache, vomiting, stomachache, difficulty falling asleep, and the number of times woken at night or feeling sleepy during the day. Answers were indicated on a 5-point category scale (*'never, a few times, once a week, a few times a week, every day or night'*). Psychometric results justify the use of a simple sum-score of these items [8]. When participants answered that they suffered at least once a week from headache, vomiting, stomachache, difficulty falling asleep, or were woken at night or felt sleepy during the day, this was scored as a "symptom". Subsequently, for every child the total number of "symptoms" was counted.

Annoyance

Annoyance at school was measured as part of a self-administered child questionnaire by means of a standard question '*Thinking about the last year, when you were at school, how much does the noise from [aircraft][road traffic] bother, disturb or annoy you ?*' The participants had to indicate their answers on a 5-point category scale ('*not at all, a little, quite a bit, very much, extremely*'). Children indicating that they were 'quite a bit', 'very much' or 'extremely annoyed' were defined as being annoyed.

Blood pressure and physical measurements

Blood pressure measurements were taken in the afternoon in a quiet room in the school building using automatic blood pressure meters (OMRON 711, OMNILABO International BV). While the child was seated, trained researchers measured systolic and diastolic blood pressure and heart rate three times with 1-2 minutes intervals; additionally, they measured height and body weight without shoes or heavy clothing. In the data analysis the mean value of the three blood pressure measurements was used. For further details of the blood pressure measurement, see Van Kempen *et al.*, 2006 [6].

Neurobehavioral Evaluation System (NES)

We selected the following tests from the NES [9]: the Simple Reaction Time Test (SRTT) measured individual reaction times (ms); the Switching Attention Test (SAT) measured the child's ability to switch rapidly between responses. Coordination was tested by means of the Hand-Eye Coordination Test (HECT); The Symbol Digit Substitution Test (SDST) is a test of perceptual coding and attention. During the Digit Memory Span Test (DMST) the subject's task was to memorise as long as possible sequences. For further details of these tests, see also Letz (1991) [9].

Data analysis

Before running the analyses, the residuals were checked for outliers. Missing values were few, except for parental hypertension (11%) and cuff size (9%). Missing cuff sizes were imputed as small. To produce effects on health and cognition, noise may have to be present for a certain length of time. Therefore, only those children who attended their present school for at least 1 year were included in the analyses.

To take into account the hierarchical structure of the data, multilevel analyses were carried out using the MIXED procedure of SAS version 9.1. Multilevel modelling enables data at both the school and the child level to be included in the same model. A two-level random effects model was used, and country was included as a fixed effect. The multilevel analyses yielded regression-coefficients (B), reflecting the estimated change in blood pressure (mmHg), the change in the number of symptoms or the change in the scores on one of the NES tests per 1 dB(A) change in noise exposure, and standard errors (SE). These were estimated under restricted maximum likelihood estimation. The 95% confidence intervals (95%CI) were calculated by means of the estimated standard errors. Statistical significance was tested under full maximum likelihood estimation, using a chi-square test of deviance. We examined four models with each of the five dependant variables (see also Table 5.2): The first model contained noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) (either aircraft or road traffic noise exposure at school), age (yrs), sex and country; the second model was the same as the first model with the addition of indicators for socio-economic status (crowding in the home, parental home ownership, parental employment status and mother's educational attainment), ethnicity (white/non-white), aircraft or road traffic noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school and a number of outcome-specific confounding variables. The outcome-specific variables were chosen according to the literature, supplemented with variables which appeared to be significantly associated with the outcome or noise. The outcome-specific variables for systolic and diastolic blood pressure were: ponderosity (weight/height ^{3}), cuff-size (small, normal), room temperature (°C), birth weight (< 2500 gr./ ≥ 2500 gr.), parental hypertension (yes/no), prematurity (born before week 36); for perceived health this was long-standing illness (yes/no). Outcome-specific variables with regard to neurobehavioural functioning were: main language spoken at home (child spoke the predominant language for the country at home English, Dutch or Spanish), long-standing illness (y/n) and parental support (assessed by a self-report scale completed by the child). Confounding (see also model 3, Table 5.2) was tested by investigating how the relationship between aircraft or road traffic noise at school and the outcome changed after including annoyance (yes/no) into the model. Differences in the relation between aircraft or road traffic noise at school and health and cognition between the group of children who were not annoyed and the group of children who were annoyed, were tested by examining the interaction between noise at school and annoyance (yes/no) (model 4). Heterogeneity between the countries was tested in the models on the pooled data by examining the interaction between country and noise exposure.

TABLE 5.2 *Overview of the models that were examined*

Model	**Variables included in the model**
1	noise at school + age + sex + country
2	noise at school + age + sex + country + SES + outcome-specific variables
3	noise at school + age + sex + country + SES + outcome-specific variables + annoyance
4	noise at school + age + sex + country + SES + outcome-specific variables + annoyance + (annoyance x noise at school)

SES: Socio-economic status

5.3 Results

Descriptive results

Table 5.3 presents general characteristics of the children and the schools they attended. The children in the British sample had a higher prevalence of annoyance due to aircraft noise at school (32.1 %) than the Dutch (18.5 %) and Spanish (18.0%) samples. There were differences between the samples in terms of parental employment status, home ownership, and crowding in the home.

Noise, health and neurobehavioural functioning

The results of the multilevel analysis (Table 5.4) indicate that aircraft noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school was not statistically significantly related to an increase in the number of symptoms ($\chi^2 = 0.3$, df = 1, p = 0.58). There were no differences between the effect sizes for each country (test of heterogeneity: $\chi^2 = 3.4$, df = 2, p = 0.18). The association between aircraft noise exposure and perceived health did not change after additional adjustment for annoyance. Similar results were found for road traffic noise exposure at school (see also Table 5.5). The results of the multilevel analyses (Tables 5.4 and 5.5) showed that the association between aircraft and road traffic noise and blood pressure hardly changed after additional adjustment for annoyance; this was also the case with regard to neurobehavioural functioning.

Annoyance, health and neurobehavioural functioning

Figure 5.1 displays that children who were annoyed due to aircraft noise at school reported significantly more symptoms compared to children that were not annoyed ($\chi^2 = 47.9$, df = 1, p < 0.0001). Similar results were found for road traffic noise at school: children who were annoyed due to road traffic noise at school reported significantly more symptoms compared to children that were not annoyed ($\chi^2 = 53.3$, df = 1, p < 0.0001).

Children who reported annoyance due to aircraft or road traffic noise at school had a lower systolic and diastolic blood pressure compared to children that reported no annoyance. Only the association between annoyance due to aircraft noise and diastolic blood pressure was statistically significant ($\chi^2 = 4.6$, df = 1, p = 0.03) (see also Figure 5.1).

TABLE 5.3 *Characteristics of the schools (N = 89) and of the participating children visiting their school for at least 1 year.*

Characteristic	UK (*N* = 903)	The Netherlands (*N* = 645)	Spain (*N* = 598)
Number of participating schools	29	33	27
Boys, %	45.5	49.7	47.8
Mean age (SD)	10.2 (0.3)	10.5 (0.6)	10.9 (0.4)
Socio-economic status			
Crowding in the home, %	22.4	31.1	9.6
Parental home ownership, %	58.8	81.6	85.3
Employed parents, %	78.4	92.6	90.0
Mean mother's education (SD)*	0.50 (0.28)	0.50 (0.29)	0.50 (0.29)
White British/Dutch/Spanish, %	65.0	89.3	91.0
Mean blood pressure (mmHg) (SD)			
Systolic blood pressure	108.5 (9.6)	105.1 (10.8)	-
Diastolic blood pressure	67.3 (7.7)	65.5 (8.6)	-
At least 3 symptoms, %	18.6	11.9	11.7
Long-standing illness, %	27.1	26.2	18.7
Annoyance, %			
Aircraft noise at school	32.1	18.1	18.0
Road traffic noise at school	23.3	14.4	15.5
Mean modelled noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) levels, dB(A) (range)†			
Aircraft noise at school	53.1 (34 – 68)	49.7 (36.3 – 62.8)	46.2 (30 – 77)
Road traffic noise at school	50.7 (37 – 67)	49.3 (34 – 62)	54.1 (43 – 71)
School glazing, %			
Single	52.5	43.6	72.6
Mixed	9.1	-	-
Double	38.4	47.6	27.4
Triple	-	8.8	-

* Ranked index of standard qualification in every country. † The range runs from the minimum value to the maximum value. ‡ Abbreviations: N: sample size; SD: Standard deviation; %: percentage; $L_{Aeq,\ 7\text{-}23hrs}$: Equivalent noise level from 7 to 23 hrs.

TABLE 5.4 *The association between aircraft noise ($L_{Aeq,\ 7\text{-}23hrs}$) at school and perceived health, blood pressure and neurobehavioural functioning in children visiting their school for at least 1 year, after adjustment for confounders*

Outcome	**Model 1**		**Model 2**		**Model 3**	
	B (SE)	**p**	**B (SE)**	**p**	**B (SE)**	**P**
Perceived health						
# symptoms	0.000 (0.004)	1.00	0.002 (0.004)	0.58	-0.006 (0.004)	0.22
Blood pressure (mmHg)						
Systolic blood pressure	0.120 (0.052)	*0.02*	0.076 (0.051)	0.11	0.097 (0.052)	*0.05*
Diastolic blood pressure	0.078 (0.041)	0.06	0.048 (0.045)	0.25	0.070 (0.047)	0.11
Simple Reaction Time Test (ms)	-0.132 (0.420)	0.75	-0.060 (0.405)	1.00	-0.112 (0.414)	0.75
Switching Attention Test						
Reaction time (ms)						
Block condition	0.097 (0.550)	0.75	0.193 (0.592)	0.75	0.237 (0.609)	0.66
Arrow condition	0.920 (0.756)	0.22	1.190 (0.809)	0.14	1.146 (0.831)	0.16
Switch condition	0.274 (1.341)	0.75	1.053 (1.307)	0.33	1.166 (1.343)	0.32
# faults						
Block condition	0.000 (0.007)	1.00	-0.000 (0.008)	1.00	0.001 (0.008)	1.00
Arrow condition	-0.004 (0.012)	0.75	-0.011 (0.012)	0.37	-0.009 (0.012)	0.48
Switch condition	0.079 (0.046)	0.08	0.088 (0.048)	*0.05*	0.066 (0.049)	0.16
Hand-Eye-Coordination test						
Deviation	0.002 (0.003)	0.53	0.001 (0.003)	0.66	0.000 (0.003)	1.00
Symbol Digit Substitution Test						
Latency	-0.005 (0.005)	0.27	-0.007 (0.005)	0.12	-0.007 (0.005)	0.15
Digit Memory Span Test						
Span-Length	0.002 (0.005)	0.66	0.004 (0.005)	0.40	0.007 (0.005)	0.19

Abbreviations: B: the estimated change per 1 dB(A) increase of the noise level; SE: Standard Error; p: p-value. Significance was tested at $\alpha = 0.05$

TABLE 5.5 *The association between road traffic noise ($L_{Aeq,\ 7\text{-}23hrs}$) at school and perceived health, blood pressure and neurobehavioural functioning in children visiting their school for at least 1 year, after adjustment for confounders*

Outcome	**Model 1**		**Model 2**		**Model 3**	
	B (SE)	**p**	**B (SE)**	**p**	**B (SE)**	**P**
Perceived health						
# symptoms	0.005 (0.005)	0.37	0.005 (0.005)	0.37	0.001 (0.005)	1.00
Blood pressure (mmHg)						
Systolic blood pressure	-0.081 (0.056)	0.14	-0.100 (0.051)	*0.05*	-0.091 (0.052)	0.06
Diastolic blood pressure	-0.023 (0.045)	0.65	-0.036 (0.046)	0.40	-0.033 (0.047)	0.44
Simple Reaction Time Test (ms)	-0.065 (0.348)	0.75	0.049 (0.331)	1.00	0.045 (0.332)	0.75
Switching Attention Test						
Reaction time (ms)						
Block condition	0.218 (0.453)	0.58	0.299 (0.482)	0.53	0.298 (0.483)	0.53
Arrow condition	-0.480 (0.627)	0.44	-0.395 (0.659)	0.53	-0.428 (0.659)	0.53
Switch condition	-1.596 (1.055)	0.12	-1.434 (1.071)	0.13	-1.420 (1.074)	0.14
# faults						
Block condition	0.002 (0.006)	0.75	-0.000 (0.006)	1.00	-0.000 (0.006)	1.00
Arrow condition	0.025 (0.009)	0.01	0.025 (0.010)	0.01	0.025 (0.010)	0.01
Switch condition	0.044 (0.038)	0.22	0.053 (0.039)	0.12	0.051 (0.039)	0.13
Hand-Eye-Coordination test						
Deviation	0.004 (0.002)	0.13	0.003 (0.002)	0.17	0.003 (0.002)	0.18
Symbol Digit Substitution Test						
Latency	0.002 (0.004)	0.58	0.004 (0.004)	0.25	0.004 (0.004)	0.27
Digit Memory Span Test						
Span-Length	-0.003 (0.004)	0.48	-0.004 (0.004)	0.32	-0.004 (0.004)	0.37

Abbreviations: B: the estimated change per 1 dB(A) increase of the noise level; SE: Standard Error; p: p-value. Significance was tested at α = 0

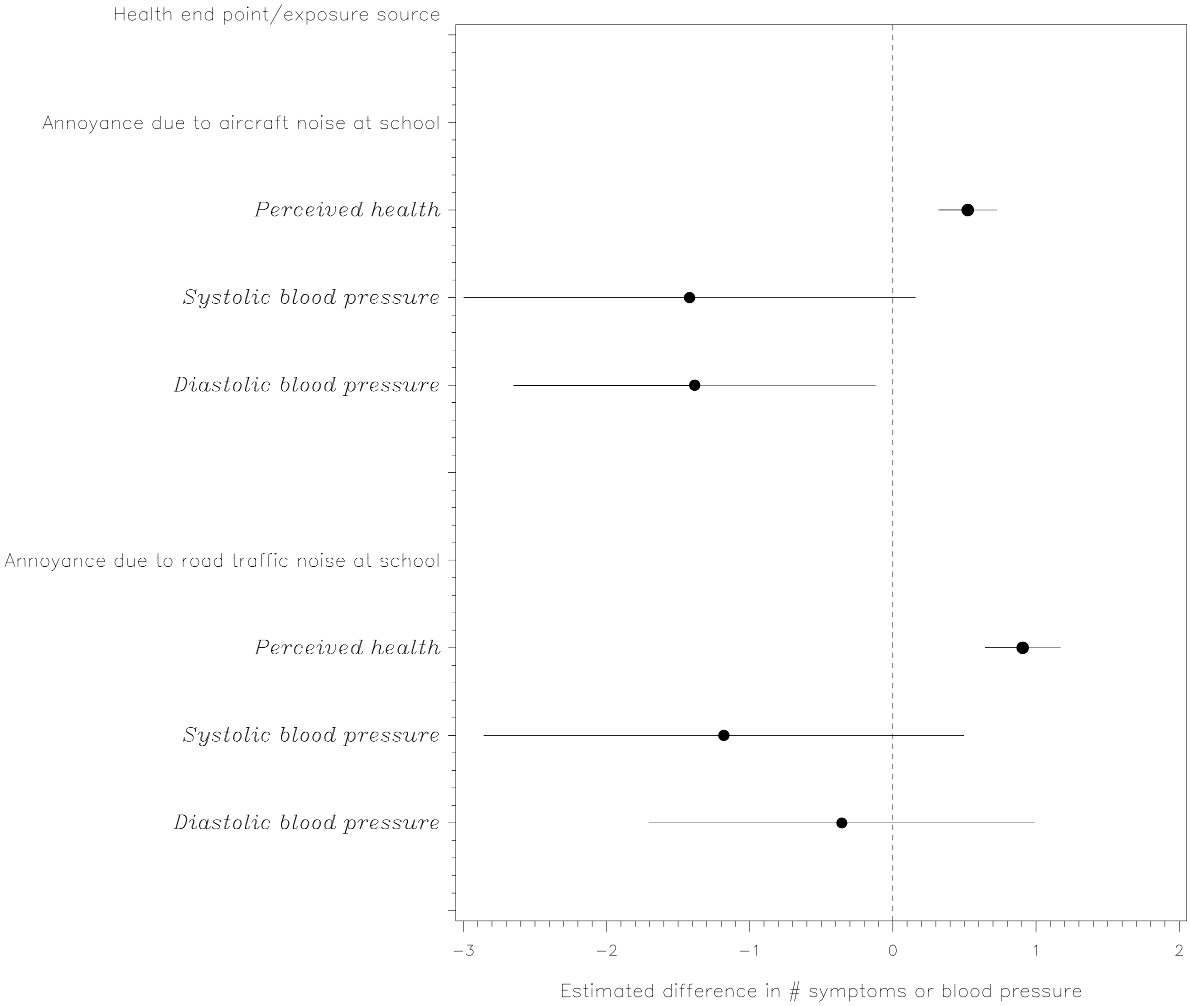

FIGURE 5.1 *The association between annoyance due to aircraft or road traffic noise at school and perceived health and blood pressure, after pooling the data and adjustment for potential confounders. The vertical line corresponds to no difference in the number of symptoms or blood pressure (mmHg) between children who were annoyed compared to children who were not annoyed. The circles correspond to the estimated difference in the number of symptoms or blood pressure (mmHg) when comparing the group annoyed with the group who were not annoyed. The horizontal lines correspond to the 95% confidence interval.*

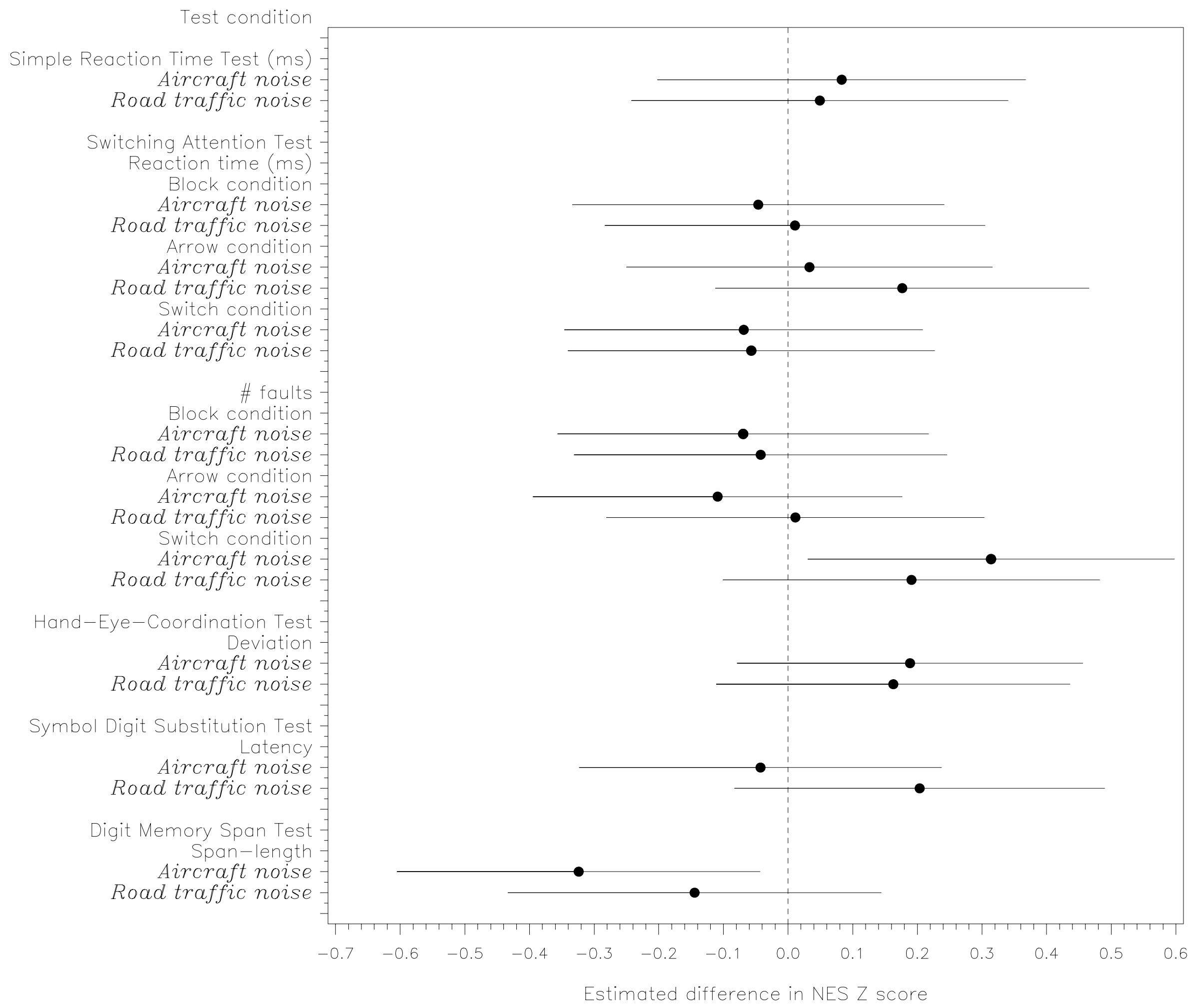

FIGURE 5.2 *The association between annoyance due to aircraft or road traffic noise at school and the scores of the Reaction Time Test, Switching Attention Test, Symbol Digit Substitution Test, Digit Memory Test, and Hand-Eye-Coordination Test, adjusted for potential confounders. The vertical line corresponds to no difference between children who were annoyed compared to children who were not annoyed. The circles correspond to the estimated difference in score when comparing the group annoyed with the group who were not annoyed. The horizontal lines correspond to the 95% confidence interval.*

Figure 5.2 shows the fully adjusted associations between annoyance due to aircraft and road traffic noise exposure at school and the different scores of the NES tests. In order to be able to present the outcomes of the multilevel analyses in one figure, we computed z-scores. Only in the difficult part of the Switching Attention Test (SAT) and the Digit Memory Span Test (DMST) we observed significant effects: children who were annoyed due to aircraft noise at school, made significantly more faults at the Switch condition of the SAT compared to children that were not annoyed ($\chi^2 = 4.7$, df = 1, p = 0.03). Furthermore, the span length on the DMST of children who were annoyed due to aircraft noise at school was significantly shorter than children who were not annoyed due to aircraft noise at school ($\chi^2 = 5.3$, df = 1, p =0.02). There were no significant differences observed in the overall scores of the NES-tests between the children who were annoyed due to road traffic noise at school and children who were not annoyed due to road traffic noise.

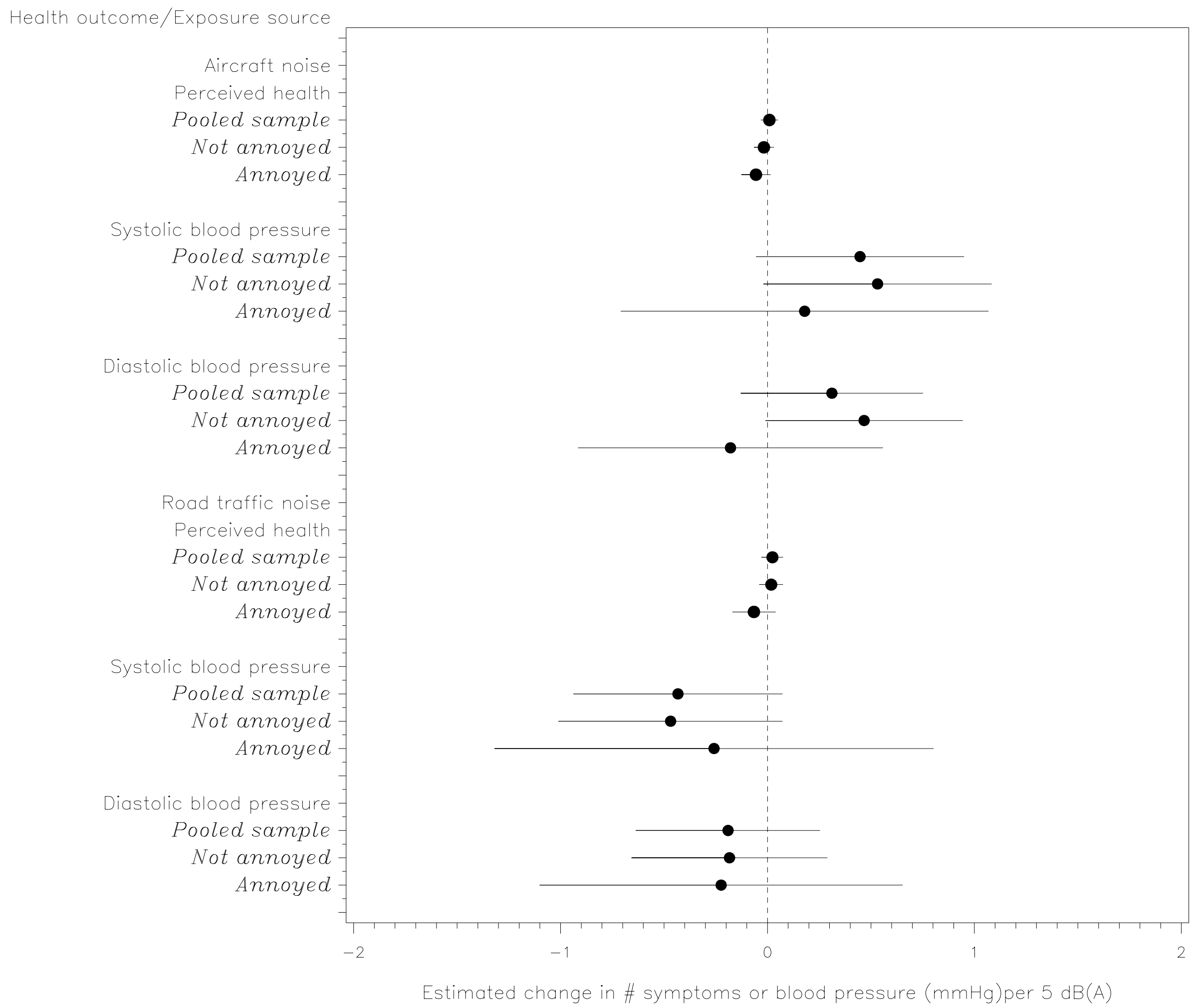

FIGURE 5.3 *The association between aircraft and road traffic noise exposure at school ($L_{Aeq, 7-23}$) and perceived health and blood pressure in children, after pooling the data, and separately for the group annoyed children and the group of children who were not annoyed. The vertical line corresponds to no effect of noise exposure on perceived health or blood pressure. The circles correspond to the estimated change in the number of symptoms or blood pressure (mmHg) per 5 dB(A) increase in noise, after adjustment for potential confounders; the horizontal line correspond to the 95% confidence interval.*

Noise, health and neurobehavioural functioning: differences between annoyance groups

Figure 5.3 shows the association between aircraft noise at school and perceived health and blood pressure after pooling the data and separately for the group of children who were not annoyed and the group of children who were annoyed. Although we observed differences between the effect sizes of both annoyance groups for the association between aircraft noise at school and perceived health, these were not statistically significant ($\chi^2 = 1.0$, df = 1, p = 0.317). Similar results were found for road traffic noise: the effect sizes of both annoyance groups for the association between road traffic noise at school and perceived health did not differ significantly ($\chi^2 = 2.3$, df =1, p = 0.129). There were no significant differences between the effect sizes of both annoyance groups for the association between noise exposure at school and blood pressure: After stratification for annoyance due to aircraft noise at school, no difference between the groups of children who were and were not annoyed could be observed. Similar results were found for road traffic noise exposure. With regard to neurobehavioural functioning, no significant differences between the effect sizes of both annoyance groups for the association between noise exposure at school and the different NES outcomes were observed (results not reported).

5.4 Discussion

Main results

This study examined the role of annoyance in the relation between aircraft and road traffic noise exposure and children’s health and cognition. There were four main findings: Firstly, no direct associations were found between noise exposure at school and self-reported health symptoms: both aircraft and road traffic noise exposure at school were not related to a statistically significant increase in the number of symptoms. Secondly, the relation between noise and neurobehavioural functioning and health was not confounded by annoyance: the association with noise hardly changed after additional adjustment for annoyance. Thirdly, associations were found between annoyance and self-reported health symptoms and the outcomes of several NES tests: children who were annoyed, reported more symptoms compared to children who were not annoyed; children who were annoyed due to aircraft noise at school made significantly more faults at the Switch condition of the SAT, and the span length of these children was also significantly shorter. Children who reported annoyance due to noise at school had a lower blood pressure compared to children that reported no annoyance. Fourthly, the relation between noise and health and neurobehavioural functioning did not differ between different annoyance groups.

Noise exposure at school and health: self-reported health symptoms
Perceived health, as indicated by symptoms or general rating of health, reflects a person's judgment about his/her own health and relates to both physical and mental health. Different studies have measured health in different ways, making comparison between studies difficult.
We found no direct associations between noise exposure at school and self-reported health symptoms. Earlier, Stansfeld *et al.* (2005) observed no effects of either aircraft or road traffic noise on self-reported health [3]. Our results were not consistent with those of the Tyrol Mountains Study (TMS), investigating the effects of local road and rail traffic noise, and showing that children from the noisier neighbourhoods reported greater stress symptoms over the previous week in comparison to those from quiet areas [13]. However, other recent studies investigating the effects of aircraft and road traffic noise on children's perceived health found no effects on perceived health [14 – 17]: Haines *et al*. (2001ab) found no associations between aircraft noise exposure and self-reported health or symptoms such as headaches, and tiredness in both the Schools Environment and Health Study (SEHS) and West London Schools Study (WLSS) [14, 15]. In the Munich Airport Study (MAS), the researchers found no differences in the physical state, one of the subscales of the KINDer Lebensqualitätsfragebogen (KINDL), between children living in a high-noise-impact urban neighbourhood and children living in a quiet urban neighbourhood [17]. Our results may be partly the consequence of relatively crude questions used in our child questionnaire measuring potentially subtle subjective health symptoms in relation to noise exposure. Since divergent definitions and terms have been used in the past, and perceived health has not been measured in a uniform manner, no definite conclusions can be reached with regard to the evidence for a relation between noise exposure and perceived health. Nevertheless, the weight of the evidence suggests no association between aircraft and road traffic noise and perceived health in children.

Annoyance as confounder
The relation between noise and neurobehavioural functioning and health was not confounded by annoyance: the observed associations between noise exposure at school and perceived health, blood pressure and the different outcomes of the NES hardly changed after additional adjustment for annoyance. The NES-findings are in keeping with earlier findings that the effect of aircraft noise exposure on reading comprehension remains after further adjustment for aircraft noise annoyance [14, 18].

Annoyance: an intermediate step?
We found associations between annoyance and self-reported health symptoms: children who were annoyed, reported more symptoms compared to children who

were not annoyed. This was in keeping with the LARES study that concluded that children who were moderately or severely annoyed due to road traffic noise reported more respiratory symptoms compared to children who were not annoyed [19]. Similar results have been found in studies investigating the effects of community noise among adults: highly annoyed persons more often report health problems compared to persons who are not annoyed [20 - 24].

We found that children who were annoyed did have a lower blood pressure than children who were not annoyed. Only the association between annoyance due to aircraft noise and diastolic blood pressure was statistically significant. These findings were not consistent with the findings of the Los Angeles Airport Study (LAAS): children who perceived their classroom to be noisier had higher diastolic blood pressures than those who perceived their classroom as less noisy; children reporting that they were bothered by classroom noise, had higher diastolic blood pressures [25]. Both the TMS and Speedwell study, investigating the association between road traffic noise and blood pressure in adults, found a negative association between annoyance and blood pressure: as annoyance increased, systolic and diastolic blood pressure decreased [26, 27], which was consistent with our results.

We observed that children who were annoyed due to aircraft noise at school made significantly more faults at the Switch condition of the SAT compared to children who were not annoyed due to aircraft noise at school. Also the span length on the DMST of these children was significantly shorter. The association between cognition and annoyance has firstly been tested in the WLSS: Haines *et al.* (2001b) observed that higher annoyance was associated with poorer reading [15]. Clark *et al.* (2006a) found that annoyance was significantly associated with reading comprehension [18]. Also children who experienced high annoyance performed more poorly on the reading test, regardless whether they engaged in the strategy of stopping work because of noise [19]. These findings suggest that noise may not only directly affect neurobehavioral functioning but may also be accounted for by the way children perceive the noise in terms of annoyance.

Differences between the annoyance groups

We observed no significant differences in the relation between noise and health and neurobehavioural functioning between the group of children who were annoyed and the group of children who were not annoyed. This interaction effect has not been tested previously. A potential problem is the relatively small group of annoyed children. This was especially the case with regard to the NES-tests, and may have influenced our group comparisons. Therefore, no definite conclusions can be reached with regard to the ‘effect-modifying’ role of annoyance.

Theoretical considerations
Based on our cross-sectional results, we cannot determine the causality of the association between noise annoyance and health. Annoyance due to noise may be either a cause or a result of poor health. Studies investigating adults' annoyance reactions and perceived health have suggested that persons with poorer perceived health often attribute the cause of their symptoms to external conditions such as their living environment [29]. If they suspect that community noise contributed to their symptoms, they may perceive more annoyance. This is in contrast to people without symptoms who do not make the connection with noise ('recall bias') [30]. In other words, if a person believes that he or she is suffering ill health because of the noise, it would increase dissatisfaction and annoyance with the noise. Thus knowledge of (or misinformed belief in) health effects may be an important factor in reaction to noise: it may have heightened effects for an individual who believes her/himself to be particularly vulnerable to the relevant health problem [31]. Whether this is also the case for children cannot be said yet, although it seems less likely for children of this age. Imitation of the adult's attitude towards the noise is more likely. There is some evidence that children model their own behaviour on that of adults in the family; the way in which children cope with conditions of illness is intimately related to the coping strategies adopted by the family [32]. However, the evidence is not consistent on this point; in the SEHS a relatively low correlation was found between child and parental annoyance [14].

In relation to noise, blood pressure elevations can be regarded as a non-specific response, typically associated with stress which is hypothesised to arise either as a consequence of the activation of the autonomic nervous system and the endocrine system or as a consequence of the appraisal of noise [5, 25]. In this paper we have investigated whether psychological models of stress, which suggest that subjective environmental assessments make a significant contribution to the prediction of blood pressure and where appraisal is an important process, can explain our findings. Our findings were not quite consistent with these psychological models of stress and with findings from earlier studies which suggest that subjective environmental assessments make a significant contribution to the prediction of stress outcomes [25]. Given our results and the results of adult studies, it is also possible that the effects of noise on blood pressure might be accounted for by other mechanisms than the appraisal of noise: the combined exposure to aircraft and road traffic noise might have affected both children's blood pressure and annoyance response. Or maybe there is some kind of compensatory effort effect: expressing their stress-feelings/irritation decreases the child's physical stress. Unfortunately, these possible mechanisms could not be further investigated on the data available in the RANCH study.

The findings of the RANCH study suggest that noise may not only directly affect cognition but may also be accounted for by the way children perceive the noise in terms of annoyance: there is the potential for motivational mechanisms to play a role in the association between noise exposure and cognition such as annoyance and learned helplessness, which can cause communication difficulties as well as distracting children from learning [5].

Measurement of annoyance and health

Since children's annoyance and perceived health were measured within the same questionnaire, there is a chance that the true association with noise might be overestimated. Many correlations between stressors (e.g. noise) and health may be spuriously inflated because of the common influence of neuroticism when both variables are measured through self-report [33]. We dealt with this by incorporating blood pressure data and not solely defining health as a score of a diversity of subjective health measures. Furthermore, recent studies have revealed that children indeed are capable of distinguishing annoyance and perceived health as measured by means of self-reported symptoms [8, 34].

Study strengths and limitations

Our study represents an improvement on previous studies because of its large sample size in terms of both numbers of participants and schools. The large sample size enabled us to perform multi-level analyses, thus taking into account the hierarchical structure of the data. A second improvement on previous studies is that the participants were distributed over a broad noise exposure range and a continuous noise exposure measure was used; to date most studies investigating the impacts of noise exposure have involved between-group comparisons (high versus low) or they have tended to create noise categories (e.g. high, medium, low) by using indicator terms for ordered polytomuous exposure categories. The results of such studies may be sensitive to decisions about cut-off points used to categorise continuous exposure variables and the method used to assign scores to exposure categories [35]. A further strength of this study is the adjustment for a comprehensive number of potential confounders and determinants that were examined.

Our study has several limitations. The cross-sectional design of our study limits causal interpretations of the possible relation with noise exposure. Our reliance on external measures of noise exposure rather than internal noise exposure may lead to exposure misclassification. The long-term assessment of exposure to road traffic noise at school was problematic as children move to a different classroom each year during their time at school, meaning that road traffic noise exposure changed. Thus, the road traffic noise levels at the façade of their current classroom might not reflect the average level of exposure during their time at school. Since perceived health was assessed on a subjective basis, these results are susceptible to over-reporting due to recall bias [36]. Also because of the large number of statistical associations that were investigated in this analysis, it is possible that some of the statistically significant results occurred by chance.

5.5 Conclusions

The results of the RANCH study and previous studies suggest no direct association between transportation noise exposure and perceived health in children. However, since divergent definitions and terms have been used in the past, and perceived health has not been measured in a uniform manner, no definite conclusions can be reached with regard to the evidence for a relation between noise exposure and perceived health.

Children who were annoyed, reported significantly more symptoms compared with the children who were not annoyed. The findings also suggest that noise may not only directly affect aspects of neurobehavioural functioning but that they also may be a result of levels of annoyance: children who were annoyed due to aircraft noise at school made significantly more faults at the Switch condition of the SAT compared to children who were not annoyed due to aircraft noise at school. Also the span length of the DMST of these children was significantly shorter.

The findings with regard to blood pressure are more difficult to interpret: Annoyance did not modify the association between noise exposure and blood pressure; annoyance was associated with decreases in blood pressure, and the observed differences between noise and blood pressure between annoyance groups were not significant. This was not quite consistent with psychological models of stress, where appraisal is an important process, and with findings from earlier studies which suggest that subjective environmental assessments make a significant contribution to the prediction of stress outcomes such as blood pressure.

On the basis of our findings it cannot be ruled out that the appraisal of the noise affects the association between aircraft-and road traffic noise exposure and children's health and cognition. However, our conclusion is limited due to the relatively small group of annoyed children, which may have influenced our group comparisons. Furthermore, the observed relation between annoyance and perceived health is possibly biased due to the fact that both were measured within the same questionnaire.

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6 A first estimation of the number of primary school children living around Schiphol Airport affected by aircraft noise exposure

The work presented in this chapter is based on: Kempen EEMM van, I Kamp van, Stellato RK, Houthuijs DJM, Fischer PH (2005). The effect of aircraft and road traffic noise on the cognitive performance, annoyance and blood pressure of primary school children. Bilthoven: National Institute of Public Health and the Environment. Report no. 441520021.

ABSTRACT

It was indicatively estimated that 110-720 pupils per school year visiting primary schools around Schiphol airport have a low test result for reading comprehension due to aircraft noise exposure using the 10^{th} percentile as cut-off point. An estimated 850 pupils per school year are severely annoyed at school due to aircraft noise.

These are the main results of an assessment in which we estimated the number of children living in the Schiphol region who are affected by aircraft noise exposure. Until recently, the insights in childhood effects of transportation noise were not sufficiently sound and consistent to allow such an assessment.

6.1 Introduction

In past decades there has been a great deal of research into the effects of noise on children. A broad range of effects has been observed and reported: Effects on hearing, cognition, motivation and the cardiovascular and the endocrine system. But also effects on mental health, annoyance, self-reported health and sleep have been investigated [1 - 3]. Current insights in childhood effects of transportation noise, however, are not sufficiently sound and consistent to allow an assessment of transportation noise on the health of children in The Netherlands. This was mainly caused by the fact that source-specific exposure-response relations describing the relation between noise exposure and effects in children are lacking. Important reasons are the limited exposure ranges used in the studies investigating the effects of noise in children [4], and the lack of uniformity of the measurement of end points. In addition, traffic noise exposure data on children are scarce and limited to a few field studies. Recently, the fifth framework project RANCH has solved some of the above-mentioned gaps. As a consequence, exposure-response relations describing the effect of aircraft noise exposure on children were derived [5 – 7], allowing subsequent assessment of the noise impact on children in The Netherlands.
The aim of this study is to estimate the number of children living in the Schiphol region affected by aircraft noise exposure using the exposure-response relations that were derived in RANCH.

6.2 Methods

For the purpose of this study we estimated the effects of aircraft noise exposure on children living in the Schiphol Region. Figure 1.5 of Section 1.6.3 summarises the methodology which was used and illustrates which type of input data were necessary to estimate the number of children affected by noise exposure. This methodology was based on the usual procedures for environmental health risk assessment [8].

Selection of end points
The starting point of this assessment are the RANCH findings with regard to aircraft noise [5 – 7]: aircraft noise was found to be related to a statistically significant increase of the percentage of severe annoyance in children, and to a significant decrease in reading comprehension levels. Furthermore, a significant decrease in recognition memory was found. For this assessment, quantitative assessments of the impact of aircraft noise exposure on children were based on severe annoyance and reading comprehension.

Assessment of population exposure

As in RANCH, aircraft noise exposure was expressed as $L_{Aeq,\ 7\text{-}23hrs}$: The average continuous equivalent sound level of aircraft noise in an area from 7 a.m. to 11 p.m. for a specified time period. In order to estimate the exposure of primary school children living in the Schiphol region, the addresses of primary schools were collected and linked with modelled noise exposure levels using a geographical information system (GIS). Modelled aircraft noise levels ($L_{Aeq\ 7\text{-}23\ hrs}$) were obtained from the Dutch National Aerospace Laboratory (NLR) for 2002.

Identification of exposure-response relations

Exposure-response relations were derived for both severe annoyance and reading comprehension.

Severe annoyance. Figure 2.1 of Section 2.3 shows the relation between aircraft noise at school ($L_{Aeq,\ 7\text{-}23hrs}$) and the percentage of children severely annoyed. According to this relation the fraction severely annoyed children increases from about 5.1% at 50 dB(A) to about 12.1% at 60 dB(A).

Reading comprehension. Aircraft noise exposure at school was linearly associated with impaired reading comprehension. In RANCH, reading comprehension was measured by means of nationally standardised tests: the Suffolk Reading Scale (UK), the CITO Readability Index for Elementary and Special Education (CRIE) (NL) and the ECL-2 (Spain). In order to be able to make comparisons between each country's test, Z-scores were computed [6]. Figure 6.1 shows the Z-score for reading comprehension adjusted for age, gender and country by 5 dB(A)-bands for aircraft noise.

n terms of reading delay, it was estimated that a 5 dB(A) difference in aircraft noise was equivalent to a 1-month reading delay in The Netherlands and a 2-month reading delay in the United Kingdom [5, 6]. By expressing the effect in this way, it was possible to demonstrate the average effect of noise on reading comprehension for an average child.

However, expressing the effects in terms of Z-score or reading delay, makes it for stakeholders difficult to understand the effect of noise on reading comprehension for all primary schoolchildren around an airport. An outcome such as "the probability that a child has a low test result for the RANCH reading comprehension test" could be more easier to understand for stakeholders. For this end point an exposure-response relation was derived using the RANCH data. Unfortunately, there are no guideline values available, indicating a low test result. Consequently, a limit value was determined based on the RANCH-data. To this end, children exposed to lower noise levels were considered as the reference group. Using the scores of the RANCH reading comprehension test of this group, cut-off points for 'a low test result' were defined based on the percentile distribution of the Z-scores. Since the value of the Z-score for the definition of 'a low test result for reading' is arbitrary, we used several cut-off points: the 20th, 10th and the 5th percentile in the low-exposed group.

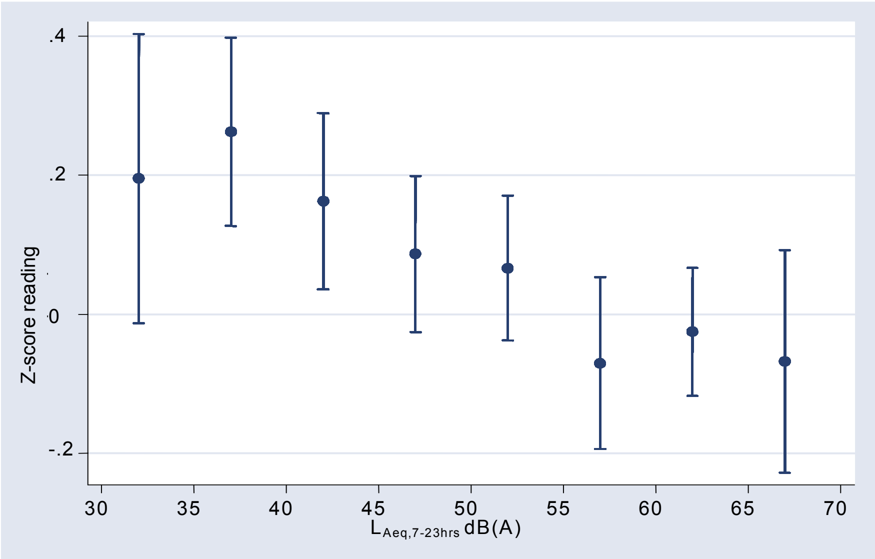

FIGURE 6.1 *Adjusted mean reading Z-scores and 95% confidence intervals for 5dB(A)-bands of aircraft noise at school adjusted for age, gender, and country [5, 6].*

To assess the relation between aircraft noise exposure at school and the probability of a 'low test result', a multi-level logistic regression was applied, using the GLIMMIX procedure of SAS version 9.1. In a logistic regression the effect of the exposure variable (aircraft noise exposure) on the outcome measure (a relatively low test result yes/no) is indicated by means of an Odds Ratio (OR). In all models, aircraft noise exposure at school was the main independent variable. Exposure to aircraft noise ($L_{Aeq,\ 7\text{-}23hrs}$) was expressed as continuous variable as well as 2.5 dB(A) exposure classes. The logistic regression models included the same confounders as in Clark *et al.*, 2006 [10]. Odds Ratios (OR) and standard errors (SE) were estimated under residual pseudo-likelihood (RSPL) estimation. Statistical significance of a coefficient was tested under maximum pseudo-likelihood (MSPL) estimation, using a Wald Chi-square test.

Aircraft noise exposure at school was significantly related to the probability of a low test result in case the 10th percentile was used (χ^2 = 8.8, df =1, p=0.003): in schools in areas with higher aircraft noise exposure the proportion children with a low test result on the reading comprehension test was significantly higher. After adjustment for confounders an OR per 5 dB(A) of 1.12 (95% CI: 1.04 – 1.22) was estimated. Figure 6.2 presents the continuous relation between aircraft noise exposure at school and the risk of a 'low test result for reading comprehension' based on the 10th percentile as well as the OR by the 2.5 dB(A) exposure categories.

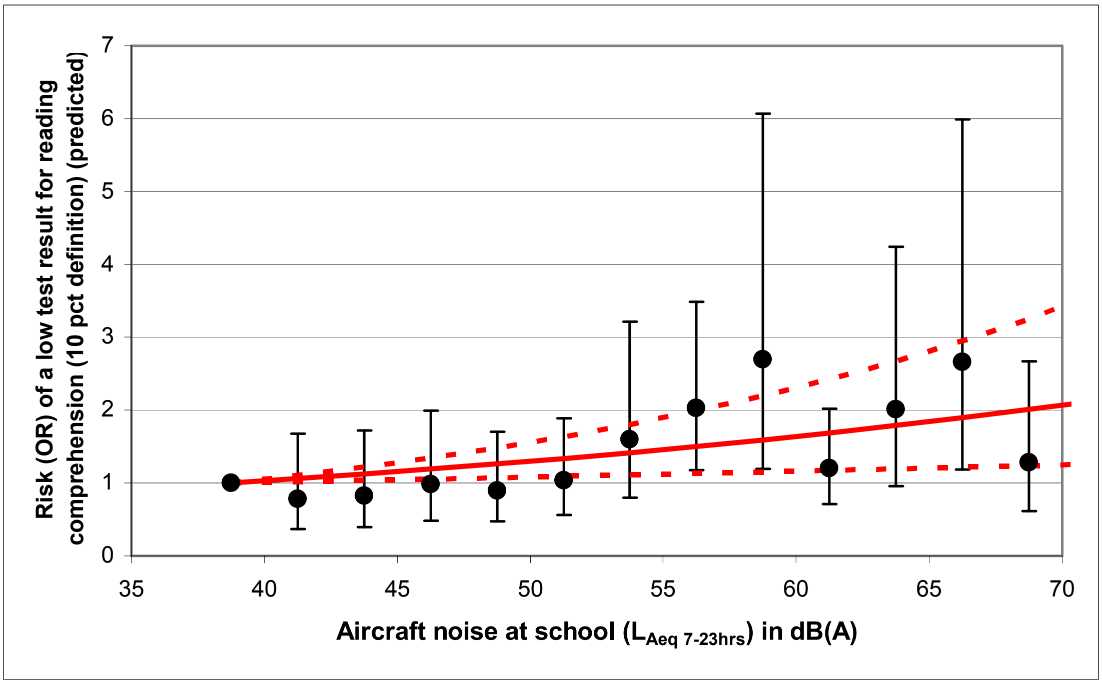

FIGURE 6.2 *The adjusted Odds Ratios and 95% confidence intervals for the probability of a low test result for reading comprehension (based on the 10th percentile) for the continuous relation as well as by 2.5 dB(A) exposure categories.*

The relation between aircraft noise exposure and the risk of a low test result for reading comprehension was not statistically significant (χ^2 = 1.6, df =1, p=0.202) in case the definition of a low test result was based on the 5th percentile [$OR_{5\ dB(A)}$ = 1.08 (95%CI 0.95 – 1.22)]; in case the definition of a relatively low test score was based on the 20th percentile, the relation between aircraft noise and the probability of a low test result for reading comprehension was statistically significant (χ^2 = 8.7, df =1, p=0.003): after adjustment for confounders, an $OR_{5\ dB(A)}$ of 1.10 (95%CI 1.03 – 1.18) was estimated.

Estimation of the attributable cases

The number of severely annoyed children was estimated by directly combining the population exposure distribution with the exposure-response relation: per exposure level the number of children was calculated by multiplying the number exposed with the percentage of severe annoyance (see also Van Kempen *et al.,* 2005 [9]).

To estimate the number of children who had a low test result on the reading comprehension test as a result of exposure to aircraft noise (the attributable burden), the population exposure distribution was combined with the exposure-response relation using population attributable fractions (see also Table 6.1). As is demonstrated in Figure 6.2, the risk for a low test result on reading comprehension increases continuously for aircraft noise levels from about 40 dB(A) ($L_{Aeq,\ 7\text{-}23\ hrs}$). This aircraft noise level was used to estimate the OR (see also Table 6.1).

TABLE 6.1 *Example of the estimation of the number of primary school children with a low test result for reading comprehension using the 10th percentile as cut-off point, attributable to aircraft noise exposure.*

Exposure category ($L_{Aeq, 7\text{-}23hrs}$)	**Percentage exposed**	**OR**	**Attributable fraction (%)**	**Population Attributable Fraction (%)**	**Number of subjects per school year**
> 36	3.0	1.00	0.0	0.0	0
36 – 40	26.3	1.00	0.0	0.0	0
41 – 45	35.4	1.10	9.4	3.6	104
46 – 50	27.6	1.24	19.3	6.2	182
51 – 55	6.3	1.39	28.2	2.4	71
56 – 60	1.1	1.56	36.1	0.6	18
61 – 65	0.3	1.76	43.1	0.2	6
Total				**13.0**	**381**

The OR was estimated by means of the log-odds derived from the logistic multilevel analysis, the aircraft noise level from which the continuous relation between aircraft noise exposure and the risk for a relatively low test result starts, and the average aircraft noise exposure level per exposure category; the following formulas are used to calculate the attributive fractions (AR%), the population attributable risk percentages (PAR%) and the absolute numbers of affected subjects (PAR) for each noise category: AR% = (OR – 1) / OR *100; PAR% = P_e/100 * (OR – 1)/(P_e/100 * (OR – 1) + 1) * 100; PAR = PAR% * N_d where P_e = the percentage of the population exposed and N_d = Number of subjects with a relatively low test result.

Sensitivity analysis

With regard to the relation between aircraft noise and reading comprehension, several uncertainties were observed. Firstly, the choice of the cut-off point for the definition of a low test results for reading comprehension. As is indicated in Section 6.2, there are no guideline values available indicating a low test result for reading comprehension.

Secondly, on the base of the RANCH results, the aircraft noise level from which primary school children are at risk for an effect on reading comprehension is not unequivocal: Clark *et al.,* (2006) found that the estimated change in reading Z-score did not significantly depart from linearity (p=0.99) [6], which is consistent with the continuous exposure-response relation of Figure 6.2 showing that the risk for a low test result on reading comprehension increases continuously for aircraft noise levels from about 40 dB(A) ($L_{Aeq, 7\text{-}23 hrs}$). However, the OR per 2.5 bands in Figure 6.2 suggest that the risk for a relatively low test result increases (OR > 1) at aircraft noise levels between 50 – 55 dB(A) ($L_{Aeq, 7\text{-}23hrs}$). How will the results change, when it is assumed that children are at risk at levels higher than 40 dB(A)?

To give an indication of the relative importance of these uncertainties, we investigated the sensitivity of the results by changing one input variable at a time, *ceteris paribus*. Examined were: a) the choice of the cut-off point for the definition of a low test result, and b) the choice of the aircraft noise level from which primary school children are supposed to be at risk for a low test result for reading comprehension.

6.3 Results

Exposure assessment

For 1,088 schools situated in the Schiphol region, the school address was linked to an aircraft noise level. Figure 6.3 shows the primary schools per 1-dB(A) class in the Schiphol region with a noise level of 35 dB(A) or more. In total, there were 911 primary schools with about 235,000 pupils (about 29,000 per school year). In the Schiphol region, 15 schools had an aircraft noise level of more than 55 dB(A) in 2002. In these 15 schools, there were in total about 3,200 pupils (400 per school year).

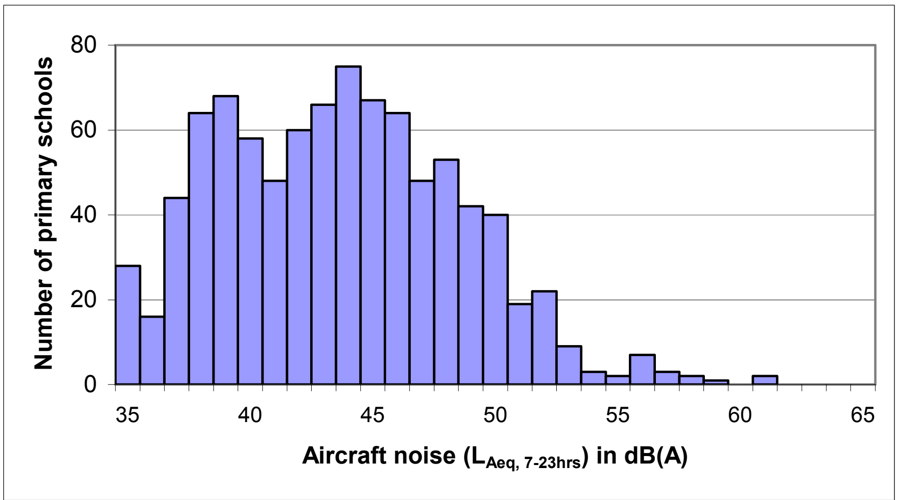

FIGURE 6.3 *Distribution of primary schools (N = 911) in the Schiphol region to aircraft noise ($L_{Aeq,\ 7\text{-}23hrs}$) of at least 35 dB(A) in 2002.*

TABLE 6.2 *Estimated numbers of pupils per school year with a low test result for reading comprehension and severe annoyance in the Schiphol region.*

Effect	**Additional pupils per school year**	
	Absolute number (95% CI)*	**As fraction of total (95% CI)**
Low test result for reading comprehension ‡		
Definition on the basis of		
5th percentile	130 (0 – 370)	0.4 (0 – 1.3)
10th percentile	390 (110 – 720)	1.3 (0.4 - 2.4)
20th percentile	640 (160 – 1200)	2.2 (0.5 - 4.0)
Severely annoyed due to aircraft noise at school †	850 (820 – 900)	2.9 (2.8 – 3.1)

* Estimated by means of the regression coefficient and standard error. † Only children exposed to aircraft noise levels ($L_{Aeq,\ 7\text{-}23hrs}$) > 40 dB(A) were included. ‡ Estimates are based on the continuous exposure-response relation in Figure 6.2, suggesting that the risk for a low test result starts from about 40 dB(A). Abbreviations: 95% CI: 95% confidence interval.

The number of cases attributable to aircraft noise exposure

Table 6.2 shows the number of pupils per school year with a low test result for reading comprehension and severe annoyance due to aircraft noise exposure in the Schiphol region. It was estimated that about 850 primary school children (2.9%) per school year in the Schiphol region were severely annoyed at school due to aircraft noise. It is estimated that due to aircraft noise exposure about 390 pupils per school year (1.3%) will have a low test result for reading comprehension, using the 10th percentile as cut-off point (see also Table 6.2).

Sensitivity analysis

Table 6.2 shows how the choice of the cut-off point used to define 'a low test result on the reading test' (as is described in Section 6.2) affects the estimated number of pupils per school year.

Table 6.3 demonstrates that the aircraft noise level from which children are supposed to be at risk for a low test result for reading comprehension, affected the attributable number of pupils per school year substantially. The point of departure for this sensitivity analysis is the continuous relation in Figure 6.2 suggesting that the risk for a low test result starts at about 40 dB(A). Subsequently, the number of pupils per school year who are suggested to be at risk at aircraft noise exposure levels of e.g. 50 dB(A) is estimated by 'counting' the number of pupils per school year exposed to noise levels of 50 dB(A) and higher.

TABLE 6.3 *The impact of the choice of aircraft noise level from which primary school children are at risk for a low test result on the reading comprehension test.†)*

Noise exposure level ($L_{Aeq\ 7\text{-}23\ hrs}$)	Absolute number of pupils per school year (95% CI)*
≥ 40	390 (110 – 720)‡)
≥ 48	210 (60 – 390)
≥ 50	130 (35 – 250)
≥ 53	40 (10 – 80)
≥ 55	25 (5 – 50)

Estimated by means of the regression coefficient and standard error. † The definition of a relatively low test result was based on the 10th percentile. ‡ Estimate based on the continuous exposure-response relation in Figure 6.2, suggesting that the risk for a low test result starts from about 40 dB(A). Abbreviations: 95% CI: 95% confidence interval.

6.4 Discussion and conclusions

The aim of this chapter is to estimate the number of children living in the Schiphol region affected by aircraft noise exposure, using the exposure-response relations that were derived in RANCH. In the Schiphol region, 911 of 1,088 schools had an aircraft noise level of more than 35 dB(A) in 2002; 15 had an aircraft noise level of more than 55 dB(A). It was estimated that 110-720 pupils per school year visiting primary schools around Schiphol Airport have a low test result for reading comprehension due to aircraft noise exposure using the 10th percentile as cut-off point. An estimated 850 pupils per school year in the Schiphol region are severely annoyed at school due to aircraft noise. Since this is the first attempt in which the effects of noise exposure on children were quantified, comparison with other assessments is not possible.

Sensitivity analysis showed that the outcomes of our assessment are sensitive for the choice of the cut-off point for the definition of a low test result, and the choice of the aircraft noise level from which children are supposed to be at risk for a low test result for reading comprehension. In addition, the results demonstrate when analysing the effects of noise exposure, not only the relation with continuous noise exposure should be examined, but one should also investigate the relation with noise exposure using noise exposure categories.

As opposed to Clark *et al.,* (2006) [6], the relation between aircraft noise exposure and the probability of a low test score was not statistically significant in case the definition of a relatively low test score was based on the 5th percentile. Furthermore, it can be noticed that the estimates of the number of attributable cases have broad 95% confidence intervals (see also Table 6.2). This may be partly explained by the fact that in comparison with the analysis using the Z-score [6], information was lost, since the score on the reading comprehension test was dichotomised.

In RANCH, the Dutch participants had a lower score on the reading comprehension test than was expected on what the participating schools would normally score on such an achievement test. How this is for the English and Spanish participants, is not known. It is, however, known that children have a lower score on achievement tests if they know that nothing depends on the outcome of the test [10]. For this assessment it was assumed that this phenomenon has not affected the relation between aircraft noise and reading comprehension.

Furthermore, one has to realise that not every child has the same average level of cognitive performance as point of departure. It is supposed that in particular children who have already a poorer reading performance, are likely to be more at risk [11 in 2].

When comparing percentages of highly annoyed people assessed in individual airport surveys investigating adult populations, with the percentage of highly annoyed people estimated with generalised curves for adults, the percentages often differ [12]. Since no national or local surveys are available that have investigated the prevalence of severe annoyance among children in The Netherlands, we cannot investigate how this applies for child populations.

Conclusion

This assessment demonstrated that the exposure-response relations between aircraft noise exposure and reading comprehension and severe annoyance, which were derived in RANCH, were applicable for the situation around Schiphol Airport.

6.5 References

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7 Discussion

This thesis examined the effects of road traffic and aircraft noise on children's health and cognition. The objectives were:

- To quantify the relation between aircraft and road traffic noise exposure in both the home and the school setting and cognitive performance, annoyance, perceived health and blood pressure in children;
- To investigate whether the appraisal of noise affects the association between aircraft and road traffic noise exposure and blood pressure, perceived health and cognitive performance in children;
- To investigate whether the effects of noise exposure on blood pressure and annoyance found in children, differ from those found in adults; and
- To estimate the number of children affected by transportation noise exposure for the Dutch situation.

To address these objectives, a meta-analysis has been carried out and the data of a cross-sectional field study, gathered in the framework of the European 5th framework project RANCH, were used. Finally, the number of primary schoolchildren living around Schiphol Airport with a low test result for reading comprehension and/or who were severely annoyed due to aircraft noise exposure, was estimated. To this end the exposure-response relations that were derived in this thesis, were applied.

Outline
After a short overview of the main results, the validity of the study designs, the exposure measurements, and measurement of outcome variables and possible confounders are discussed in section 7.2. Then, in section 7.3, the results are discussed in the light of the current literature on this topic. This also includes RANCH-papers focussing on the impact of road traffic and aircraft noise on children's cognitive functioning and health [1 – 3]. After a comparison with existing international guidelines in section 7.4, the findings will be discussed in the light of existing theories about the possible underlying (biological) mechanisms of how noise exposure affects health and cognition (section 7.5). Before the conclusions and recommendations will be presented, some remarks of the meaning of the findings for the later life of the children will be given in section 7.6

7.1 Main results

Tables 7.1 to 7.4 present an overview of the main findings, structured by the objectives and approaches used.

TABLE 7.1 *The relation between aircraft and road traffic noise exposure in the home and the school setting and cognitive performance, annoyance, perceived health and blood pressure in children: main findings from the cross-sectional studies*

Aircraft noise	**At school**	**At home**
Neurobehavioural functioning	Effects of aircraft noise exposure ($L_{Aeq,\ 7\text{-}23\ hrs}$) at school were observed in the more difficult and demanding parts of the Switching Attention Test	No effects of aircraft noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at home were found
Annoyance	An exposure-response relation was demonstrated between exposure to aircraft noise ($L_{Aeq,\ 7\text{-}23hrs}$) at school and severe annoyance in children. This finding was consistent across the three samples	An exposure-response relation was demonstrated between exposure to aircraft noise ($L_{Aeq,\ 7\text{-}23hrs}$) at home and severe annoyance in children. This finding was consistent across the three samples
Blood pressure	After pooling the Dutch and British data, aircraft noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school was related to a statistically non-significant increase in blood pressure and heart rate. This finding was not consistent across both samples.	Aircraft noise exposure during the day-evening period ($L_{Aeq,\ 7\text{-}23hrs}$) at home was related to a statistically significant increase in blood pressure. Aircraft noise exposure during the night period ($L_{Aeq,\ 23\text{-}7hrs}$) at home was positively associated with blood pressure; only the association with systolic blood pressure was statistically significant. The findings differed between the Dutch and British samples.
Perceived health	Aircraft noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school was not related to an increase in the number of symptoms. This finding was consistent across the three samples	-
Road traffic noise		
Neurobehavioural functioning	Effects of road traffic noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school were observed in the more difficult and demanding parts of the Switching Attention Test	No effects of road traffic noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at home were found
Annoyance	An exposure-response relation was demonstrated between exposure to road traffic noise ($L_{Aeq,\ 7\text{-}23hrs}$) at school and severe annoyance in children. This finding was consistent across the three samples	-
Blood pressure	After pooling the data, negative but non-significant associations were found between road traffic noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school and blood pressure. These findings were consistent in the Dutch and British sample	Road traffic noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at home was related to a statistically non-significant decrease in blood pressure. This was only investigated in the Dutch sample.
Perceived health	Road traffic noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school was not related to an increase in the number of symptoms. This finding was consistent across the three samples	-

-: not investigated

TABLE 7.2 *Does the appraisal of noise affect the association between aircraft-and road traffic noise exposure and blood pressure, perceived health and cognitive performance in children? Main findings of the cross-sectional studies*

	Aircraft noise	**Road traffic noise**
Neurobehavioural Functioning	1. The association between aircraft noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and neurobehavioural functioning did not change substantially after additional adjustment for annoyance; 2. Children who were annoyed due to aircraft noise at school made significantly more faults at the Switch condition of the Switching Attention Test (SAT) compared to children that were not annoyed; the span length on the Digit Memory Span Test of children who were annoyed due to aircraft noise at school was significantly shorter than children who were not annoyed due to aircraft noise at school; 3. No significant differences were observed in the relation between aircraft noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and behavioural functioning between the group of children who were annoyed and the group of children who were not annoyed	1. The association between road noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and neurobehavioral functioning did not change substantially after additional adjustment for annoyance; 2. No differences were observed in the overall scores of the NES-tests between the children who were annoyed due to road traffic noise at school and children who were not annoyed due to road traffic noise; 3. No significant differences were observed in the relation between road traffic noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and neurobehavioral functioning between the group of children who were annoyed and the group of children who were not annoyed
Blood pressure	1. The association between aircraft noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and blood pressure did not change substantially after additional adjustment for annoyance; 2. Children who reported annoyance due to aircraft noise at school had a lower blood pressure compared to children that reported no annoyance. Only the association between annoyance due to aircraft noise and diastolic blood pressure was statistically significant; 3. No significant differences were observed in the relation between aircraft noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and blood pressure between the group of children who were annoyed and the group of children who were not annoyed	1. The association between road traffic noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and blood pressure did not change substantially after additional adjustment for annoyance; 2. Children who reported annoyance due to road traffic noise at school had a non-significant lower blood pressure compared to children that reported no annoyance; 3. No significant differences were observed in the relation between road traffic noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and blood pressure between the group of children who were annoyed and the group of children who were not annoyed
Perceived health	1. The association between aircraft noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and perceived health did not change substantially after additional adjustment for annoyance; 2. Children who were annoyed due to aircraft noise at school reported significantly more symptoms compared to children that were not annoyed; 3. No significant differences were observed in the relation between aircraft noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and perceived health between the group of children who were annoyed and the group of children who were not annoyed	1. The association between road traffic noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and perceived health did not change substantially after additional adjustment for annoyance; 2. Children who were annoyed due to road traffic noise at school reported significantly more symptoms compared to children that were not annoyed; 3. No significant differences were observed in the relation between road traffic noise exposure ($L_{Aeq, 7\text{-}23hrs}$) at school and perceived health between the group of children who were annoyed and the group of children who were not annoyed

TABLE 7.3 *Are the effects of noise exposure on blood pressure and annoyance found in children different from those found in adults?*

Approach	Annoyance	Blood pressure
Cross-sectional studies	The shape of the exposure-response relation describing the association between aircraft noise exposure ($L_{Aeq,\ 7\text{-}23\ hrs}$) at home and severe annoyance in the mothers was very comparable with that of their children	-
Meta-analysis	-	The effects of road traffic and aircraft noise exposure on blood pressure in both adult and child studies are inconsistent

-: not investigated

TABLE 7.4 *The number of primary schoolchildren living around Schiphol Airport with a low test result for reading comprehension and/or who were severely annoyed due to aircraft noise exposure.*

End point	Mean additional number of pupils per school year and 95% CI
A low test result for the reading comprehension test*)	390 (110 – 720)
Severe annoyance	850 (820 – 910)

* based on the 10th percentile definition and on the continuous exposure-response relation in Figure 6.2, suggesting that the risk for a low test result starts from about 40 dB(A).;
† Abbreviation: 95% CI: 95% confidence interval

7.2 Strengths and weaknesses

In this Section the validity of the study designs, the exposure measurements, and measurement of outcome variables and possible confounders are discussed.

Results of the cross-sectional studies

Strengths

Design. In comparison with previous studies that have investigated the effects of transportation noise on children [4 - 18], the findings of the cross-sectional studies (see also Tables 7.1 and 7.2) were robust: because of the size of both the number of participants and schools, the power was relatively high. The sample was selected so that the participants were uniformly distributed over a broad exposure range. As a consequence the contrast in noise exposure was optimal, which made the data presented in this thesis more suitable for the quantification of the relation between noise exposure and children's health and cognition.

Compared to previous studies [4-18], a large number of factors that might possibly affect the relation between noise and health and cognition in children have been measured and taken into account: during the selection of the participants, schools were matched on socio-economic status.

From some characteristics of the individual schools it is suggested that these may have a more powerful effect on children's cognition than exposure. Therefore, certain types of schools (such as specialist teaching centres) were excluded from participating, since it is assumed that the effect of school on cognitive performance might be a consequence of differences in resources, head teachers, reputation and selection factors such as the children it attracts [11].

The measurement of children's cognitive performance, health and annoyance. To ensure accurate conceptual equivalence, questionnaires used to measure annoyance and perceived health, were translated from English into Dutch and Spanish and back. The participating children were tested in a group setting where the investigators saw that they understood the questions and tests and worked individually. Since there is no gold standard for the measurement of annoyance in children, children's annoyance reactions were measured by means of child-adapted versions of standardised questions that were recently recommended by the International Commission on Biological Effects of Noise (ICBEN) and the International Organisation of Standardization (ISO) for measuring the degree of annoyance among adults [20]. Both the Schools Environment and Health Study (SEHS) and West London Schools Study (WLSS) already had good experiences with such questions for children [11 – 13].

In addition to what is common in the field of noise and cognition, cognitive functioning was operationalised by means of a set of tests selected from the Neurobehavioral Evaluation System (NES) (see also Figure 4.1). As is described in Chapter 4, this method gives test-leader independent results, minimal observer bias, and results that are less sensitive to cultural differences. Additionally to the paper-and-pencil tests, the selected NES-tests measure some different aspects of attention: response speed and switching attention.

Bias of the blood pressure measurements was reduced by the use of automated blood pressure meters, a standardised measurement protocol and training of the field workers who carried out the blood pressure measurements. Despite these precautions, bias due to different blood pressure measurers (inter-measurer bias) could not be completely ruled out [19]. However, since the differences in the blood pressure measurements between the measurers and blood pressure machines were small, the impact on the findings was probably not substantial. To cover the range of different arm sizes in the children, two different cuffs were used (see also Section 3.1). Because cuff size showed an association with blood pressure, it was controlled for statistically in the data-analyses.

The measurement of confounders. Previous studies investigating the effects of noise in children [4 - 18] did not always have the opportunity to adjust for important potential confounders. In RANCH, a broad range of possible confounding factors such as socio-economic status (SES), parental support, insulation (window glazing), ethnicity and long-standing illness were measured in a uniform way across the countries.

Weaknesses

Design. As a consequence of the cross-sectional design it is not clear when and how fast the effects of noise develop, and whether they increase in case noise exposure lasts longer; in other words, the time course of the effects found is unknown.

Exposure assessment. As is the case in most epidemiological studies, it can not be ruled out that the cross-sectional studies suffer from a degree of misclassification. Firstly, the way noise exposure was assessed is fairly crude: Noise exposure for each child was assessed by linking home and/or school addresses to modelled equivalent aircraft and road traffic noise levels, predicting the average outdoor noise exposure during a specified time interval. In all participating countries, aircraft noise levels ($L_{Aeq,\ 7\text{-}23\ hrs,}$ and $L_{Aeq,\ 23\text{-}7hrs}$) were obtained from nationally available noise contours. In comparison with aircraft noise which exposes an area in a relatively uniform pattern, road traffic noise is more difficult to predict (i) because it is a ground-based source with a complex propagation path from source to receptor, and (ii) because of the uncertainties in traffic flow throughout the day [21]. Moreover, the estimated road traffic noise levels at the façade of the children's school might not reflect the average exposure during their time at school: In the study presented in this thesis, the noise level was estimated only at one façade of the school building and attributed to all children visiting this school. In some circumstances this procedure might have lead to an over- or underestimation of the noise level affecting some parts of the schoolbuilding. In reality, children move in and out of settings daily and change classrooms during their time at school. Since the difference in noise load between the different façades of the schoolbuilding was not estimated, the impact on the findings of the way road traffic noise levels for the school situation was estimated, is unknown.

The measurement of children's cognitive performance, health and annoyance. Because both annoyance and perceived health were measured within the same questionnaire, there is a chance that the true association between annoyance and perceived health might be overestimated: it appears that many correlations between stressors and health may be spuriously inflated because of the common influence of neuroticism when both variables are measured through self-report [22].

Cognitive performance was not measured under quiet conditions; as a consequence it is unclear whether noise interferes directly with test performance or if the abatement-related differences reflect an after-effect of noise although, with the exception of neurobehavioural functioning, effects of acute noise exposure were adjusted for in the analyses [1, 2].

Despite the careful selection-procedure, the matching of schools, and the measurement of confounders, differences in socio-economic status and ethnic composition of the participating samples could not be prevented. However, with the exception of blood pressure (see also Section 3.1) the effect on the results was probably small, since the association between noise exposure and the different outcomes under investigation was hardly affected by the inclusion of potential confounding factors into the statistical models.

Results of the meta-analysis

Strenghts

In comparison with the traditional narrative and/or qualitative reviews, a meta-analysis is often more systematic [23]. However, still the studies that were included into the meta-analysis differed considerably in their designs, data collection methods and the definition of the exposure and/or outcome and confounder variables. To overcome this and to investigate whether differences in study characteristics could explain the observed variability of the study results, a consistent measure of association was used. As is demonstrated in Sections 3.2 and 3.3, several sources of heterogeneity were investigated. A second concern that has already been addressed elsewhere in this is publication bias: If the reasons that studies remain unpublished are associated with their outcome, the validity of a systematic review or meta-analysis can be seriously threatened [24]. For the meta-analysis presented in this thesis it appeared that studies with negative results have been published less often (see also Section 3.2).

Since 2000 more case-control and cohort studies have been carried out in order to investigate the relation between transportation noise and cardiovascular disease. This is a positive development: in comparison with cross-sectional studies, the design of case-control and cohort studies is usually considered as having a higher validity and credibility.

Weaknesses

There are concerns with regard to the measurement of the different cardiovascular outcomes in the studies that were included in the meta-analysis. Outcomes such as the prevalence of hypertension and the use of cardiovascular medicines were often measured by means of questions about doctor diagnosed hypertension and medication use that were part of a questionnaire. As is addressed in Section 6.4, the reliability of such a method is questionable, making the results sensitive for bias.

Most studies investigating the impacts of transportation noise exposure on blood pressure and cardiovascular disease have involved between-group comparisons. It is recognised that the results of these studies may be sensitive to decisions about cut-off points used to categorise continuous exposure variables and the method used to assign scores to exposure categories [140]; this might have caused exposure misclassification.

Assessment of the number of cases attributable to aircraft noise exposure

Chapter 6 already addressed some concerns with regard to the estimated number of primary school children living around Schiphol Airport that were affected by aircraft noise exposure. Since there are no guideline values for reading comprehension available, indicating a low test result, cut-off points for ‘a low test result’ were defined based on the percentile distribution of the scores of the reading test. It appeared that the outcomes of the assessment were sensitive for the choice of the cut-off point for the definition of a low test result for reading comprehension: Using the 5^{th} percentile instead of the 10^{th} percentile for the definition of a low test result changed the number of attributable cases from 390 to 130 per school year; in case it is supposed that children are at risk for a low test result at 55 dB(A) instead of 50 dB(A) the number of attributable cases changed from 130 to 25 pupils per school year. Sensitivity analysis also demonstrated that the outcomes of the assessment of Chapter 6 are sensitive for the choice of the aircraft noise level from which children are supposed to be at risk for a low test result for reading comprehension.

7.3 How do the findings relate to previous research?

The effects of noise on children's cognitive performance
Effects of road traffic and aircraft noise exposure at school were observed on the more difficult parts of the Switching Attention Test (SAT) from the NES. In earlier RANCH analyses, associations were identified between exposure to aircraft noise at school and impairment of reading comprehension and recognition memory. It was estimated that a 5 dB(A) difference in aircraft noise was equivalent to 2-month reading delay in the United Kingdom and a 1-month reading delay in The Netherlands. Road traffic noise exposure was linearly associated with increases in episodic memory. Neither aircraft noise nor road traffic noise exposure affected sustained attention or prospective memory [1]. In addition, the association with noise exposure at home was investigated. Aircraft noise exposure at home was highly correlated with aircraft noise exposure at school and demonstrated a similar association with impaired reading comprehension [2]; this was not the case for neurobehavioural functioning, where no effects of home noise exposure were found (see also Chapter 4).

Aircraft noise exposure. The results for aircraft noise were in agreement with the results of other recent field studies investigating the effects of transportation noise exposure at school on children's cognitive functioning: In the Munich Airport Study (MAS) the effect of aircraft noise exposure was investigated in 326 children (mean age 10.8 years), taking advantage of a naturally occurring experiment which resulted from the re-allocation of Munich Airport. Effects of aircraft noise exposure ($L_{Aeq\ 24hrs}$) were found on reading, episodic memory, working memory and attention. Children living in the noisier areas made significantly more faults on the reading test than children living in the quiet areas. In addition, children from noise exposed communities had more errors on a difficult subscale of a German standardized reading test than children from quiet communities; the groups did not differ on the easy and intermediate portions of the test [9, 10]. Adverse impacts on the more complex memory tasks were found, after comparing simulated and actual aircraft noise exposure in the laboratory and in the field [27]. The significant association between aircraft noise exposure and long-term memory and sustained attention was not replicated in RANCH. A possible explanation could be the fact that in the MAS children were tested under quiet conditions in a sound attenuated laboratory, thus teasing apart chronic from acute noise exposure during testing.
The results on reading comprehension can be compared directly with the findings of both the WLSS and SEHS, comparing the cognitive performance of primary school children attending high noise schools with children attending control schools exposed to lower levels of aircraft noise [11 – 13]. In both studies reading comprehension was measured by means of the Suffolk Reading test, as was also the case for the British

children participating in RANCH [2, 11 - 13]. The RANCH results were consistent with the results of the SEHS, indicating that exposure to aircraft noise was associated with impaired reading comprehension. This was equivalent to a 6 month delay in reading comprehension in those children exposed to high levels of aircraft noise ($L_{Aeq,\ 16hrs}$ > 66 dB(A)) compared to those exposed to low levels of aircraft noise ($L_{Aeq,\ 16\ hrs}$ < 57 dB(A)) [11, 12]. The RANCH-findings were not consistent with the findings of the WLSS. In this study, investigating 451 children aged 8-9 years, no significant differences on the score of the reading comprehension test, memory and sustained attention were found between children in the noise ($L_{Aeq,\ 16hrs}$ > 63 dB(A)) and quiet groups ($L_{Aeq,\ 16hrs}$ < 57 dB(A)). However, when the 15 most difficult items of the reading test were analysed separately, a significant difference was found between the two noise exposure conditions [13].

The researchers of the Los Angeles Airport Study (LAAS) found impaired performance on difficult cognitive tasks in 262 primary school children aged 8-9 years: As an indication of the effects of noise on attention, children chronically exposed to noise were tested to examine whether they would become inattentive to acoustic cues. These tests were administered under quiet conditions [6 - 8]. Similar to RANCH, no association with noise exposure was found. However, in the LAAS, the exposed children were more easily distracted as they were longer exposed, while the children in the control group were less easily distracted [7]. For reading, scores of the California Test of Basic Skills were gathered from school files. These tests were administered in the classroom. Aircraft noise exposure at school had no effect on the reading scores. There were, however, effects of home noise levels on reading scores: children from noisier homes had poorer reading scores than did children from quieter homes [6].

Possible explanations for the fact that no effects of aircraft noise at school were found on reading in both the WLSS and the LAAS, were their relatively limited contrasts in aircraft noise exposure. Furthermore, the children participating in these studies were somewhat younger (age 8-9 years) than the children participating in the RANCH study (9-10 years): achievement tests for younger children may be less reliable and thus produce lower statistical power [6]. In addition, there could be an age-related noise effect on reading because of the longer exposure to noise.

Road traffic noise exposure. For the effects of road traffic noise exposure, a comparison with other studies is more difficult, since only a few studies investigating the impact of noise exposure on children’s cognitive functioning, have focussed on the effects of road traffic noise exposure. Cohen and colleagues (1973) investigated the effects of road traffic noise in 73 children living in four 32-floor apartment buildings located near an expressway. They found that children living on the lower floors of the 32-storey buildings (exposed to higher noise levels) showed greater impairment of reading achievement than children living in the higher-floor apartments. The longer the children had lived in the apartment complex, the stronger the correlation between noise levels and reading deficits [4]. However, it seems that the levels of noise exposure in this study were typically above 80 dB(A). Which may explain the lack of effects in RANCH, where annual equivalent road traffic noise levels ($L_{Aeq,\ 7\text{-}23hrs}$) ranged from 32 to 71 dB(A).

Recently, the results of the Tyrol Mountains Study (TMS) were reported, investigating the effects of road- and rail traffic noise exposure on the cognitive performance of 123 children (aged 9-10 years) from rural Alpine areas [14]. Half of the sample came from areas where noise levels were below 50 dB(A) (L_{dn}) and half from areas where noise levels were above 60 dB(A) (L_{dn}). In the TMS, attention was indicated by a visual search task where the children had to identify one or more target stimuli among an array. As was the case in RANCH, no association was observed between road- and rail traffic noise exposure and attention. A possible explanation of finding no effects of road traffic noise on attention may be due to task sensitivity: in both studies, the attention task may have been too easy. As opposed to RANCH, in the TMS effects of noise on intentional[1] memory were found: as noise increased, the memory became impaired [14]. Procedural factors could account for the difference in outcome: The TMS tested children under quiet conditions thus teasing apart chronic from acute noise exposure during testing. Another difference is the way the stories for the memory test were presented: In the TMS the children had to read a story, while the stories in RANCH were presented by audio-cd. Furthermore, one should realise that the memory tests of the paper-and-pencil test battery that have been used in RANCH have been developed for the RANCH-project and have not been standardised on large, representative populations of children. As a consequence the precision of the RANCH memory tests may be lower in comparison with for example the reading comprehension test. In comparison with the TMS, the contrast in road traffic noise exposure in RANCH is on the other hand relatively large; possibly the effects of road traffic noise exposure in the RANCH study are affected by the fact that the participants were also exposed to aircraft noise.

Conclusion. Since the NES was not administered in other studies investigating the effects of transportation noise exposure at school on children, a direct comparison with the results of other studies was not possible. However, because of their consistency with the results of other recent studies which investigated the effects of transportation noise on the more complex and difficult parts of cognitive tests, the results point to the conclusion that exposure to aircraft noise impairs children's performance mainly on the difficult tasks; performance on simple tasks is less

[1] Children read stories and were afterwards tested for recall of prose material; children are aware at the time of encoding that they will be subsequently tested.

susceptible to the effects of noise than performance on more complex tasks, requesting increased mental performance [56].

Furthermore, the findings of earlier studies with regard to aircraft noise were confirmed, indicating that there is an effect of aircraft noise on reading, which may run at a maximum to a reading delay of about 6 months. The results of the effects of aircraft noise exposure on children's memory and attention that were found in the literature were less consistent. This could be due to differences in testing procedure (administration of cognitive tests in the class-room versus tests that were administered in a sound-attenuated laboratory), the limited exposure range of some studies or the age of the study population under investigation.

The RANCH findings with regard to road traffic noise exposure were less straightforward: on one hand impairments in switching attention were found (Chapter 4), while on the other hand improvements of episodic memory were found [1]. This was not the case for aircraft noise exposure, where both memory and attention were impaired. A possible explanation for the difference in cognitive effects found between aircraft noise exposure and road traffic noise exposure might be due to the fact that aircraft noise is more intense and less predictable than road traffic noise exposure [1] suggesting that the effects of road traffic noise exposure might be affected by the fact that the participants were also exposed to aircraft noise. Furthermore, there is not enough study material available to draw general and definite conclusions with regard to the effects of road traffic noise on children's cognitive performance.

Children's annoyance reactions

Exposure-response associations were found between aircraft and road traffic noise exposure and the percentage of severe annoyance in children. This was consistent with results of all previous studies investigating children's annoyance reactions to aircraft and road traffic noise [9 – 13, 15, 18, 28], which demonstrated that annoyance was significantly higher among children in high noise schools and areas compared with low noise schools and areas. However, due to amongst others a lack of a standard methodology for measuring annoyance in children, a direct comparison with these previous studies is difficult. Since (i) annoyance was measured uniformly across the three samples, (ii) the size of the number of participants and (iii) because sample selection was done in such a way that the participants were uniformly distributed over a broad exposure range for both road traffic and aircraft noise exposure, it was possible to derive source specific exposure-response relations for children. As is demonstrated in Chapter 6, these relations can be used to assess the impact of noise exposure on children. This is an advance on earlier work.

From the results of this thesis it can be concluded that children's annoyance can be reliably measured by means of a questionnaire. This was demonstrated in a factor-analysis (Chapter 2) indicating that the way annoyance was measured was valid for children; additionally, the correlational pattern and factor structure of the data indicate that children are capable of making a distinction between annoyance and other related constructs.

Another finding of this thesis was that annoyance was found to be related to poorer performance on two of the neurobehavioural tests and self-reported health symptoms. As is addressed in Chapter 5, this was consistent with the few other studies that have investigated the effect of annoyance on cognitive functioning [2, 13, 29] and self-reported health [30]. There is however a chance that the true association between annoyance and perceived health might be overestimated, since both were measured within the same questionnaire (see also section 7.2).

Unexpectedly, children who reported annoyance due to noise at school had a lower blood pressure compared to children that reported no annoyance. Since this association has not yet been investigated in children, a direct comparison with other studies is not possible. Psychological models of stress which suggest that subjective environmental assessments make a significant contribution to the prediction of stress outcomes such as blood pressure can only partly explain these findings. It is possible that the combined exposure to aircraft and road traffic noise might have affected both children's blood pressure and annoyance response. Or maybe there is some kind of compensatory effort effect: expressing their stress-feelings and/or irritation decreases the child's physical stress.

No significant differences were observed in the relation between noise and health and neurobehavioural functioning between the group of children who were annoyed and the group of children who were not annoyed. This interaction effect has not been tested previously. A potential problem is the relatively small group of annoyed children; this may have influenced the group comparisons. Therefore, no definite conclusions can be reached with regard to the 'effect-modifying' role of annoyance.

The effect of noise on children's blood pressure

Due to differences between the samples, the relation between aircraft noise and blood pressure was not fully consistent; negative associations were found between road traffic noise exposure and blood pressure; the evidence in previous studies investigating the effects of noise on children's blood pressure [9 – 13, 15, 18, 28, 31 - 34] was not consistent. Therefore, no unequivocal conclusions can be drawn with regard to the effect of noise on the blood pressure of children.

The effect of aircraft noise exposure on blood pressure differed between the samples (see also Section 3.1). The observed differences in annoyance cannot explain this: Although children who reported annoyance due to noise at school had a lower blood pressure compared to children that reported no annoyance, annoyance did not modify the association between noise exposure and blood pressure. Furthermore, it appeared that the observed differences between noise and blood pressure between annoyance groups were not significant. Possibly, differences in the effect of the ethnic composition might have played a role: due to these differences, the impact of ethnicity on the association between noise exposure and blood pressure might differ between the samples. As a consequence, statistical adjustment might not have lead to a complete adjustment for confounding factors. Alternative explanations for the difference between the samples are: differences caused by life-style factors such as salt intake and physical exercise, differences in the frequency and type of insulation of both the schools and homes.

As is addressed in Section 3.1, the unexpected negative associations found between road traffic noise exposure and children's blood pressure could possibly be explained by the way road traffic noise exposure was assessed.

Comparison with the results of this thesis with the inconsistent results of previous studies investigating the effects of noise exposure on children's blood pressure [9 – 13, 15, 18, 31 - 34] is difficult due to differences in exposure metrics and differences in adjustment for confounders across these different studies.

The effect of noise exposure on children's perceived health

No direct associations were observed between noise exposure at school and perceived health. Earlier, Stansfeld *et al.* (2005) observed no effects of either aircraft or road traffic noise on self-reported health [1]. Other recent studies investigating the effects of aircraft and road traffic noise on children's perceived health also found no effects on perceived health [9, 11 – 13]. The results of this thesis were not consistent with those of the TMS showing that children from the noisier neighbourhoods reported greater stress symptoms over the previous week in comparison to those from quiet areas [16]. The results found in this thesis may be partly the consequence of relatively crude questions used in the child questionnaire measuring potentially subtle subjective health symptoms in relation to noise exposure. As was already addressed in Section 1.4.2, divergent definitions and terms have been used in the past, and perceived health has not been measured in a uniform manner. Therefore, no definite conclusions can be reached with regard to the evidence for a relation between noise exposure and perceived health. Nevertheless, the weight of the evidence suggests no association between aircraft and road traffic noise and perceived health in children.

The effect of noise exposure on the cardiovascular system

The results of the meta-analysis were consistent with a slight increase of cardiovascular risk in populations exposed to aircraft and road traffic noise. However, they are limited because of possible exposure misclassification, reporting bias due to the fact that the cardiovascular outcomes of the participating studies were usually measured by means of self-report, the limited adjustment for important confounders, and the occurrence of publication bias.

Direct comparison with the results of other meta-analyses investigating the effects of noise on cardiovascular disease is difficult. Outcome measures of the meta-analysis presented in this thesis were the Relative Risk (RR) on hypertension, angina pectoris, myocardial infarction, use of cardiovascular medicines, consultation of a GP/specialist per 5 dB(A) increase of the noise level, assuming that there is a linear relation between noise exposure and the prevalence or incidence of these cardiovascular outcomes. This is different from a recent other meta-analysis investigating the association between road traffic noise exposure ($L_{Aeq,\ 6\text{-}22hrs}$) and myocardial infarction [26]. In this study, risks (Odds ratios or Relative Risks) per noise exposure group were estimated; persons exposed to noise levels equal or less than 60 dB(A) were used as reference group [26]. By doing this, it was implicitly assumed that no effects of noise will occur below these levels.

Children and adults

Scientific evidence from studies investigating the susceptibility of children to noise in a systematic way is lacking. Comparative research between children and adults is lacking [3]. In Section 3.4 an attempt was made to compare the estimates derived from child studies with the estimates derived from adult studies. Since the results of both the child and adult studies were inconsistent, no conclusions can be drawn with regard to the difference between adults and children. The findings with regard to annoyance have more power, since annoyance in children and their parents was measured by similar questions. Although the mothers were more annoyed at higher aircraft noise levels, the results show that the shape of the exposure-response relations describing the relation between aircraft noise exposure and annoyance in the mothers was very comparable with that of their children. Similar results were found in the TMS [15] investigating the effects of road traffic noise and annoyance reactions of children and their parents. Boman and Enmarker (2004) investigating the differences and similarities of pupils' and teachers' annoyance reactions due to road traffic noise, demonstrated that the annoyance structure was of the same nature for pupils and teachers [36]. This supports the findings of our factor analysis in chapter 2 and earlier findings that children's annoyance reactions are not different from those found in adults [37].
With regard to sleep, the results of the few studies investigating children's sensitivity to the effects of traffic noise in comparison to adults, are inconsistent: Lukas (1972) concluded that children are less prone to awakenings due to aircraft noise than adults [38], while Muzet *et al.* (1980) showed that 6-10 year old children had a higher cardiovascular response to traffic noise than young adults and elderly people [39]. Eberhardt (1987, 1990) estimated that the same sleep EEG-reactions occur in adults and children if the noise is 10 dB(A) higher for children than for adults [40, 41]. Also, inconsistent results from RANCH were reported: it appeared that children had better perceived sleep quality and fewer awakenings than their parents, while sleep

assessed by wrist-actigraphy revealed less body movements for parents than for children [3].

Given the results presented in this thesis and the findings in other studies, it can be concluded that children do not always appear to react differently to noise exposure than adults do; children per se are not more impaired than adults by noise exposure. However, it has to be kept in mind that children may be longer exposed to higher future levels throughout their life than the adults that were studied. On the other hand the chance that children move to another address is also higher compared to adults, so current high exposed children might have a lower exposure in future.

The number of primary schoolchildren in the Schiphol region affected by aircraft noise exposure

Chapter 6 demonstrated that the exposure-response relations that were derived for annoyance and reading comprehension were applicable for the situation around Schiphol Airport. Until recently, the insights in childhood effects of transportation noise were not sufficiently sound and consistent to allow such an assessment. It was estimated that 110-720 pupils per school year visiting primary schools around Schiphol Airport have a low test result for reading comprehension due to aircraft noise exposure using the 10^{th} percentile as cut-off point. An estimated 850 pupils per school year in the Schiphol region are severely annoyed at school due to aircraft noise. Since this is the first attempt in which the effects of noise exposure on children were quantified, comparison with other assessments is not possible.

The estimates that are presented in Chapter 6, make clear what the reported effects on reading comprehension can mean for all primary school children living around Schiphol airport. An average delay in reading difference of 1-2 months per 5 dB(A) increase of the aircraft noise level was found. The majority of children will probably not notice this in real life. However, the impact of noise differs between children and reading delays may be greater or lesser in some children than in others. In addition, not every child has the same average level of cognitive performance as point of departure so in particular children who have already a poorer reading performance, are likely to be more at risk; low achievers are more susceptible to the detrimental effects of noise on reading scores. This hypothesis is supported by sketchy evidence: after comparing standardized reading and math scores of low, medium and high achiever high school students in noisy and quiet schools, it appeared that students with low aptitude attending noisy schools had the clearest noise-associated deficiencies in math and reading [42 in: 6].

7.3 Comparison with existing guidelines

In the World Health Organization's Noise Guidelines, children are considered as a vulnerable group, since they behave differently, and their coping mechanisms are not fully developed [43, 44]. In table 7.5 guidelines for settings where most children spent a part of their time are presented.

TABLE 7.5 *WHO Guidelines for noise [44].*

Specific environment	**Critical health effect(s)**	**L_{Aeq} (dB(A))**	**Time base (hours)**
Outdoor living area	Serious annoyance, daytime and evening	55	16
	Moderate annoyance, daytime and evening	50	16
Dwelling, indoors	Moderate annoyance, daytime and evening	35	16
School classrooms and pre-schools indoors	Speech intelligibility, disturbance of information extraction, message communication	35	During class
School, playground outdoor	Annoyance (external source)	55	During play

The exposure of primary school children to transportation noise
A direct comparison of the WHO guideline values with population-exposure distributions of primary school children in The Netherlands is not possible because some WHO-guideline values are expressed as indoor values and/or are valid for certain types of activities. However, when looking at the distribution of primary schools in The Netherlands to transportation noise exposure, the following picture emerges: Figure 7.1 shows the number (N = 6,584) of primary schools per dB(A) in The Netherlands with a road traffic noise level (outdoor, expressed in $L_{Aeq,\ 7\text{-}23hrs}$) of at least 35 dB(A) in 2002. It is estimated that about 717 schools have a road traffic noise level of more than 55 dB(A). This is about 10% of all Dutch primary schools; about 173,000 pupils are present at these schools. Of the 1,088 primary schools that were situated in the Schiphol region, 911 (84%) had an aircraft noise level of 35 dB(A) or more. Fifteen schools (1.4%) had an aircraft noise level of more than 55 dB(A) in 2002. On these 15 schools, there were in total about 3,200 pupils (see also Figure 6.3 in Chapter 6).

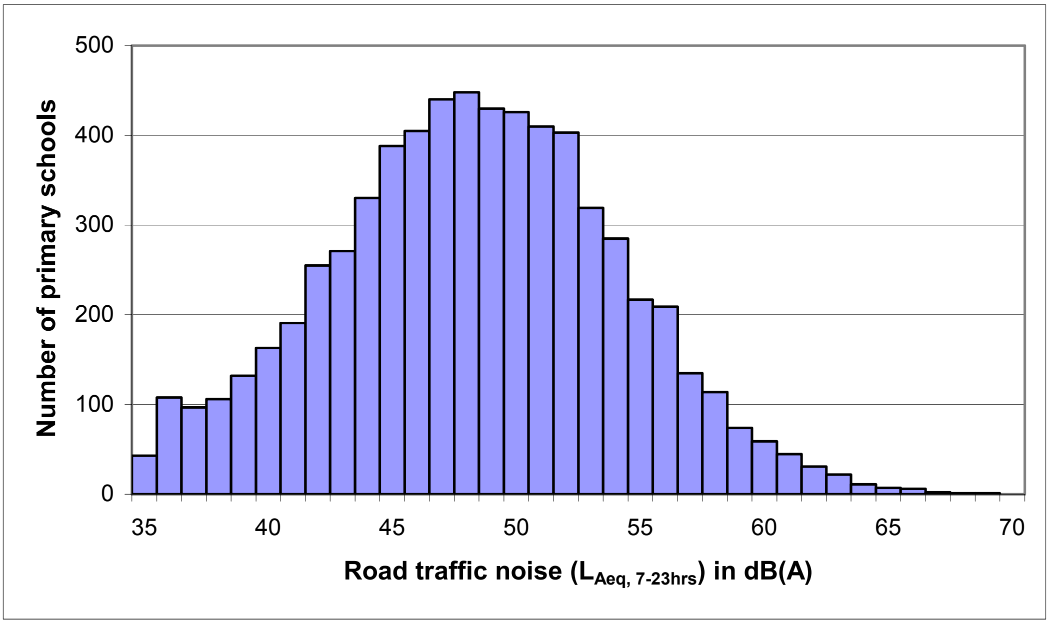

FIGURE 7.1 *Distribution of primary schools in The Netherlands (N = 6,584) to road traffic noise levels ($L_{Aeq, 7\text{-}23hrs}$) of at least 35 dB(A).*

The relation between noise and children's health and cognition

An exposure-response relation was found between aircraft noise exposure at school and impaired reading comprehension. The estimated change in reading Z-score did not significantly depart from linearity [1, 2] suggesting that within the exposure range under investigation ($L_{Aeq, 7\text{-}23hrs, outdoor}$: 35-70 dB(A)) no indications for a threshold were found. This is consistent with the continuous exposure-response relation of Figure 6.2 showing that the risk for a low test result on reading comprehension increases continuously for aircraft noise levels from about 40 dB(A) ($L_{Aeq, 7\text{-}23\ hrs}$). However, the OR per 2.5 bands in Figure 6.2 suggest that the risk for a relatively low test result increases (OR > 1) at aircraft noise levels between 50 – 55 dB(A) ($L_{Aeq, 7\text{-}23hrs}$) (outdoors); the 5 dB(A)-bands in Figure 6.1 even suggest that the risk increases between 55 – 60 dB(A) (outdoors). Given the fact that the WHO community guidelines recommend a L_{Aeq} of 35 dB(A) *indoors* for schools with regard to speech intelligibility, disturbance of information extraction, and message communication, this could suggest that the guidelines probably not need to be lowered; however, the effects of sound insulation at school on children's cognitive performance are not yet clear: it is unknown whether sound insulation has ameliorative effects on impairments in cognitive performance.

For annoyance, the WHO community guidelines recommend a L_{Aeq} of 55 dB(A) (outdoor) for noise from external sources for school. The findings in Chapter 2 indicate that some children were already severely annoyed at lower levels ($L_{Aeq, 7\text{-}23hrs\ outdoor}$ 45 dB(A)) which suggests the WHO community guidelines for annoyance may need to be lowered to protect these children. Unfortunately, nothing is mentioned in the WHO community guidelines with respect to the effects of noise on children's blood pressure and/or perceived health.

It is important to mention that it was not possible to say whether the effects of noise on cognition and blood pressure were solely caused by noise exposure at school or at home. This is different for annoyance: It was specifically asked whether the child was annoyed at home or at school by the noise source.

The relation between transportation noise and cardiovascular disease

With regard to cardiovascular effects, the WHO-guidelines state that "epidemiological studies show that cardiovascular effects occur after long-term exposure to noise with $L_{Aeq\ 24hr}$ values of 65-70 dB. However, the associations are weak. The association is somewhat stronger for ischemic heart disease than for hypertension" [44]. At the moment there is still discussion about a possible threshold value for the relation between transportation noise exposure and cardiovascular disease. In his recent meta-analysis, Babisch assumes that no effects of road traffic noise exposure will occur below levels of 60 dB(A) ($L_{Aeq\ 6\text{-}22hrs}$) [26]. However, the decision about cut-off points used to categorise continuous exposure, may have affected the shape of the presented relation with road traffic noise. The meta-analysis that is presented in this thesis was confined to the estimation of relative risks ($RR_{5dB(A)}$) for hypertension, angina pectoris, myocardial infarction, ischemic heart disease, the use of cardiovascular medicines, and consultation of a GP/specialist per 5 dB(A) increase of the noise level. The most important reason for the use of $RR_{5dB(A)}$ is that most participating studies have involved between-group comparisons using different 'reference' groups across the studies: for example some studies considered persons exposed to road traffic noise levels less than 60 dB(A) ($L_{Aeq,\ 6\text{-}22\ hrs}$) as reference group [48, 51]; some considered persons exposed to road traffic noise levels less than 55 dB(A) ($L_{Aeq,\ 6\text{-}22\ hrs}$) as reference group [45, 52, 53]; others considered persons exposed to road traffic noise levels 51 – 55 dB(A) ($L_{Aeq,\ 6\text{-}22\ hrs}$) as reference group [54]. By doing this, researchers implicitly assumed that no effects of noise will occur below these levels. But, what is the 'best' reference group for a meta-analysis? At the basis of the studies that participated in the meta-analysis it is therefore concluded that at the moment it is impossible to derive possible threshold values for the relation between noise exposure and cardiovascular disease.

However, Chapters 2 and 6 have demonstrated that it can be useful to investigate the relation with both continuous noise exposure and noise exposure as a categorical variable; investigating the relation with noise exposure as a continuous variable only, gives an incomplete picture.

7.4 Implications for underlying (biological) mechanisms

In this Section the findings will be discussed in the light of existing theories about the possible underlying (biological) mechanisms of how noise exposure affects health and cognition that were indicated in the introduction.

The findings of this thesis partly support the idea that noise may act as a physiological stressor, suggesting that blood pressure elevations are vegetative responses: in the Dutch sample, aircraft noise exposure was associated with a statistically significant increase in blood pressure; this was not the case in the British sample. The findings for road traffic noise were difficult to interpret, since negative associations were found. Since the observed differences in blood pressure were small, our findings could be due to chance.

Based on the findings in this thesis it cannot be ruled out that the appraisal of the noise affects the association between aircraft-and road traffic noise exposure and children's health and cognition. However, this conclusion is limited due to the relatively small group of annoyed children, which may have influenced our group comparisons. Furthermore, the observed relation between annoyance and perceived health is possibly biased because both were measured within the same questionnaire.

At the moment there is still no clear working mechanism that can adequately account for the circumstances in which noise will affect cognitive performance. Several theories are known, of which the most important ones are described in Section 1.3.2. Unfortunately, it was not possible to test any of these hypotheses with the data gathered for this thesis.

The weigh of evidence for the hypothesis that the noise-related effects found in children might be the consequence of a decrease in sleep quality, caused by noise exposure during the night is rather weak: Because of the high correlations between aircraft noise levels during the day-evening period ($L_{Aeq,\ 7\text{-}23\ hrs}$) and aircraft noise during the night period ($L_{Aeq,\ 23\text{-}7\ hrs}$) that were observed in the cross-sectional studies of RANCH, no conclusions can be drawn about the relative importance of school- and night-time noise exposure. Also the findings of the meta-analysis were not supportive: two studies were included that investigated the association between road traffic noise and myocardial infarction for both the day-evening period ($L_{Aeq\ 6\text{-}22\ hrs}$) and the night period ($L_{Aeq\ 22\text{-}6\ hrs}$); this involved a cross-sectional (prevalences) [45] and a case-control study (incidences) [46 - 48]: in the cross-sectional study an increase of road traffic noise during the day-evening period was associated with an increase of the prevalence of self-reported myocardial infarction, while an increase of road traffic noise exposure during the night period was associated with a decrease of the prevalence of self-reported myocardial infarction [45]. In the case-control study an increase of road traffic noise during the day-evening period was associated with an increase of the incidence of myocardial infarction only in men; an increase of road traffic noise during the night period was associated with an increase of the incidence of myocardial infarction [46 – 48] (see also Figure 3.12 in Section 3.3). For the relation between aircraft noise exposure and the self-reported use of cardiovascular medicines, the estimated $RR_{5\ dB(A)}$ for aircraft noise exposure during the night was somewhat lower than the $RR_{5\ dB(A)}$ for aircraft noise exposure during the day-evening-night period (see also Figure 3.13 in Section 3.4) [25].

Alternatively, compensatory mechanisms might possibly form the link between the effects of noise found on health and cognition: Research shows that people tend to keep their performance relatively constant, in spite of fatigue or stressing factors such as noise. Most people can overcome the aversive effects of a stressor on task performance by increased effort. Annoyance might mean that there are physiological costs connected to the endeavour to adapt to the situation. Costs that have been more or less identified are the inability to cope with new stressors, reduced motivation, cardiovascular problems [49]. Effects of school noise exposure were observed in the more difficult parts of the SAT together with effects on blood pressure. It was possible is that the switching attention test was too difficult or that cognitive testing lasted too long for the children. As a consequence, the children might not have been motivated enough, since they were trying to adapt to the situation resulting in a good score on the other cognitive tests. The observed blood pressure elevations may be the ‘costs’ of adaptation to the noise situation. Unfortunately, these possible mechanisms could not be further investigated on the data available for this thesis.

A pathway through which noise also might affect children’s health and cognitive performance is restoration. Restoration from cognitive fatigue and stress is affected by properties of the built environment [50].

7.5 The implications for the later life of the children

As is indicated in section 7.3, children probably will not notice a reading delay of 1-2 months per 5 dB(A) increase of the noise exposure level. The elevations in the number of faults that were made on the SAT (Chapter 4) and were found in relation to noise exposure were small Since there is insufficient specificity to employ the neurobehavioural tests to diagnose (neurotoxic) disorders in individuals [55], the significance of such minor changes is difficult to determine.

Furthermore, the observed effects on children’s cognitive performance may be reversible when noise exposure is reduced. Indications for this were found in the MAS [9, 10]: In 1992 the old airport closed, and a new airport was opened.

Longitudinal analyses indicated improvements in long-term memory and reading comprehension at the old airport. In addition, it appeared that, children with greater exposure duration, independent of grade level and pre-existing reading deficiencies, and those exposed to noise both at home and at school, suffer greater adverse reading impacts; additionally, children in higher grades are more adversely impacted by ambient noise exposure [50].
Based on the results of this thesis it cannot be determined what the meaning of annoyance is for the children in the long term. In keeping with what was found in studies investigating adults, it was observed that annoyed children reported more health symptoms compared to children who were not annoyed. However, because of the cross-sectional results the causality of this association cannot be determined. And since both annoyance and health symptoms were measured within the same questionnaire the results are sensitive to reporting bias.

It is unknown whether and in what way the findings with regard to blood pressure indicate health risks in the later life of the children. As is already indicated in Section 3.1.4, the observed differences in blood pressure were rather small; as a consequence it is difficult to determine their clinical relevance. Furthermore, the blood pressure values that were measured in the participating children fall within the range of what is considered as normal for children of that age. Finally, it is unknown whether the effects of aircraft noise that were found in children living around Schiphol airport are temporary or whether they increase when exposure will last longer.

7.6 Conclusions

Transportation noise exposure impairs children's performance mainly on the difficult tasks. Effects of noise exposure at school were observed in the more difficult and demanding parts of the SAT. This was consistent with the results of other recent studies which investigated the effects of transportation noise on the more complex and difficult parts of cognitive tests. It was demonstrated that the findings with regard to the relation between aircraft noise and reading comprehension are also applicable for the situation in the Schiphol region. Until now, this was not clear. Because of the size of both the number of participants and schools, the power of these findings was high compared to previous studies. Furthermore, the sample selection was done in such a way that the participants were uniformly distributed over a broad exposure range. It is however, unknown whether the observed effects of aircraft noise exposure are temporary or whether they increase when exposure will last longer.

No definite conclusions can be drawn with regard to the effects of road traffic noise on children's cognitive functioning: the findings were difficult to interpret and only a few studies that have investigated the effects of road traffic noise on cognition are known. Possibly, the results might be affected by exposure misclassification.

This was one of the first this studies that systematically measured children's annoyance reactions due to aircraft and road traffic noise in both the home and school setting. The findings were consistent across the three samples. This allowed the estimation of source-specific exposure-response relations for children, and subsequent assessment of the noise impact on children in The Netherlands.

The effects of noise on children's blood pressure are more difficult to interpret. The relation between noise exposure and blood pressure was not consistent: In the Dutch sample, blood pressure increased as aircraft noise increased; this was not the case for the British sample. There were differences in the effects of noise on blood pressure between road traffic and aircraft noise. In addition, the results of previous studies investigating the relation between transportation noise exposure and children's blood pressure, were inconsistent. As a consequence no exposure-response relation for blood pressure could be derived. The clinical relevance of the observed blood pressure changes is still unclear; it is unknown whether and in what way the findings indicate health risks for the later life of children.

The results of this thesis and previous studies suggest no direct association between transportation noise exposure and perceived health in children. However, since divergent definitions and terms have been used in the past, and perceived health has not been measured in a uniform manner, no definite conclusions can be reached with regard to the evidence for a relation between noise exposure and perceived health. Although it can be concluded that there are indications that noise exposure can contribute to an increase of the risk of cardiovascular disease, the evidence for a relation between noise exposure and ischemic heart disease is still inconclusive, because of possible exposure misclassification, reporting bias due to the fact that the cardiovascular outcomes of the participating studies were usually measured by means of self-report, and the occurrence of publication bias.

The findings of this thesis partly support the idea that noise may act as a physiological stressor, suggesting that blood pressure elevations are vegetative responses. In addition, the effects of noise exposure on children's perceived health and cognitive functioning may be a result of the appraisal of noise as a stressor. However, since children's annoyance and perceived health were measured within the same questionnaire, there is a chance that this association is biased. Another problem is the relatively small group of annoyed children; and due the cross-sectional design no conclusions can be drawn with regard to the causality of these findings. The weight of evidence for the hypothesis that the noise-related effects might be the consequence of a decrease in sleep quality, caused by noise exposure during the night is weak: In the cross-sectional study, high correlations were observed between the noise metrics. As a consequence, it is not possible to draw definite conclusions about the relative importance of noise exposure at different settings and periods of the day and possible interactions. The results of the meta-analysis were also not supportive.

Children per se are not more impaired than adults by noise exposure. This conclusion is mainly supported by the finding that exposure-response relations for the association between aircraft noise and annoyance among children were broadly comparable to those among their parents.

7.7 Recommendations

In this thesis, cognitive functioning was operationalised by means of a method that not only minimises observer-bias, gives test-leader independent results, and results that are less sensitive to cultural differences, but also complements the commonly used paper-and-pencil tests in a useful way; we therefore recommend that the use of the NES-test should be more encouraged in future studies investigating the effects of noise on children's cognitive functioning.

Because the effects found on cognitive performance are specific for children, a feasibility study is recommended investigating the possibility of monitoring the effects of noise exposure by means of data of national standardised cognitive tests that are collected yearly at primary schools.

Since there is a lack of a standard methodology for measuring annoyance in children, the use of one uniform annoyance question for children with a uniform definition for (severe) annoyance should be more promoted. Besides, it would be good to link up with methods that are already in use for adults: the standardised questions that were recently recommended by the International Commission on Biological Effects of Noise (ICBEN) and the International Organization of Standardization (ISO). An additional advantage would be that this improves the possibilities for comparative research between children and adults with regard to annoyance.

More structured comparative research is recommended to find out whether and why children are more vulnerable to the effects of noise than adults.

In future, studies should be carried out on whether cognitive impairments diminish and annoyance and/or blood pressure elevations reduce if children are removed from noisy environments, or whether these effects increase if children remain in noisy environments. Such studies would help to discover whether these noise-related effects are temporary or permanent. The results of such studies may also help to find out what repercussions the effects on children's health and cognition have for their later life.

With regard to the exposure assessment of road traffic noise exposure at school, it is recommended to assess the exposure levels the different façades of the school building in order to get more insight into the variation in road traffic noise levels and to decrease possible exposure misclassification.

On the base of the research presented in this thesis it was not possible to fully establish the relative contribution of home and school noise exposure over a 24-hour period to the effects on children's health and cognition. This is an important challenge for future research.

7.8 References

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Summary

Background. This thesis focuses on the effects of exposure to transportation noise on children. Children's exposure may differ from adults' exposure to noise; furthermore, children are suspected of being more susceptible to noise exposure. At the moment, there is a lack of source-specific exposure-response relations describing the association between noise exposure and specific health and cognitive outcomes in children. This is because different, sometimes competing, working mechanisms of how noise affects children's health are suggested. Given the variety of the assumed working mechanisms, no single exposure indicator emerges as the indicator of choice. Day-time and night-time exposure both appear relevant. Furthermore, there are shortcomings in the design and methods of studies investigating the effects of transportation noise on children such as a limited noise exposure range, and the lack of uniformity of the measurement of end points. Moreover, the shortcomings in design and methods hamper the possibilities for quantitative meta-analysis and subsequent assessment of the noise impact on children in The Netherlands.

Objectives. This thesis had the following objectives: (i) to quantify the relation between aircraft and road traffic noise exposure in both the home and the school setting and cognitive performance, annoyance, perceived health and blood pressure in children; (ii) to investigate whether the appraisal of noise affects the association between aircraft and road traffic noise exposure and blood pressure, perceived health and cognitive performance in children; (iii) to investigate whether the effects of noise exposure on blood pressure and annoyance found in children differ from those found in adults; and (iv) to estimate the number of children affected by noise exposure for the Dutch situation.

Approach. To investigate these objectives, a meta-analysis investigating the relation between noise exposure, blood pressure and/or ischemic heart disease (ICD-9: 410-414) was conducted. Secondly, the data of a cross-sectional field study investigating the effects of aircraft and road traffic noise in primary school children living around three airports in the United Kingdom, The Netherlands and Spain were used. The latter were gathered in the framework of the European 5th framework project RANCH. The number of children affected by aircraft noise exposure was estimated using exposure-response relations that were derived in this thesis.

In ***Chapter 2*** children's annoyance reactions to aircraft and road traffic noise in both the home and the school setting were investigated using the data gathered in RANCH. In addition, children's annoyance reactions were compared with those of their parents. An exposure-response relation was demonstrated between exposure to aircraft noise ($L_{Aeq, 7\text{-}23hrs}$) at school and severe annoyance in children: after adjustment for confounders, the percentage severely annoyed children was predicted

to increase from about 5.1% at 50 dB(A) to about 12.1% at 60 dB(A). The findings were consistent across the three samples. Aircraft noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at home demonstrated a similar relation with severe annoyance. Children attending schools with higher road traffic noise levels ($L_{Aeq,\ 7\text{-}23hrs}$) were more annoyed. The exposure-response relation between exposure to aircraft noise and severe annoyance found among children was comparable to the one found in their parents.

Chapter 3.1 investigated the effects of aircraft and road traffic noise exposure on children's blood pressure and heart rate in both the home and the school setting. After pooling the Dutch and British RANCH-data, aircraft noise exposure ($L_{Aeq,\ 7\text{-}23hrs}$) at school was related to a statistically non-significant increase in blood pressure and heart rate. Aircraft noise exposure during the day-evening period ($L_{Aeq,\ 7\text{-}23hrs}$) at home was related to a statistically significant increase in blood pressure. Aircraft noise exposure during the night during the day-evening period ($L_{Aeq,\ 23\text{-}7hrs}$) at home was positively associated with blood pressure; only the association with systolic blood pressure was statistically significant. The findings differed between the Dutch and British samples. After pooling the data, negative but non-significant associations were found between road traffic noise exposure and blood pressure, which cannot be explained.

Chapters 3.2 and ***3.3*** presented the results of a meta-analysis. To this end, more than 65 epidemiological studies published between 1970-2007, investigating the relation between noise exposure (both occupational and community), blood pressure and/or ischemic heart disease (ICD-9: 410-414) were selected and evaluated. A wide range of effects, varying from blood pressure changes to a myocardial infarction, was studied. With respect to the association between noise exposure and blood pressure, small blood pressure differences were noticed. A significant increase in systolic blood pressure was evident for occupational noise exposure: for systolic blood pressure an increase of 0.51 (95%CI: 0.01 – 1.00) mmHg per 5 dB(A) was estimated. A significant association for occupational noise exposure and hypertension was demonstrated: a RR of 1.14 (1.01 – 1.29) per 5 dB(A) noise increase was estimated. Road traffic noise exposure was positively but non-significantly associated with hypertension, angina pectoris and myocardial infarction. However, in most of these studies, the prevalence of hypertension, angina pectoris was assessed by means of one or more questions about doctor diagnosed hypertension or angina pectoris that were part of a social survey questionnaire. Statistically significant associations were found between aircraft noise exposure and hypertension and the self-reported use of cardiovascular medicines.

For the purpose of this thesis, the meta-analysis was extended with observational studies (***Section 3.4***), investigating the association between road traffic and aircraft noise exposure and children's blood pressure in order to investigate how the effects of noise on blood pressure that were found in children relate to what was found in adults. Comparison of the estimates derived from child studies with the estimates derived from adult studies is difficult due to the heterogeneity of the results of the studies.

Chapter 4 presented the relation between aircraft and road traffic noise exposure and cognitive performance in the Dutch RANCH-participants. Cognitive performance was operationalised by means of selected tests from the Neurobehavioral Evaluation System (NES). Effects of school noise exposure were observed in the more difficult parts of the switching attention test: children attending schools with higher road or aircraft noise levels made more faults. No effects of home noise exposure were found.

In ***Chapter 5*** was investigated how annoyance affects the relation between aircraft and road traffic noise exposure and children's health and cognition. Also the association between aircraft and road traffic noise exposure and perceived health was investigated. To this end the data that were gathered in RANCH were used. No direct associations were found between noise exposure at school and self-reported health symptoms: both aircraft and road traffic noise exposure at school were not related to a statistically significant increase in the number of symptoms.

The relation between noise and neurobehavioral functioning and health was not confounded by annoyance: the association with noise hardly changed after additional adjustment for annoyance. Associations were found between annoyance and self-reported health symptoms and the outcomes of several NES tests: children who were annoyed, reported more symptoms compared to children who were not annoyed; children who were annoyed due to aircraft noise at school made significantly more faults at the Switch condition of the Switching Attention Test (SAT), and the span length of these children was also significantly shorter. Unexpectedly, children who reported annoyance due to noise at school had a lower blood pressure compared to children that reported no annoyance. The relation between noise and health and neurobehavioral functioning did not differ between different annoyance groups.

In ***Chapter 6*** it was indicatively estimated that 110-720 pupils per school year visiting primary schools around Schiphol airport have a low test result for reading comprehension due to aircraft noise exposure using the 10^{th} percentile as cut-off point. An estimated 850 pupils per school year are severely annoyed at school due to aircraft noise. Sensitivity analysis showed that the outcomes of our assessment are sensitive for the choice of the cut-off point for the definition of a low test result, and the choice of the aircraft noise level from which children are supposed to be at risk for a low test result for reading comprehension.

Conclusions

Transportation noise exposure impairs children's performance mainly on the difficult tasks. Effects of noise exposure at school were observed in the more difficult and demanding parts of the Switching Attention Test. This was consistent with the results of other recent studies which investigated the effects of transportation noise on the more complex and difficult parts of cognitive tests. It was demonstrated that the findings with regard to the relation between aircraft noise and reading comprehension are also applicable for the situation in the Schiphol region. Until now, this was not clear. Because of the size of both the number of participants and schools, the power of these findings was high compared to previous studies. Furthermore, the sample selection was done in such a way that the participants were uniformly distributed over a broad exposure range.

This was one of the first studies that systematically measured children's annoyance reactions due to aircraft and road traffic noise in both the home and school setting. The findings were consistent across the three samples. This allowed the estimation of source-specific exposure-response relations for children, and subsequent assessment of the noise impact on children in The Netherlands.

The results of this thesis and previous studies suggest no direct association between transportation noise exposure and perceived health in children. However, since divergent definitions and terms have been used in the past, and perceived health has not been measured in a uniform manner, no definite conclusions can be reached with regard to the evidence for a relation between noise exposure and perceived health.

The effects of noise on children's blood pressure are more difficult to interpret. The relation between noise exposure and blood pressure was not quite consistent: In the Dutch sample blood pressure increased as aircraft noise increased; this was not the case for the British sample. There were differences in the effects of noise on blood pressure between road traffic and aircraft noise. In addition, the results of previous studies investigating the relation between transportation noise exposure and children's blood pressure, were inconsistent. As a consequence no exposure-response relation for blood pressure could be derived. The clinical relevance of the observed blood pressure changes is still unclear; it is unknown whether and in what way the findings indicate health risks in the later life of the children.

Although it can be concluded that there are indications that noise exposure can contribute to an increase of the risk of cardiovascular disease, the evidence for a relation between noise exposure and ischemic heart disease is still inconclusive, because of possible exposure misclassification, reporting bias due to the fact that the cardiovascular outcomes of the participating studies were usually measured by means of self-report, and the occurrence of publication bias.

The findings of this thesis partly support the idea that noise may act as a physiological stressor, suggesting that blood pressure elevations are vegetative responses. In addition, the effects of noise exposure on children's perceived health and cognitive functioning may be a result of the appraisal of noise as a stressor. The weigh of evidence for the hypothesis that the noise-related effects might be the consequence of a decrease in sleep quality, caused by noise exposure during the night is weak.

Children per se are not more impaired than adults by noise exposure. This conclusion is mainly supported by the finding that exposure-response relations for the association between aircraft noise and annoyance among children were broadly comparable to those among their parents.

Samenvatting

Achtergrond. In dit proefschrift worden de effecten van de blootstelling aan transportgeluid op het cognitief functioneren, hinderbeleving en gezondheid van kinderen onderzocht. Kinderen zijn mogelijk gevoeliger voor geluid dan volwassenen. Bovendien worden ze mogelijk aan andere niveaus blootgesteld. Tot dusver ontbreken bronspecifieke blootstelling-respons relaties die de effecten van blootstelling aan transportgeluid op het cognitief functioneren, gezondheid en welzijn van kinderen beschrijven. Voor de effecten van de blootstelling aan geluid bij kinderen worden verschillende onderliggende (biologische) werkingsmechanismen verondersteld, waardoor het onduidelijk is wat de beste blootstellingindicator is; zowel de blootstelling aan geluid overdag als tijdens de nacht periode lijkt van belang. Daarnaast hebben de studies die de effecten van transportgeluid bij kinderen onderzoeken, een aantal tekortkomingen wat betreft onderzoeksopzet en gebruikte meetinstrumenten zoals het beperkte contrast in blootstelling en de diversiteit aan gehanteerde meetmethodes aan de effectkant. Het gevolg is dat het niet mogelijk is om op basis van de bestaande resultaten, bronspecifieke blootstelling-respons relaties af te leiden waardoor het niet duidelijk is of bij de heersende geluidsniveaus in Nederland effecten bij kinderen te verwachten zijn.

Vraagstellingen. Dit proefschrift heeft een aantal vraagstellingen: (i) het verwerven van inzicht in de blootstelling-respons relaties tussen de blootstelling aan geluid afkomstig van vlieg- en of wegverkeer thuis en op school en cognitieve effecten, hinder, bloeddruk en ervaren gezondheid bij kinderen; (ii) het verwerven van inzicht in de mogelijke rol die hinder speelt in de relatie tussen de blootstelling aan geluid afkomstig van vlieg- of wegverkeer en cognitieve effecten, hinder, bloeddruk en ervaren gezondheid bij kinderen; (iii) het verwerven van inzicht over de mate dat de effecten van blootstelling aan geluid afkomstig van vlieg- en of wegverkeer en hinder en bloeddruk bij kinderen verschillen van volwassenen; en (iv) het toepassen van de eventueel afgeleide blootstelling-respons relaties op de situatie in Nederland om de omvang van de effecten van geluid in de populatie te beschrijven.

Onderzoeksopzet. Om de vraagstellingen te onderzoeken, is een meta-analyse uitgevoerd waarin epidemiologische studies zijn onderzocht die zijn gepubliceerd tussen 1970 en 2007, en die de relatie tussen blootstelling aan geluid, bloeddruk en of coronaire hartziekten hebben onderzocht. Daarnaast is gebruik gemaakt van de data van een epidemiologisch veldonderzoek onder basisschoolkinderen in de omgeving van drie luchthavens in het Verenigd Koninkrijk, Nederland en Spanje. De laatstgenoemde data zijn verzameld in het kader van het RANCH-project, dat werd uitgevoerd in het kader van het Vijfde Kader programma van de Europese Unie. Voor het bepalen van het aantal kinderen dat is toe te schrijven aan de blootstelling van geluid in Nederland, zijn gegevens over de

verdeling van de geluidblootstelling van Nederlandse basisscholen en de in dit proefschrift afgeleide blootstelling-respons relaties met elkaar gecombineerd.

In ***hoofdstuk 2*** is de hinderbeleving bij kinderen ten gevolge van geluid van vlieg- en wegverkeer thuis en op school onderzocht met behulp van de data die zijn verzameld in het RANCH-project. Daarnaast is de hinderbeleving van de kinderen vergeleken met die van hun ouders. Het percentage ernstig gehinderde kinderen hing statistisch significant samen met geluidniveau van vliegverkeer op school en op het thuisadres. Dit effect werd in alle drie de landen gevonden. Het bleek dat het percentage ernstig gehinderde kinderen door geluid van vliegverkeer op school toeneemt van ongeveer 5,1% bij 50 dB(A) tot ongeveer 12,1% bij 60 dB(A). Geluid van vliegverkeer op het thuisadres vertoonde een vergelijkbare relatie met ernstige hinder. Het percentage ernstige hinder door geluid van wegverkeer op school blijkt gemiddeld hoger te zijn bij hogere geluidniveaus van wegverkeer; dit effect werd in alle drie de landen gevonden. De blootstelling-respons relatie voor de associatie tussen geluid van vliegverkeer en ernstige hinder bij kinderen was vergelijkbaar met de blootstelling-respons relatie die is gevonden bij hun ouders.

In ***hoofdstuk 3.1*** werden de effecten van de blootstelling aan geluid van vlieg- en wegverkeer op school en het thuisadres op de bloeddruk en hartslag bij kinderen onderzocht met behulp van de data van het RANCH-project. In de gecombineerde Nederlandse en Engelse gegevens bleek dat de bloeddruk en de hartslag positief waren gerelateerd aan het geluidniveau van vliegverkeer op school. De bloeddruk en hartslag bleken gemiddeld hoger te zijn bij hogere geluidniveaus van vliegverkeer op school. Deze associaties waren echter niet statistisch significant. Voor de blootstelling in de periode van 7 tot 23 uur thuis werden wel statistisch significante verbanden gevonden: De bloeddruk bleek gemiddeld hoger te zijn bij hogere geluidniveaus van vliegverkeer op het huisadres. De blootstelling aan geluid van vliegverkeer tijdens de nacht op het huisadres was alleen statistisch significant geassocieerd met de systolische bloeddruk.

Het effect van geluid van vliegverkeer op de bloeddruk verschilde tussen de beide onderzoeksgroepen. Voor de blootstelling aan geluid van wegverkeer werden na samenvoeging van de Nederlandse en de Engelse data negatieve associaties gevonden; deze waren statistisch niet significant.

In ***hoofdstuk 3.2 en 3.3*** werden de resultaten van een meta-analyse gepresenteerd waarin het effect van geluid op de bloeddruk en ischemische hartziekten werd onderzocht. Daartoe zijn uiteindelijk meer dan 65 epidemiologische studies geselecteerd en geëvalueerd, die zijn gepubliceerd tussen 1970 en 2007. Als gevolg van de blootstelling aan verschillende geluidbronnen kon een breed scala aan effecten worden gemeten die varieerden in ernst. Er werden kleine verhogingen van de bloeddruk gevonden. Alleen voor de arbeidsstudies werd een statistisch significante toename van de systolische bloeddruk gevonden: 0,51 (95% BI: 0.01 – 1.00) mmHg per 5 dB(A). Daarnaast was de blootstelling aan geluid op de werkplek positief geassocieerd met hypertensie; er werd een statistisch significante associatie gevonden: $RR_{5dB(A)}$ is 1,14 (95%BI: 1.01 – 1.29). De blootstelling aan geluid van wegverkeer was positief geassocieerd met respectievelijk het risico op hypertensie, angina pectoris en myocard infarct. Het betreft hier echter vooral studies waarin is gekeken naar de prevalentie van zelfgerapporteerde hypertensie en angina pectoris. De blootstelling aan geluid van vliegverkeer was statistisch significant geassocieerd met respectievelijk hypertensie en het zelfgerapporteerde gebruik van hartvaatmiddelen.

In het kader van dit proefschrift is de meta-analyse uitgebreid met observationele studies waarin de relatie tussen geluid van vlieg en wegverkeer en bloeddruk bij kinderen werd onderzocht. Het doel was om te onderzoeken in welke mate de effecten van blootstelling aan geluid op de bloeddruk bij kinderen verschillen van de effecten die gevonden worden bij volwassenen (***paragraaf 3.4***). Vanwege de grote variatie in de resultaten van de studies was het echter moeilijk om de resultaten van de kinderstudies te vergelijken met de resultaten van de volwassenen studies.

In ***hoofdstuk 4*** werd de relatie tussen de blootstelling aan geluid van vlieg- en wegverkeer op school en het thuisadres op het cognitief functioneren bij basisschoolkinderen rondom de luchthaven Schiphol onderzocht. Deze data waren verzameld in het kader van het RANCH-project. Het cognitief functioneren werd gemeten met behulp van een aantal gecomputeriseerde testen die afkomstig zijn uit het Neurobehavioral Evaluation System (NES). Er werd een associatie gevonden met de meest complexe onderdelen van de wisselende aandachtstest: bij hogere geluidsniveaus van vlieg- of wegverkeer op school maakten de kinderen meer fouten op deze test. Er werden geen associaties gevonden tussen geluid op het thuisadres en een van de NES-testen.

In ***hoofdstuk 5*** is de mogelijke rol van hinder in de relatie tussen de blootstelling aan geluid afkomstig van vlieg- of wegverkeer en cognitieve effecten, hinder, bloeddruk en zelfgerapporteerde gezondheid bij kinderen, onderzocht. Ook werd de relatie tussen de blootstelling aan geluid van vlieg- en wegverkeer en zelfgerapporteerde gezondheid bij kinderen onderzocht. Hiervoor zijn de data van het RANCH-project gebruikt. Er werd geen directe relatie gevonden tussen geluidblootstelling op school en het aantal zelfgerapporteerde gezondheidsklachten: zowel geluid van vlieg- als wegverkeer op school was niet gerelateerd aan een toename van het aantal symptomen. De relatie tussen de blootstelling aan geluid en het cognitief functioneren en gezondheid werd niet vertekend door hinder: de associatie met geluid veranderde nauwelijks na correctie voor hinder. Er zijn associaties gevonden tussen hinder en het aantal zelfgerapporteerde gezondheidsklachten en de scores op een aantal NES-testen. Kinderen die waren gehinderd door geluid van vliegverkeer op school rapporteerden meer gezondheidsklachten dan kinderen die niet waren gehinderd; bovendien maakten deze kinderen meer fouten op het moeilijkste onderdeel van de wisselende aandachtstest en was hun geheugenspanne op de geheugentest significant korter. Een onverwachte bevinding was dat kinderen die gehinderd waren door geluid op school een lagere bloeddruk hadden in vergelijking met kinderen die niet gehinderd waren. Er werden geen verschillen gevonden in de relatie tussen blootstelling aan geluid en gezondheid en cognitief functioneren tussen gehinderde en niet-gehinderde kinderen.

In ***hoofdstuk 6*** werd geschat dat door de blootstelling aan geluid van vliegverkeer op basisscholen in een gebied rondom Schiphol er per schooljaar 110 tot 720 leerlingen extra zijn die een lage score op de leestest hebben. Het aantal kinderen met ernstige hinder tengevolge van het geluid van vliegverkeer op school werd geschat op 850 leerlingen per schooljaar. Met behulp van een onzekerheidsanalyse is geprobeerd om meer inzicht te verkrijgen in de invloed van een aantal aannames op de omvang van de schattingen van het aantal kinderen met een lage score op de leestest, dat is toe te schrijven aan de blootstelling aan geluid van vliegverkeer.

Conclusies

Blootstelling aan transport geluid heeft vooral een ongunstig effect op de complexere taken: In Nederland is een samenhang tussen onderdelen van de gecomputeriseerde wisselende aandachtstest en geluid van zowel weg- als vliegverkeer gevonden. Deze bevindingen zijn consistent met de resultaten van andere recente studies.

De onderzoeksresultaten laten zien dat de bevindingen met betrekking tot cognitief functioneren uit deze en andere recente studies ook van toepassing zijn op de situatie rondom Schiphol. Dit was voorheen niet duidelijk. Ten opzichte van eerder uitgevoerd onderzoek is de zeggingskracht van de resultaten in dit proefschrift relatief groot omdat er een groot aantal kinderen aan heeft deelgenomen. Bovendien is de studiepopulatie zodanig geselecteerd dat ze evenredig verdeeld is over een brede blootstellingrange.

Met deze studie is voor het eerst systematisch de hinderbeleving van kinderen in kaart gebracht, zowel ten gevolge van vlieg- als wegverkeergeluid in de school en op het thuisadres. De bevindingen zijn eenduidig in de drie onderzochte landen. Dit laat de berekening van bronspecifieke blootstelling-respons relaties voor kinderen toe.

The resultaten suggereren dat er geen directe relatie is tussen transport geluid en zelf-gerapporteerde gezondheid in kinderen. Echter, vanwege de diversiteit aan gehanteerde meetmethodes en gebruikte definities in de diverse studies die relatie met geluid hebben onderzocht, kunnen er geen definitieve conclusies worden getrokken met betrekking tot de bewijslast voor een relatie tussen geluid en zelf-gerapporteerde gezondheid.

De effecten op bloeddruk bij kinderen zijn moeilijker te duiden. De relatie tussen geluid en bloeddruk is niet eenduidig: in Nederland nam de bloeddruk toe bij hogere geluidniveaus van vliegverkeer; in Engeland was dat niet zo. Er waren verschillen in effect op de bloeddruk tussen geluid van vlieg- en wegverkeer. Bovendien was er in de literatuur gebrek aan eenduidigheid, Dit maakt dat er nog geen blootstelling-respons relatie voor bloeddruk kan worden opgesteld. De gezondheidskundige betekenis van de waargenomen bloeddrukveranderingen is nog onduidelijk; het is niet duidelijk wat ze betekenen voor de gezondheid in het latere leven van de kinderen.

Hoewel er kan worden geconcludeerd dat er aanwijzingen zijn dat de blootstelling aan geluid bijdraagt aan een verhoging van het risico op hartvaatziekten, is de bewijslast voor een relatie tussen de blootstelling aan geluid en ischemische hartziekten nog steeds niet eenduidig. Mogelijk is er sprake van misclassificatie van de blootstelling en worden de resultaten vertekend door het feit dat de cardiovasculaire eindpunten in de deelnemende studies vaak werden gemeten door middel van zelfrapportage. Daarnaast is er sprake van publicatiebias.

De resultaten in dit proefschrift ondersteunen slechts ten dele de hypothese dat geluid een fysiologische stressor is, waardoor bloeddrukverhogingen kunnen worden beschouwd als vegetatieve reacties. De effecten van de blootstelling aan geluid op zelf-gerapporteerde gezondheidsklachten en cognitief functioneren kunnen mogelijk ook worden verklaard door het feit dat de kinderen geluid als stressor beoordelen. De bewijslast voor de hypothese dat gevonden effecten mogelijk het gevolg zijn van een vermindering van de slaapkwaliteit ten gevolge van geluidblootstelling tijdens de nacht is zwak.

Kinderen ondervinden niet meer ongunstige effecten van geluid dan volwassenen. Deze conclusie wordt voornamelijk ondersteund door de bevinding in RANCH en andere recente studies dat de blootstelling-respons relaties voor de associatie tussen geluid van vlieg- en wegverkeer en hinder bij kinderen vergelijkbaar zijn met de blootstelling-respons relaties die zijn gevonden bij hun ouders.

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Elise van Kempen was born on February 8th, 1975 in Roermond, the Netherlands. In 1993 she graduated from secondary school at the Bisschoppelijk College in Echt. One year later she obtained her propaedeutic diploma Health Sciences and started her study Environmental Health Sciences both at Maastricht University. In the framework of her study she worked shortly at the Municipal Health Office (GGD-OZL) in Heerlen. In 1998 she obtained her Master’s degree Environmental Health Sciences and started working as an environmental epidemiologist at the National Institute of Public Health and the Environment (RIVM) in Bilthoven at what is now called the Centre of Environmental Health Research (MGO). In the period 2000 - 2005 she worked as researcher for the RANCH-project.

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Appendix I. Sound and exposure metrics

Sound

Noise is often used to refer to an unwanted sound; it is an undesirable component that obscures a wanted signal. Sound is produced by moving objects displacing air molecules. The alternating compressions and decompressions of the air ripple out from the source as waves. The sound waves most keenly detected by human ears are between 1000 and 4000 cycles per second or Hertz (Hz). The entire audible range extends from 20 to 20.000 Hz.

The distance between the peaks and valleys of a sound wave is called its amplitude. A term that is often mentioned with regard to amplitude is the sound pressure; this is the pressure deviation from the local ambient pressure caused by a sound wave. The amplitude or sound pressure level (SPL) is experienced as loudness; the SPL is measured in units called decibels (dB). As the human ear can detect sounds with a very with range of amplitudes sound pressure is often measured as a level on a logarithmic decibel scale. The quietest sounds that humans can hear have an amplitude of approximately 20 microPascals or a sound pressure level of 0 dB. The distance between adjacent wave peaks is the wavelength. The number of wavelengths occurring per unit time is the frequency. The frequency of sound waves is experienced as pitch. The greater the frequency, the higher the sound pitch [1-3].

Sound waves produced by an event such as the passage of an aircraft can be measured by means of a microphone. A microphone has a membrane; when they reach the membrane, the sound waves push against the membrane and cause it to alternately bow inward and outward. This vibration is subsequently converted into an electrical signal that can be analysed and saved. The maximum level (L_{Amax}) of a particular event and the total amount of sound energy in a particular event can be determined. In order to compare and ‘sum’ different sounds, the total amount of sound energy in a particular event is often normalised to a period of one second. This is called the sound exposure level: The SEL of a noise event, such as the noisy passage of an aircraft, is the equivalent sound level during the event, normalised to the period of 1 second. One can add up the SEL values of individual events to calculate a $L_{Aeq,T}$ over some time period (T) of interest (see also Formula (1)).

Since the human ear does not have a flat spectral response, sound pressure levels are often frequency weighted so that the measured level will match perceived levels more closely. Several weighting schemes are available. A-weighting attempts to match the response or the human ear to noise and A-weighted sound pressure levels are labelled dB(A). C-weighting (dB(C)) is used to measure peak levels [1-3].

Noise exposure metrics
A number of different noise descriptors are commonly used to quantify the noise environment. These are based on physical quantities to which “corrections” are applied that take into account the sensitivity of the human ear. Existing noise descriptors fall into two categories:

(i) metrics that indicate the maximal noise level (e.g. maximum level); and
(ii) metrics that sum the noise level over a certain period, the so-called equivalent noise metrics ($L_{Aeq,\,T}$).

Metrics such as the equivalent continuous sound pressure level sum up the total energy over some time period T and give a level equivalent to the average sound energy over that period. In formula:

(1) $$L_{Aeq,T} = 10x\,Log_{10}\left(\frac{1}{T}\right)\int 10^{\frac{L(t)}{10}}dt$$

Where L(t) is the A-weighted sound level at time t; T is the duration of the exposure period (in seconds).

Exposure periods (T) that are commonly used in studies investigating the effects of noise exposure are from 07:00 to 23:00 hours ($L_{Aeq,\,7\text{-}23hrs}$) or from 6:00 to 22:00 hours ($L_{Aeq\ 6\text{-}22\ hrs}$). Equivalent sound levels are usual being used for more or less continuous sounds such as road traffic noise.

In the past, time-varying environmental sound levels have also been described in terms of percentile levels (E.g. L_{10}). These are derived from a statistical distribution of measured sound levels over some period. The L_{90} is noise level that is exceeded for 90% of time and gives an indication of background levels; L_{10} gives an indication of the higher noise levels, while L_{min} and L_{max} show typical minimum and maximum noise levels.

Although noise indices differ per country and within a country even per transport mode, mostly, average noise exposure levels and A-equivalent indices (L_{Aeq}-type) are more common for policy provisions than statistical indices (L_{10} -, L_{50}-type).

Recently, the EU has proposed 2 noise indicators: L_{den} and L_{night}. The day-evening-night level (L_{den}) is an indicator of annoyance from long-term exposure to noise, whereas L_{night} is an overall night-time indicator related to ‘self-reported sleep disturbance’ again from long-term exposure. Both indicators are based on the L_{Aeq} scale (see also equation 1). From this, noise indicators L_{den} and L_{night} are defined as follows:

(2) $$L_{den} = 10x\,Log_{10}\left(\frac{1}{24}\right)\left(12x\,10^{L_{day}/10} + 4x\,10^{(5+L_{evening})/10} + 8x\,10^{(10+L_{night})/10}\right)dB(A)$$

Where L_{day} is the A-weighted equivalent noise level over the 12-hour day time period from 07:00 to 19:00 hours. $L_{evening}$ is the A-weighted equivalent noise level over the 4-hour evening period from 19:00 to 23:00 hours; L_{night} is the A-weighted equivalent noise level over the 8-hour day time period from 23:00 to 07:00 hours. $L_{evening}$ and L_{night} have a 5 and 10 dB weighting applied to each to take account of the difference in annoyance due to the time of day.

The A-weighted equivalent noise level L_{night} is also used as separate noise indicator, but does not include the 10 dB weighting that is applied when determining the noise indicator L_{den} [1, 2]

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