NATIONAL INSTITUTE OF PUBLIC HEALTH AND ENVIRONMENTAL PROTECTION
BILTHOVEN, THE NETHERLANDS

Reportnr 441520004

# Noise and Public Health
# Workshop report

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July 1995

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research for
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This project was conducted under assignment of the Ministry of Housing, Spatial Planning and the Environment, Directorate for Noise and Traffic.

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## SUMMARY NOISE AND PUBLIC HEALTH - A WORKSHOP

### Nature and scope

In 1993 an Environmental Impact Assessment (EIA) was published regarding the planned expansion of the national airport of the Netherlands, Schiphol Airport. In the framework of this EIA several studies on the environmental and health risks of current and future airport activities were carried out, and deficiencies in knowledge identified. From the onset of these studies it was clear that the health impact assessment would have a limited scope due to the short time-frame and limited data availability. For this reason the Ministry of Housing, Spatial Planning and the Environment, the Ministry of Traffic and Transportation, and the State Medical Inspectorate asked the National Institute of Public Health and Environmental Protection (RIVM) to prepare further (epidemiological) studies of aircraft pollution and health effects.
Study proposals were developed concerning a questionnaire survey on perceived environmental quality, health status, annoyance and risk perception and field studies on aircraft noise and, respectively, sleep disturbance and neurobehavioural effects in children.

To ensure the quality and study efficiency of the proposed studies a review of the study proposals by independent international experts was organized. For this reason RIVM convened an international workshop "Noise and Public Health" involving scientists with a broad range of expertise (sleep research, psychology, neurobehavioural science, acoustics, epidemiology). A special meeting on noise and sleep research was organized in collaboration with the universities of Amsterdam and Gothenburg. For this meeting experts from universities, research laboratories, regional health authorities, public-interest groups and consultancies were invited.

### Objectives and context

The main objective of the workshop was to discuss and review proposals for future research into aircraft noise exposure and health effects around Schiphol Airport. In addition, the participants of the noise and sleep meeting discussed the state of the art with regard to knowledge on noise and sleep disturbance and identified research needs and methodology that would enhance the understanding of the relationship between night-time noise exposure and possible health effects. This report is a reflection of the discussion and general conclusions, and where possible, gives an indication of those issues on which different opinions were expressed.

## Main findings and conclusions

### *Research priorities relationship night-time noise, sleep disturbance and health*

The main priorities for future research on noise and sleep are the estimation of the number of people affected by night-time noise and the severity of noise-induced effects, the attribution of noise exposure to long-term health effects and the identification of vulnerable groups.
Due to large discrepancies in exposure-response relationships between laboratory and field studies on noise-disturbed sleep, it is difficult to compare the results of these studies and to develop a single exposure-response curve for sleep disturbance. Moreover, few comprehensive field studies on aircraft noise and sleep disturbance are reported.
Field studies should be carried out to study the impact of environmental noise in large populations and to identify vulnerable subgroups. Laboratory studies should mainly be used to develop and test new methodology and measures and to study the magnitude of susceptibility of risk-groups.

Decreased daily functioning or performance was recognized as the most-important health effect of noise-disturbed sleep. The feasibility of performance tests to measure performance in field studies objectively needs to be assessed. Important other parameters that should be focused on in field research are awakenings or total periods not awakened, difficulties falling asleep, subjective sleep quality, and daily functioning expressed by sleepiness during the day. There was consensus among the workshop participants about the necessity to study several response parameters in parallel to each other, as there is no superior sleep disturbance indicator available.

### *Proposals for field studies into aircraft noise exposure and health effects*

All proposals seem feasible given that adequate resources and exposure assessment are available and some adaptations, as suggested at the workshop, are implemented.

The main objectives of the proposed questionnaire survey are to study the (baseline) prevalence of *annoyance, perceived health and risk perception*, to estimate exposure-response relationships and to study the frequency of health complaints in time, using a self-administered questionnaire and a diary (repeated observations study). It was recognized that the study aims (assessment of prevalence rates and the estimation of exposure-response relationships) may call for different study designs. Although the potentially different design requirements were identified, consensus about an optimal combination of designs could not be reached. It was recommended to carefully evaluate whether the different requirements of the designs can be met efficiently, or whether two separate but parallel studies with different designs are more appropriate. The workshop participants agreed with the proposed options to perform a questionnaire survey in a large

sample (n≈10 000) to study baseline-prevalences or to conduct a split-mode questionnaire survey (2-3 short questionnaires in separate samples). In addition, they agreed to use face-to-face interviews in small independent subsamples (n≈2000) to study more complex issues (i.e. coping).
As an alternative to the proposed diary study to study seasonal variation, repeated administration of the questionnaire in different subsamples has been suggested.
The discussants did not formulate clear-cut conclusions with regard to the selection of outcome variables and mediators.

A combination of actimetry and a diary study is proposed to expand the knowledge about exposure-response relationships between night-time aircraft noise exposure and *sleep disturbance* and after-effects. Five groups of about 50-60 individuals with different noise exposure levels will be selected, each individual will be observed during a month. With the design proposed it is possible to make a comparison between high- and low-exposed groups, but also to compare the repeated daily measurements within groups (repeated observations study). The basic design found general approval but could be improved by including a control group and by increasing the sample size depending on the outcome measure studied. A suggestion was to nest the smaller actimetry study within the larger sleep disturbance questionnaire sample, to enhance the overall study design. A core set of sleep disturbance indicators will be studied consisting of arousals/awakenings, perceived sleep quality and perceived daily functioning (sleepiness, fatigue etc.) using actimetry and questionnaires.
It was advised to carry out the main study first and subsequently, in case sensitive subgroups are identified, decide about further investigations of these groups. It was not recommended to carry out performance tests in the home environment unless they will prove to be feasible in the field.

To study the relation between chronic exposure to aircraft noise and *neurobehavioural functioning* in children, a cross-sectional design is proposed. Two groups of 90 children will be compared, one group living in a high-exposed noise area (>65 dB(A), exposed group) and one group living in a low-exposed noise area (<53 dB(A), control group). The neurobehavioural effects will be tested on a groupwise basis by paper-and-pencil tests (measuring attention) and by computerized tests (measuring attention, psychomotor performance, perceptual coding and learning and memory).
To achieve optimal comparability of study results, the workshop participants recommended to use the same study protocols and methods as in previous studies, if possible. The proposal should be more specific about the type of effect that is measured (acute effect due to noise exposure in the previous night versus chronic effects) and the measurement and analysis of noise exposure and potential confounders.

The discussants agreed that the overall study design might be enhanced if the study group is restricted to an age group of only 8 years old. Also, it should be considered though to increase the sample size for the main study. In addition to the proposed neurobehavioural tests, a reading and intelligence test should be added.
Finally, a pilot study should be performed to test the feasibility of the proposed methods for application in the school environment.

The participants concurred that there are no superior indicators to characterize aircraft *noise exposure*. They agreed with the study proposals to study different noise metrics. All the proposals should clearly specify the noise metrics, the time period the metric concerns and the statistics that will be recorded.
Equal energy measures of noise in the form of contours are necessary for all the studies proposed, and is sufficient for the questionnaire study in which noise annoyance is the main outcome. For the sleep disturbance study validation of model calculations is recommended by measurements of indicators such as $L_{Aeq,night}$, SEL, $L_{A,max}$ and number of noise events exceeding certain $L_{A,max}$ levels. The proposal to carry out indoor noise measurements was strongly supported. For the neurobehavioural study, noise measurements both at home and at school are advised.
With the existing noise monitoring system around Schiphol the potential for a good noise characterization around Schiphol airport is available, as long as an independent quality control of the measurements or audit is guaranteed. In addition, a pilot is warranted to assess the reliability of the fixed noise monitors and to study the representativeness of NOMOS measurements for the exposure of the population at large. Also, some indoor measurements in a limited number of houses are recommended to study the outdoor/indoor attenuation in noise exposure.

The research proposals will be finalized according to the workshop's recommendations. The studies will be carried out in 1995-1997 by a collaborating team of research staff from various research institutes and universities. The studies will be guided by a steering committee and a panel of experts. Local health authorities and public interest groups will regularly be informed about the studies' progress. The final results of Phase II will be presented and discussed at an international expert meeting.

## SAMENVATTING

### *Inleiding*

In verband met de voorgenomen aanleg van een vijfde baan bij de luchthaven Schiphol is in 1993 een Milieu Effect Rapportage (MER) gepubliceerd. In het kader van het Evaluatieprogramma van de MER heeft het Ministerie van VROM het RIVM verzocht verder (epidemiologisch) onderzoek naar de gezondheidseffecten van milieuverontreiniging gerelateerd aan vliegverkeer voor te bereiden en te coördineren. Het onderzoek bestaat uit twee delen: onderzoek naar de huidige gezondheidstoestand van de omwonenden van de luchthaven gericht op slaapverstoring, cognitieve prestaties en gedrag en hinder, gecombineerd met metingen van geluid en luchtverontreiniging en een monitorings-onderzoek voor het signaleren van veranderingen in de milieukwaliteit en gezondheidstoestand bij uitbreiding van de luchthaven.

Om een aantal onderzoeksvoorstellen door externe deskundigen te laten beoordelen heeft het RIVM een internationale workshop 'Noise and Public Health' georganiseerd in samenwerking met de universiteit van Amsterdam en Göteborg. Dit rapport geeft een samenvatting van de discussies en conclusies van de workshop.
Het doel van deze workshop was tweeledig. Enerzijds het presenteren van de stand van kennis op het gebied van geluid en slaap(verstoring) en het vaststellen van prioriteiten en geschikte methoden voor verder onderzoek op dit gebied. Daarnaast zijn voorstellen voor verder onderzoek naar de gezondheidstoestand van de bevolking woonachtig rondom de luchthaven Schiphol beoordeeld door een panel van internationale deskundigen van verschillende disciplines. De onderzoeksvoorstellen die zijn besproken betreffen een vragenlijstonderzoek naar beleving van de milieukwaliteit, ervaren gezondheid, hinder en risicobeleving rondom Schiphol en een tweetal veldonderzoeken naar het effect van blootstelling aan (vliegtuig)geluid op de slaap bij volwassenen en op de cognitieve prestatie en het gedrag van kinderen.

### *Prioriteiten voor onderzoek naar effecten van geluid op de slaap*

Prioriteiten voor verder onderzoek naar geluid en slaapverstoring zijn: het vaststellen van de ernst en de omvang van de gezondheidseffecten door blootstelling aan nachtelijk (vliegtuig)geluid, met nadruk op lange-termijn effecten en het identificeren van gevoelige groepen.
Bevolkingsonderzoek uitgevoerd in de woonsituatie is nodig om de omvang van de gevolgen van slaapverstoring door blootstelling aan (vliegtuig)geluid in de leefomgeving vast te stellen. Aanbevolen wordt om bij een dergelijk bevolkingsonderzoek meerdere respons parameters parallel te bestuderen omdat een superieure indicator voor het vaststellen van de mate van slaapverstoring ontbreekt. De meest relevante indicator voor

gezondheidseffecten van geluid als gevolg van slaapverstoring is het functioneren overdag (slaperigheid overdag). Andere belangrijke respons parameters voor veldonderzoek zijn ontwaakreacties (of totale periode zonder ontwakingen), moeite met inslapen en ervaren slaapkwaliteit.

***Voorstellen voor onderzoek naar gezondheidseffecten van blootstelling aan vliegtuiggeluid***

Alle onderzoeksvoorstellen zijn positief beoordeeld en worden zinvol en haalbaar geacht, mits enkele aanpassingen, zoals voorgesteld tijdens de workshop, worden toegevoegd en adequate financiering gewaarborgd is.

*Vragenlijstonderzoek*

De deelnemers stemden in met het voorstel om de prevalentie van hinder, gezondheids-klachten en risicobeleving vast te stellen aan de hand van een vragenlijstonderzoek. Dit bestaat uit een schriftelijke vragenlijst in een grote steekproef (≈ 10.000) en persoonlijke interviews in een kleine subgroep (≈ 2.000). Onderwerpen van de vragenlijst zijn ervaren gezondheid, de mate van hinder, risicobeleving en gezondheidsklachten (b.v. slaapverstoring). De interviews zijn geschikt voor het bestuderen van complexe onderwerpen (b.v. omgaan met milieuproblemen).

*Slaapverstoringsonderzoek bij volwassen*

Een gecombineerd design is voorgesteld om de relatie tussen vliegtuiggeluid en slaapverstoring bij volwassenen te onderzoeken. Een vragenlijstonderzoek geeft een beeld van de prevalentie van slaapverstoring in de algemene bevolking. Om de relatie tussen blootstelling aan nachtelijk vliegtuiglawaai en het optreden van slaapverstoring (ontwaakreacties), de ervaren slaapkwaliteit en effecten op het functioneren vast te stellen wordt een zogenaamd 'herhaalde waarnemingen onderzoek' voorgesteld bij 300 volwassenen (> 40 jaar, vijf groepen van 50-60 personen, 4 weken) die blootstaan aan verschillende nachtelijk geluidsniveaus. De deelnemers stemden in met de voorgestelde aanpak en methoden. Suggesties voor verbetering van het design zijn o.a. het toevoegen van een controlegroep, het uitbreiden van de leeftijdsrange en het verhogen van het aantal deelnemers per onderzoeksgroep, afhankelijk van de onderzochte effectparameter. Objectieve tests voor het bepalen van het functioneren overdag kunnen alleen worden toegepast als deze haalbaar blijken te zijn voor toepassing in de woonsituatie.

*Onderzoek naar cognitieve prestaties en gedrag van kinderen*

Om de effecten van vliegtuiggeluid op de cognitieve prestaties en het gedrag bij kinderen te bepalen wordt een dwarsdoorsnede-onderzoek voorgesteld bij twee groepen van 90 kinderen met een hoge en een lage belasting aan vliegtuiggeluid. Het cognitief en motorisch functioneren van de kinderen zal op school onderzocht worden met behulp van pen- en papiertaken en computertests. De computertests vormen een selectie uit het Neurobehavioural Evaluation System (NES) en meten de domeinen: aandacht, leervaardigheid, perceptuele verwerkingssnelheid, motorische vaardigheid en geheugen. De workshop deelnemers adviseerden om zoveel mogelijk dezelfde methodiek en tests te gebruiken als bij soortgelijk onderzoek rond andere luchthavens. Het type effect dat gemeten wordt, de manier waarop de geluidsblootstelling gemeten en geanalyseerd wordt en de mogelijke confounders moeten in het onderzoeksvoorstel nader gespecificeerd worden. Daarnaast is voorgesteld om een lees- en intelligentietest toe te voegen aan de voorgestelde tests. De haalbaarheid van de voorgestelde tests voor toepassing in een schoolomgeving moet in een pilot onderzocht worden.

*Geluidsmetingen*

Het is onduidelijk wat de beste maat is om de mate van blootstelling aan vliegtuiggeluid te beschrijven. De deelnemers stemden daarom in met het voorstel om tijdens de diverse veldonderzoeken de blootstelling aan vliegtuiggeluid in verschillende maten te beschrijven. De blootstellingsmaten en de tijdsperiode waarover de geluidsbelasting bepaald wordt moet in de verschillende voorstellen nog nader gespecificeerd worden. Voor elk onderzoek zijn verschillende blootstellingsmaten vereist, maar gegevens over equivalente geluidsniveaus (in de vorm van contouren) zijn voor alle onderzoeken gewenst. Het bestaande GeluidMeetSysteem (GMS) van de luchthaven Schiphol is bruikbaar voor een goede blootstellingskarakterisering, mits een onafhankelijke kwaliteitscontrole gegarandeerd is. Aanbevolen wordt om een pilot studie uit te voeren naar de representativiteit van de gegevens van het GMS voor de blootstelling van de bevolking rond Schiphol. Daarnaast zijn geluidsmetingen aanbevolen in een aantal woningen voor het bepalen van het verschil tussen geluidsniveaus buiten en binnen (met name in de slaapkamer).

# 1 INTRODUCTION

## 1.1 Background

A major expansion is planned for the national airport of the Netherlands, Schiphol airport. In 1993, an Environmental Impact Assessment (EIA) was published in which the impact of the expansion and its alternatives on both the environment and public health was described. The Health Impact Assessment (HIA, phase I) was carried out by the National Institute of Public Health and Environmental Protection (RIVM) in collaboration with TNO Prevention and Health, TNO Toxicology, the Free University of Amsterdam and the University of Groningen[1]. From the onset of the HIA, within the framework of the EIA, it was clear that the assessment would have a limited scope due to the short time-frame and limited data availability. In line with the advice of the Commission for Environmental Impact Assessment about the EIA Schiphol airport, RIVM was therefore asked by the Ministry of Housing, Spatial Planning and the Environment to prepare and coordinate further studies to assess the current impact of airport pollution on public health. To this end RIVM drafted several research proposals[2] and organized a workshop 'Noise and Public Health' to review the study proposals and to identify critical research needs. This report summarizes the discussion and main conclusions of the workshop.

The HIA is being conducted in several stages. Phase I studies have been performed within the framework of the EIA, ending in 1993.
Phase II studies will be carried out during the period 1995-1997. Phase II of the HIA consists of three parts. The first part is an extension of the analysis of data from existing health registries which were not available in time for Phase I.
The second part consists of field studies to characterise the exposure to noise and air pollutants, and epidemiological investigations into the relation between aircraft-related exposures and health effects such as sleep disturbance, perceived health, annoyance and risk perception. The proposals and motivation of the Phase II studies are described in a working document[2]. The proposals for the air pollution studies will be developed at a later stage.
The third part of the HIA is the development of a monitoring system, consisting of a feasibility study based on the results of the other Phase II research activities and pilot studies for additional data collection, e.g. general practitioner registries.

## 1.2 Approach and objectives

The objectives of the workshop were:

1) To discuss and review proposals for future research on health effects from exposure to aircraft noise around Schiphol airport.
2) To present the state of the art with respect to the knowledge on noise and sleep disturbance and discuss priorities and methodology for further research on noise and sleep.
3) To enhance communication on research outcomes and possibilities for future research between scientists, technical engineers and decision-makers from government and public-interest groups.

The workshop was held on 2-4 October 1994 at Noordwijkerhout, the Netherlands, involving 30-40 participants. In collaboration with the Universities of Amsterdam and Gothenburg a special meeting on noise and sleep research was organized on October 2, to discuss the research priorities formulated at the 'Noise and Man' conference in Nice in 1993 with several sleep researchers. On October 3, a general lecture meeting was held consisting of keynote presentations addressing the current knowledge on issues concerning noise, sleep disturbance and health as well as methodology. This general lecture meeting and subsequent discussion was open to experts from universities, governmental organizations, consultant agencies, regional health authorities and public-interest groups. Subsequently, on October 4, the study proposals for Phase II of the HIA have been discussed in a small group of scientists from the field of sleep research, psychology, neurobehavioural science, acoustics and epidemiology (see annex 1 for a complete programme, and a list of reviewers and working group members). Prior to the workshop several experts in the research areas concerned were asked to review the study proposals. The comments of the reviewers were used for the discussion in separate workgroups.

The outcome of the workshop is presented in this report. It reflects the discussion and general conclusions, and where possible, gives an indication of those issues on which different opinions were expressed. Chapter 2 gives an overview of the state of the art on noise and sleep research as well as recommendations for further research in this area. Chapter 3 is a summary of the comments of the reviewers and subsequent discussion about the separate study proposals. The general conclusions and recommendations as well as the future implications for the research proposals are presented at the end of each section in chapter 3. Annex 2 contains the list of workshop participants.

The authors gratefully acknowledge the significant contribution of all workshop participants. Special thanks go to the reviewers and to Marion Drijver (Municipal Health Service Zuid-Kennemerland) for her contribution to chapter 3.3 of this report. The Ministry of Housing, Spatial Planning and the Environment funded the workshop.

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# 2 NOISE, SLEEP (DISTURBANCE) AND HEALTH EFFECTS
## State of the art and research needs

## 2.1 Introduction

This chapter is a summary of the meeting on noise, sleep disturbance and health which addressed the state of the art and research priorities in this area, in particular focusing on field studies on environmental noise and sleep disturbance (see annex 1 for programme). The main issues discussed were health effects of (noise) disturbed sleep, including aspects of biological rhythm and daily functioning, and methods for field studies on sleep disturbance by (aircraft) noise. Methods for the evaluation of sleep quality were addressed, such as questionnaires ('subjective sleep quality') as well as more objective methods like the sleep-EEG or actimetry measuring body movements.

Four main research questions were pivotal in the discussions:

*1) What are the night-time noise-induced effects (including effects both during and after sleeping time)?*
*2) What are the exposure-response functions for the general population?*
*3) Which risk-groups can be identified?*
*4) What is the public health relevance of these noise-induced effects?*

To a large degree the information presented by the keynote speakers only pertained to the first three questions.

The following sections provide an overview of the current understanding of the relation between exposure to night-time aircraft noise and health effects, the characterization of night-time noise exposure, appraisal of night-time noise, effects induced by night-time noise, methods to measure night-time noise induced effects and critical issues in field studies. The main conclusions with regard to future field studies are summarized in section 2.7.

## 2.2 Relation between exposure to night-time aircraft noise and health effects

In theory, when sufficient data and knowledge are available, the impact of environmental noise on public health can be estimated on the basis of the environmental noise exposure of the population in question and the exposure-response relations derived for aircraft noise-induced effects. Due to large discrepancies in exposure-response relationships

between laboratory and field studies on noise-disturbed sleep, however, it is difficult to develop a single exposure-response curve for sleep disturbance. Moreover, few comprehensive field studies on aircraft noise are reported in the literature. Recent literature overviews show that although the same effects are observed under both laboratory and field conditions, the magnitude of effects differs considerably[1,2]. Figure 2.1 shows that at the same Sound Exposure Level, the percentage of subjects aroused or awakened is much higher in laboratory studies than in field studies. The same pattern but to a somewhat lesser extent, is observed for sleep stage changes. In figure 2.1 the results of a recent field study in the United Kingdom are also shown[3]. The effect of aircraft noise on sleep was studied using actimetry in 400 people living near four airports. An increase in awakenings was observed at SEL values of 80 dB(A) outdoors or 55 dB(A) indoors. The results comply with earlier field studies.

The workshop participants agreed that habituation to environmental noise and the use of different methods are important reasons for the discrepancy between laboratory and field studies. These discrepancies can be understood from the scheme presented in figure 2.2.

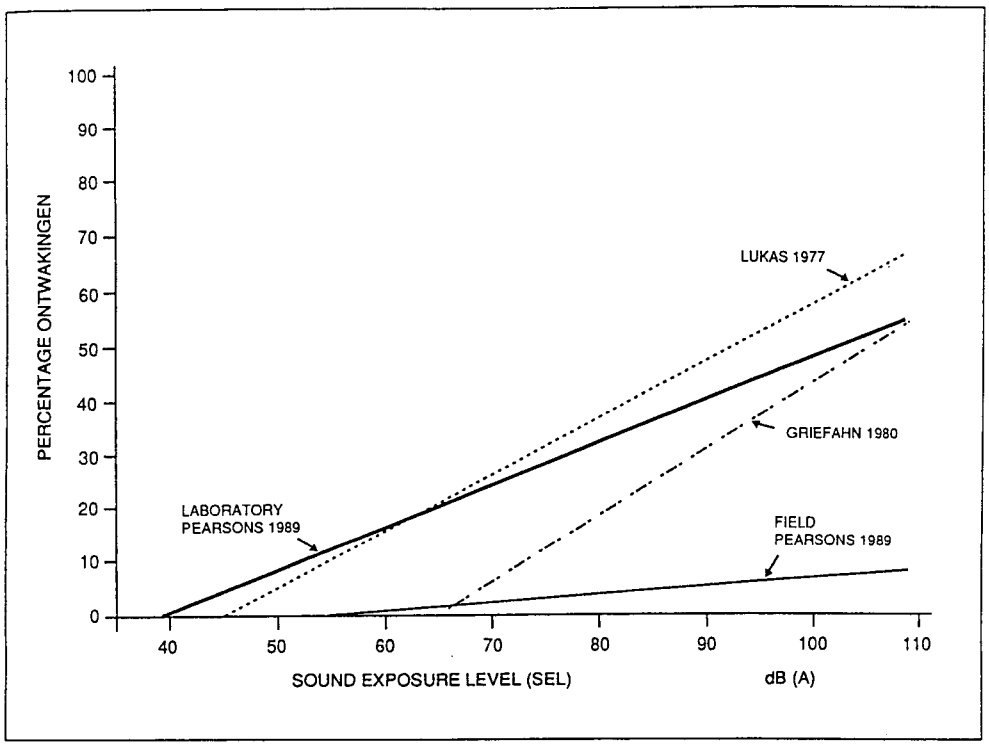


*Figure 2.1* *Comparison of reviews showing awakening or arousal for various Sound Exposure Levels (Source: Pearsons, 1989[1]; Passchier-Vermeer, 1993[2]).*

The model presented in figure 2.2 is adapted from a recent publication of the Health Council of the Netherlands[4] and describes the relationship between night-time noise exposure and health effects. The cause-effect chain is divided into three steps: exposure to noise, appraisal by the organism and effect. In all steps, so-called modifying factors play an important role. The modifying factors for exposure, appraisal and effect obviously are very different in laboratory and field conditions. Differences between these two conditions are therefore not only expected for outcomes like awakenings, as pictured in figure 2.1, but also for other outcomes like sleep stage changes or self-rated sleep quality. The role of (potential) modifying factors is discussed in more detail in the following sections.

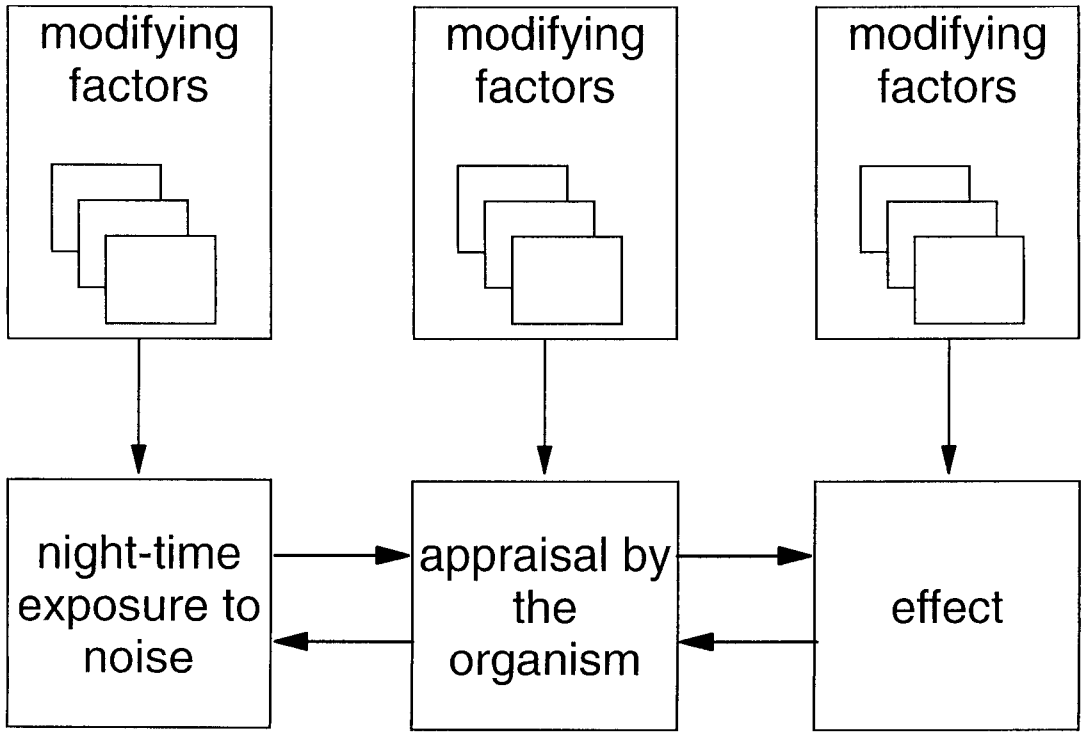


*Figure 2.2* *Model of the relation between night-time noise exposure and a noise-induced effect. For different noise-induced effects different modifying factors may be of importance.*

## 2.3 Characterization of environmental night-time noise exposure

To characterize noise exposure of a more or less isolated noise event, noise measures such as the maximum sound level ($L_{A,max}$) and the sound exposure level (SEL) are in use. To characterize exposure to environmental noise, such as aircraft noise, values representative

of longer exposure durations are used. The equivalent sound level ($L_{Aeq,T}$) over a period of T hours is such a measure. In the equivalent sound level the individual SEL values and the number of noise events are taken into account in a specified way. In the simple case that the SEL values of all noise events occurring during a period of time are equal, the $L_{Aeq,T}$ over that time is determined by the sum of this SEL value and 10 times the logarithm of the number of noise events. Also other overall measures of night-time noise exposure, such as $L_1$ (the sound level exceeded in 1% of the night-time period), are sometimes used. Another measure is the number of noise events during the night, or the number exceeding a certain SEL value or $L_{A,max}$ value.
Modifying factors which influence the actual noise exposure of populations are described below.

***Indoor noise exposure***

In laboratory experiments on sleep disturbance, noise exposure is usually expressed in terms of noise metrics determined indoors (in the bedroom). Field investigations usually describe noise exposure by (measured) outdoor sound levels. The difference between outdoor and indoor noise levels depends upon many factors such as type of dwelling, type of aircraft, operation of the aircraft (descent or take-off), state of the windows (open or closed) and type of window-glazing (single or double glazing). Measurements in the Netherlands have shown average sound insulation values of 20 dB(A) for single glazing and 25 dB(A) for double glazing. These empirical average values, however, should be considered as indicative, only to be used as a 'rule of thumb' when comparing the results of laboratory studies with those of field investigations, since sound insulation varies widely in individual situations.

***Night-time noise exposure***

At certain times of the night people are more liable to be aroused by noise than at other times. Considerable interindividual differences in sleep-patterns, as shown by the preferred times of getting up, have been reported between 'morning-' and 'evening-'sleepers and between young and elderly people. These inter-individual differences in sleep-pattern appear to follow from differences in circadian rhythm, as expressed in the body temperature rhythm: the body temperature is closely associated with the optimal period of sleep. As a consequence, any external disturbance during the beginning and the end of the socially accepted sleep period has a differential individual effect. In particular 'morning-types' or early sleepers seem to be more sensitive to sleep disturbance than 'evening-types' or late sleepers.
In the night-time noise regulations in the Netherlands with respect to aircraft noise, the night is defined as a period of 7 consecutive hours in the period from 23.00 to 7.00 hours. However, an investigation into the activities of people[5] has shown that the duration of the

night-rest of people covers a longer period. Moreover, people working in nightshifts and infants have their sleep period also during the day.

***Type of environmental noise***

The exposure pattern arising from different types of noise sources may vary considerably. For instance, around Schiphol Airport the number of aircraft noise events during one night (23.00-6.00 hours) in 1993 was on average about 30. Close to a main highway, the pattern of noise events is quite different with the number of road vehicles amounting to 3000 or more per night.

## 2.4 Appraisal by the organism

All acoustic signals of sufficient intensity activate the central nervous system, and are unconsciously evaluated by the organism in order to determine required immediate actions, which may be necessary to survive. But noise exposure is also evaluated on a longer time scale. In that case, factors such as coping and the relation to the environmental noise source may influence the appraisal and thus the noise-induced effects. One very important difference between laboratory and field investigations concerns the habituation of the test subjects to the noise exposure. In field investigations, test-subjects are used to the night-time noise events and in laboratory studies this is usually not the case. It depends on the effect under study whether habituation has a modifying effect. Awakenings seem to be highly affected by habituation to night-time noises. No habituation to noise exposure at night, however, occurs with respect to sleep stage changes or cardiovascular parameters such as heart rate and vasoconstriction, as suggested by an European field study on road traffic noise[6].

Some of the factors which modify the appraisal are familiarity with the noise signal, habituation, information content of the noise, relation to the noise source and behaviourial characteristics.

## 2.5 Effects induced by night-time noise

Noise-induced effects which have been observed in laboratory studies or field investigations are listed in table 2.1. There seems to be no clear relationship between objective sleep disturbance measures, such as changes in the sleep structure, and subjective measures, such as self-reported sleep quality. Good correspondence has been observed though between actimetry results (total periods not awakened or immobility index) and subjective notions of sleep quality [7,8].

*Table 2.1. Night-time noise-induced effects*

| |
|---|
| Increase in the number of awakenings during the sleep period |
| Changes in time falling asleep |
| Changes in the number of sleep stage changes, from deeper sleep to a lighter stage |
| Changes in sleep structure |
| Increase in the number of body movements |
| Increase in the number of arousals |
| Changes in heart rate and other cardiovascular parameters |
| Changes in hormone levels |
| Annoyance |
| Changes in subjective assessment of sleep quality |
| Changes in mood during the day |
| Tiredness during the day |
| Changes in performance during the day |
| Accidents and mistakes during the day |
| Increased medical consumption |
| Changes in physical health |
| Changes in social well-being |

Decreased daily functioning and daytime performance are recognized by the workshop participants as the most important health effects of noise-disturbed sleep. Sleep disturbance as such may not be directly detrimental to health, but sleepiness can have indirect effects such as increased risk at work. Both laboratory and field studies show that exposure to night-time noise induces cardiovascular changes. No habituation for this effect is observed and cardiac responses occur even when the sleep structure is not influenced. Whether these cardiovascular responses have any health implications remains uncertain though. Cardiovascular changes may lead to permanent health damage in people with long-term exposure to road traffic noise but could be of lesser importance in the situation of aircraft noise exposure due to differences in exposure patterns.
It is not clear whether night-time noise exposure affects the immune system. Studies into noise-disturbed sleep and effects on the immune system show no consistent findings.

Many effect-modifying parameters emerge from the results of laboratory and field investigations. These include: age, gender, personality aspects, day-time stress, tiredness during the daytime, and sleep deficit. Tiredness during the day and sleep deficit in fact could be the result of noise-disturbed sleep or other factors but, if present, modify the effect at subsequent exposures.

A distinction can be made between 'vulnerable' groups, i.e. groups which show a larger noise-induced effect than an average population and 'noise-sensitive' groups, i.e. groups of people that estimate themselves more sensitive to noise (which consider themselves more annoyed) than the average population. Shift workers, elderly people and children have been identified as vulnerable groups (see also section 2.3).
It became clear during the meeting that a subgroup which is more vulnerable with respect to one noise-induced effect, is not necessarily also more vulnerable with respect to another noise-induced effect. It also became clear that vulnerability and sensitivity do not correlate well: people who consider themselves noise-sensitive do not necessarily show the largest night-time noise-induced effects.

## 2.6 Critical issues in field studies

The participants identified the following main priorities for future research on noise and sleep: the estimation of the number of people affected by night-time noise and the severity of noise-induced effects, the attribution of noise exposure to long-term health effects and the identification of vulnerable groups.

The choice of methodology in field studies depends on the type of noise source, effects under study and the feasibility of the measurements in large populations. In case of road traffic noise (with many noise events) the most important effect to focus on appears to be cardiac responses and in case of air traffic noise (with fewer noise events) awakenings, decreased sleep quality and, if feasible, performance.

The participants identified the following effects as priorities for field research:
- tiredness or sleepiness the next day,
- number of intermittent awakenings,
- number of body movements,
- periods without body movements,
- subjective sleep quality,
- ability to fall asleep,
- cardiovascular parameters,
- effects on early sleepers.

These effects were considered to be important, since they seem to allow the determination of a clear noise-induced effect. On a long-term basis they might be related to health. Other sleep parameters such as stability of the sleep, amount of REM and deep sleep measured by EEG are important too but difficult to study in a field situation due to logistic reasons.

There was consensus among the workshop participants about the necessity to study several response parameters in parallel to each other, as there is no superior sleep disturbance indicator available. For each field study a careful selection of a core-set of indicators is needed.

Outcome measures to be studied in field studies can be separated in night-time measures and next-day measures. Examples of night-time measures are 'time to fall asleep', arousals or awakenings. Next-day measures are perceived sleep quality and sleepiness during the day.

Sleep structure can be studied by electroencephalogram (EEG). Because the feasibility of EEG measurements in large field studies is problematic, alternative methods have been developed to study sleep disturbance. Awakenings or arousals can be estimated indirectly by actometers registering body movements[7]. Other more subjective methods to investigate awakenings are behavioral measures such as pressing a button or questionnaires after sleeping time. The push-button method is only advised in a field study when used for a period of more than one 1 month (with perhaps exclusion of the first week measurements). Sleep latency or ability to fall asleep can be measured subjectively using diaries or estimated by actigraphy.
Subjective sleep quality can be expressed as difficulty to fall asleep, perceived awakenings and feelings in the morning about sleep[8]. Subjective sleep quality can be measured by repeated questionnaires (diaries) which refer to the night prior to the measurement or a general questionnaire which refers to a longer time period. Morning questionnaires are available that concentrate on perceived awakenings, sleep latency and sleepiness. Also questionnaires during the day can be used to evaluate mood, fatigue and sleepiness. Evening questionnaires can be used to measure tiredness during the day. It is important that these questionnaires are always filled in at the same time.
Daily functioning or performance can be investigated by subjective measures (sleepiness during the day) or more objective performance tests. The feasibility of using performance tests in a large field study with adults has to be investigated further.

## 2.7 Conclusions and recommendations for future research on noise and sleep disturbance

It is difficult to predict the health effects of noise-disturbed sleep due to large discrepancies in exposure-response relationships derived from laboratory and field studies and the limited number of comprehensive field studies on aircraft noise.
It was concluded that the use of different methods and the role of modifying factors such as habituation to environmental noise are important reasons for the observed discrepancy

between laboratory and field studies. Modifying factors for exposure, appraisal of noise and effects are very different in laboratory and field conditions. Important modifying factors which can influence the actual noise exposure of populations in different studies are sound insulation, night-time noise regulations and type of noise source. Examples of factors which may modify the appraisal are habituation, familiarity with the noise signal, information content of the noise signal and relation to the noise source. Awakenings seem to be highly affected by habituation to night-time noises. No habituation to noise exposure at night, however, is observed with respect to sleep stage changes or cardiovascular parameters. Finally, modifying factors which can influence the magnitude of effects include age, gender, personality, day-time stress, tiredness during the day and sleep deficit. Because of inter-individual differences in sleep-pattern, noise disturbance during the beginning and the end of the socially accepted sleep period may have a differential individual effect. In particular 'morning-types' or early sleepers and elderly people seem to be more sensitive to sleep disturbance.

The workshop participants agreed that field and laboratory studies can be used to serve different purposes. Field studies should be carried out to study the impact of environmental noise in large populations and to identify vulnerable subgroups. Laboratory studies should mainly be used to develop and test new methodology and measures and to study the magnitude of susceptibility of risk-groups identified in field research. Shift workers, elderly people and children have been identified as vulnerable groups.

It was concluded that there is not one universal measure available to characterize noise exposure. The participants recommended to measure noise exposure in such a way that more than one metric can be derived ($L_{Aeq}$, $L_{A,max}$, SEL as well as the number of noise events). Different metrics can than be analyzed in relation to the outcome measures. To describe the relation between noise exposure and awakenings, metrics like $L_{A,max}$ and SEL are recommended. For describing the relation between more or less continuous noise and a cumulative effect like perceived sleep quality, the $L_{Aeq}$ seems to be more suitable. Also, it might be important to consider the difference between the background and maximum noise levels.

The participants concluded that there is no single superior sleep disturbance indicator available. Thus, it is necessary to study several carefully selected response parameters in parallel.
Decreased daily functioning and day-time performance were recognized as the most important health effects of noise disturbed sleep. Sleep disturbance (expressed in awakenings, sleep stage changes) as such may not be directly detrimental to health, but sleepiness can have indirect effects.

For field research it is recommended to study awakenings/arousals or total periods not awakened, sleep latency, subjective sleep quality, and daily functioning expressed by sleepiness during the day or more objective performance measures.

Actimetry is recommended for measuring awakenings or arousals in field studies. To study the after-effects of noise-disturbed sleep such as perceived sleep quality and sleepiness, the (repeated) use of standardized questionnaires or diaries is recommended. The feasibility of studying performance in field studies using computer tests as an objective measurement tool needs to be investigated.

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# 3 REVIEW AND DISCUSSION OF THE STUDY PROPOSALS

## 3.1 Introduction

Each research proposal described in the working document has been reviewed by two experts. At the workshop, after plenary presentation of the comments of the reviewers, the proposals were discussed in separate working groups of experts. A list of reviewers and working group members is given in annex 1.
In this chapter the comments of the reviewers and discussants on the three separate proposals are summarized. Section 3.2 focuses on the questionnaire survey. In sections 3.3 and 3.4 a summary is given of the discussion on the field studies on aircraft noise and sleep disturbance in adults and neurobehavioural effects in children, respectively. Finally, in section 3.5 comments on the proposed noise measurements are presented. Each section starts with a brief summary of the proposal and ends with the main conclusions and recommendations.

## 3.2 Questionnaire survey on perceived environmental quality, health status, annoyance and risk perception

### 3.2.1 Summary proposal

The main objective of this study is to assess the (baseline) prevalence of self-rated health, annoyance, risk perception and health complaints as a reference for future monitoring activities and to study the relationship between these prevalences and noise exposure. Another aim is to assess the (frequency of) occurrence of health complaints in time in relation to exposure to environmental pollution origination from Schiphol airport (e.g. noise, air pollution). Two approaches are proposed for this study: a questionnaire survey and a repeated observations (diary) study. The questionnaire will be used for the assessment of the prevalence of selected health indicators and background prevalences of important mediators. This information can be used as a starting point for monitoring activities. A self-administered mailed questionnaire study will be conducted among a random sample (n≈10 000) of the adult population living in a study area around Schiphol airport, shortly before or after the summer period. Since the number of questions is large (75-100) and some issues rather complex, two options for the administration of the questionnaire are proposed: a split-mode postal survey with two separate questionnaires and face-to-face interviews to gain information on more complex issues. To study the frequency of occurrence of e.g. sleep disturbance and stress, a diary study will be conducted in a small sample of the adult population. This study consists of repeated

observations in four seasons for a period of 14-30 days e.g. to address seasonal differences in response. These may be caused by differences in noise emission (more flights in summer months) or changes in the exposure pattern (periods spent outdoors, or windows opened).

### 3.2.2 Discussion

The discussion mainly focused on formulating general criteria for performing questionnaire studies on health outcome in relation to aircraft pollution.

***Aim and background***

One of the aims of the study is to provide further quantitative information on exposure-response relationships. The necessity of assessing these relationships in addition to the assessment of current and future health status of the population (monitoring objective) has been discussed. A few reasons were brought up why the assessment of specific exposure-response relationships for the area is important:

* Comparability with other (inter)national studies where different noise metrics have been used;
* Socio-cultural aspects may change over time and can affect exposure-response relationships, in particular those of subjective health outcomes. Therefore, reference exposure-response relationships may be needed for future studies of the Schiphol population;
* The establishment of exposure-response relationships for a wide range of health outcomes (in addition to annoyance);
* The ability to assess relationships in different noise metrics ($L_{Aeq}$ instead of Ke),
* The need for more data on lower-exposed groups. A shift in complaints to the lower exposed groups has been observed, while knowledge on exposure-response relationships only exists for the higher exposed groups (the upper part of the exposure-response relationship).

Some of the discussants considered that a description of the current health status (prevalence) and monitoring are more important to the policy making process than the assessment and refinement of exposure-response relationships.

***Design and sample size***

The study aims i.e. the assessment of baseline prevalences and the development of prevalences in the future (monitoring) as well as assessing exposure-response relationships call for different approaches that may not be efficiently combined in one study.

To study prevalences a high response rate is of primary interest while contrasts in exposure and collection of information on confounders are less relevant. However, when changes in prevalence over time are the object of study, i.e. in a monitoring context, changes in the relevant health determinants need to be taken into account, to allow conclusions about the effect of changes in noise exposure on these prevalences. The assessment of exposure-response relationships on the other hand requires contrasts in exposure levels and exclusion of confounders (or statistical controlling for their effect). This might be achieved by selecting a relatively small number of people in selected areas with different noise levels. In contrast, the monitoring activities should cover the whole study area, and should have sufficient power to detect changes in prevalence in rather unpopulated areas, where projected changes in noise exposure are likely to occur.

Although the potentially different design requirements were identified, consensus about an optimal (combination of) design(s) could not be reached. It was recommended to carefully evaluate whether the different design requirements due to the different study objectives can be met efficiently in a single study, or whether separate, but parallel, studies with different designs are more appropriate.

The proposed overall sample size (n≈10 000) was considered to be sufficient for the prevalence study, but unnecessarily large for studying exposure-response relationships. For the assessment of exposure-response relationships, a sample size of n≈2500-3000 was judged to be sufficient.

With respect to the assessment of prevalences, concern was expressed that the number of questions in the questionnaire may lead to lower response rates. High response rates (>80%) are required for good prevalence estimates. Therefore, it was suggested to split the questionnaire in 2-3 short self-administered questionnaires that will be conducted in separate samples (total sample size n≈10 000).

A pilot study was recommended to develop a common core of questions for a split-mode questionnaire and to test the length of the questionnaire and the sequence of questions.

The added value of the diary study was discussed. This would only be suitable for studying the frequency of annoyance reactions within individuals, possibly in relation to fluctuation in exposures. Diary studies often are a burden to the participants, potentially leading to selective non-response. Therefore, the diaries are not suitable for prevalence studies. Currently, there is very limited information on seasonality in annoyance reactions.

The optimal timing of questionnaire administration is therefore uncertain. As an alternative to diary studies on seasonal variation, repeated administration of the questionnaire in subsamples in different seasons has been suggested.

***Response rate***

The discussants agreed that the expected response rate may be low (≤ 60%), since people in the study area may have become tired of questionnaires.
A high response rate should be aimed at to get better estimates of the prevalences. It is therefore recommended to consider the use of incentives to motivate the study subjects e.g. a financial compensation.
The participants agreed that information on non-responders has to be collected to allow non-response analysis.

***Variables and mediators***

No clear-cut conclusions have been formulated with regard to the selection of variables to be studied. The discussants agreed that the number of variables should be reduced to those variables which are clearly noise-related and area-relevant and to variables that are important based on prior experience. They confirmed that biological plausibility, as described in the working document, should be an important criterium for the selection of variables. Another criterium is whether the variable provides useful information for policy makers. After concluding that the number of questions should be reduced as far as possible, some new questions and items were put forward by different participants. These are summarized below.

It was recommended to include the questions on annoyance as suggested by Fields (1993)[1]. Focusing on specific annoyance, it will be useful to ask how many times a respondent performs a specific activity. If combined exposure to noise and odour occurs this should be taken in consideration. Since it is expected that a lot of houses will have sound-proofing measures in the next few years, a question on the effect of these measures should also be included in the study.

The number of mediating variables is large. Mediators can potentially influence the endpoints studied. Important mediating variables are: personal or susceptibility factors (e.g. socio-economical situation, sex, education), attitudinal and environmental or situational factors.
Noise sensitivity is considered to be one of the most important mediators. It is a predictor for noise annoyance and other health-related outcomes. General life style factors are not considered to be important mediating variables, except perhaps smoking.
Mediating variables that were not mentioned in the proposal, but should be addressed, are employment status, housing tenure, ethnicity/migrant status and length of residence.

The need of measuring mediating variables (confounders and effect-modifiers) in the study was questioned by some discussants. Confounders are variables associated with both the exposure and disease under study. They can cause bias since they distort the exposure-response relationship. The existence of confounding depends on the design of the study. Effect modification is a change in the magnitude of an effect due to some other variable than exposure. It is a natural phenomenon existing independently of the study. Whereas confounding is a bias that the investigator wants to prevent or to control (e.g. beforehand in designing the study, afterwards by stratification or multivariate analysis), effect modification is a finding to be reported. Thus it was considered important to measure confounders and effect modifiers as far as possible.

Stress-related aspects were discussed in detail. It was concluded that there is no single measure of stress available. Stressors and stress responses should clearly be separated in the study. Stress responses, such as anxiety, depression, sleep disturbance and social withdrawal, can be measured using brief questionnaires. Emotional responses such as general stress feelings (e.g. daily hassles) have not been mentioned in the proposal. If possible they should be included in the study. Emotional responses are, however, very likely to be confounded by health status, which makes it conceptionally rather complex to study this aspect in the proposed study. Therefore it is preferred to measure chronic stressors which are concrete such as housing problems, financial problems (related to ability to move away) and life events. Chronic stress scales can be used to measure these stressors. Also other environmental or noise sources (e.g. neighbourhood noise, work situation) and economic disadvantages (loss of property) are important stressors. In conclusion, it is recommended to study both stress responses and the presence of stressful conditions.

***Sequence of questions***

The preferred sequence of questions has not been discussed in detail. The experiences on this aspect differed between researchers. It is important to ask the most important questions first, when there is full attention. The total number of questions will be influenced by the use of masking questions. Masking questions may be relevant in face-to-face interviews but were considered of minor interest in written self-administered questionnaires.

To avoid over-reporting it was suggested not to mention aircraft noise or relate issues directly to noise exposure in the questionnaire.

### 3.2.3 Conclusions and recommendations questionnaire survey

It was recognized that the study aims (assessment of (baseline) prevalence rates and the estimation of exposure-response relationships) may call for different study designs. The discussants did not reach consensus on the most suitable design. The different options for the questionnaire study that were suggested in the study proposal found general approval though. The proposed options are to administer a general questionnaire in a large sample (n≈10 000) or to perform a split-mode questionnaire survey (2-3 short questionnaires in separate samples). Other proposed options were face-to-face interviews in small independent subsamples (n≈2000) to study more complex issues and a diary study to study seasonal variation. As an alternative to diary studies, repeated administration of the questionnaire in different subsamples has been suggested. Finally, it was recommended to perform a pilot study to test the questionnaire(s). A response rate of 50% or more should be aimed at to make the study representative of the population. To enable non-response analysis, information on non-responders should be collected.
The discussants did not formulate clear-cut conclusions with regard to the selection of variables and mediators.

## 3.3 Sleep disturbance and aircraft noise

### 3.3.1 Summary proposal

The protocol addresses the complex problem whether higher residential aircraft noise exposure during the night is associated with sleep disturbance, that may in turn result in short and/or long-term health consequences.
To estimate the prevalence of sleep disturbance in the population living in the vicinity of the airport, a questionnaire study is proposed (see 3.2).
To expand the existing knowledge of the exposure-response relationships between night-time aircraft noise exposure and sleep disturbance and after-effects, a combination of actimetry and a diary study (repeated observations study) is recommended.
The proposed study makes use of methods similar to those used in a recent field study in the UK[2], with some additions and improvements. This will allow comparison of results and a better estimation of the relationship between residential aircraft noise and sleep disturbance.

The objective of the questionnaire study is to assess the distribution of sleep disturbance through perceived sleep quality. The outcome of the exposure-response study focuses on the number of awakenings, perceived sleep quality and (perceived) daily functioning. A hybrid design is proposed. Five groups, each consisting of approximately 50-60 individuals

(age ≥ 40 years), with different average levels of night-time aircraft noise exposure levels will be selected. Each individual will be observed on a daily basis over a period of about one month. With this design, sleep disturbance indicators can be compared between groups (cross-sectional study). Also the repeated daily measurements within and between groups can be analyzed (repeated observations study). The overall duration of the field observation period will be half a year. A convenience sample will be constructed consisting of 50 individuals living within a radius of 250 m from a selected noise measuring unit in single- and multi-family housing. A further 10 individuals will be selected on the basis of high noise sensitivity, based on questionnaire information or complaints. Information about aircraft noise levels will be collected using an existing monitoring system with fixed sites. A pilot study is proposed to carry out indoor (bedroom) noise measurements in a small number of houses of different types and using different noise insulation techniques.

### 3.3.2 Discussion

***Study design***

The hypothesis of the study calls for a repeated-measurements design: during nights with noise events of sufficient intensity (bedroom level of 55 dB(A)) more awakenings are expected to occur in the same test subjects than during nights without such events. It also implies that the design does not depend on (control) areas not exposed to night-time aircraft noise. Some of the discussants nevertheless recommended to include a non-exposed control group. This would increase the range in exposure levels between the five groups and increase the power of between-group cross-sectional comparisons. This was considered important since habituation may mask intra-individual variation. Also because of habituation it was advised not to include individuals who recently (less than 3-12 months) moved into the area exposed to aircraft noise.
The discussants agreed with the study proposal to do both inter-individual and group comparisons.

Since a convenience sampling is proposed, a highly selected sample of individuals will be studied. Thus it should be kept in mind that the selected study groups may not be representative of the general population.

It was suggested to explore the possibility to use an 'experimental' design i.e. to carry out measurements on a population before the new runway is added (even if the numbers are small) and to repeat these measurements after about a year of exposure to aircraft noise. However, runway configuration and flight patterns may not allow such a design.

***Indicators for sleep disturbance***

The workshop participants agreed that there are no superior indicators for sleep disturbances. They agreed with the proposal to select a core set of indicators to be studied consisting of arousals/awakenings, perceived sleep quality and perceived daily functioning (sleepiness, fatigue etc.). Actimetry measures are considered to be sensitive enough to apply in field studies, but perhaps some additional EEG validation is warranted as the validation in the CAA-study was based on a relative small sample (40 subjects). More emphasis might be placed on estimating the relationship between residential aircraft noise and sleep disturbance by using questionnaires on perceived sleep quality, daytime mood, sleepiness and fatigue at the end of the day. Other important indicators to consider are the time to fall asleep and total time in sleep stage (time not awake) as they may give more information about those aspects of sleep which have a health significance.

***Methods***

At the moment actimetry and questionnaires/diaries are the most suitable methods for a large field study to assess arousals/awakenings and sleep quality/sleepiness. Two types of questionnaires need to be used: a short one suitable to administer to a large population (for prevalence and screening purposes) and a more elaborate diary type to assess perceived sleep quality and performance daily in a small population. Standardized questionnaire or diaries for these purposes are available.

It is not recommended to record performance with computerized tests in a small sample without prior validation and a feasibility study. Currently, no objective tests are available which are suitable for measuring performance on a repeated daily basis in the home environment. The proposed performance test (Simple Reaction Time Test) was not considered to be a viable measure for a field study. Daytime performance may also be studied by asking questions about sleepiness, day-time napping and problems which indicate concentration disturbance at work. Additional performance tests may be carried out in subsequent studies in identified sensitive groups.

The discussants did not agree with the study proposal to perform additional EEG-measurements in a small subset of the study population as this would not provide any useful information due to the limited study size. Again, it could be useful though to carry out EEG-measurements in subsequent studies in sensitive groups.

***Selection study population***

It was understood that the exposure-response study does not need to be carried out in a representative sample of the population around Schiphol, but the overall study design might be enhanced if the smaller actimetry study could be nested within the larger sleep disturbance questionnaire sample. It is advised to select study populations (at least at one site) that are representative of the aircraft noise exposed populations but similar on

background noise. Selection of such sites may be difficult though if the sites are to be similar on other variables such as age, sex, socio-economic status and ethnicity. The participants concurred that background noise levels should be taken into account though, not only to detect threshold effects but also to assure that characteristics which are not controlled for in the study are similar.

An option is to assess all of the households in the highest noise-exposed areas and all of those in the lower, non-exposed areas by questionnaire with only a smaller sample followed by actimetry. This will provide more insight in both the distribution of sleep disturbance in the general population and in the exposure-response relationships in a smaller sample. The prevalence-questionnaire can also serve as a screening-questionnaire. Eligible persons can be invited to participate in the actimetry/diary study. Selection can take place based on convenience criteria, but similarity between study and general population as well as between different study groups should be pursued as much as possible (i.e. proximity to noise-monitoring station, similar age-distribution).

The existence of vulnerable and noise-sensitive groups was generally recognized. However, it is extremely difficult to give an a-priori definition of such groups that allow the identification and selection of such individuals for the sleep study. Potential vulnerable groups include shift workers, elderly, children and individuals with cardiovascular diseases (hypertensives) or chronic diseases. From a methodological point of view, selection of vulnerable individuals may improve the study efficiency because a smaller sample size will suffice to detect effects. However, results obtained in such subpopulations may be difficult to generalize to the population at large. Since clear-cut a-priori criteria for selection are not available, it was concluded not to focus on vulnerable or noise-sensitive subgroups but to have a slight overrepresentation (maximum n=10 per group) of self-perceived noise-sensitive persons. In this context it was also suggested to expand the proposed age-group of more than 40 years old to 25-75 years of age. A-posteriori identification of sensitive subjects in the study population was considered a possibility, on the basis of interindividual differences in response. A follow-up study might further investigate such individuals in future research (e.g. laboratory studies with EEG).

***Study size and period***

A number of 50-60 subjects per site was considered to be sufficient for the within-subject analyses, but may be too small to enable between-group comparisons. Especially, the number of noise sensitive subjects (10) is very small and will only allow limited comparisons.

Another uncertainty is whether there will be a sufficient number of people exposed to levels high enough above background noise levels to detect a difference in awakenings.

The discussants suggested to increase the sample size depending on the different outcome measures, e.g. the questionnaire/diary study on sleep quality can be performed in a larger sample than proposed. A more indepth sleep study using actimetry can be performed in the sample size proposed.

A study period of one month per individual was considered as rather long given the burden to the participant. This may have a negative impact on compliance. An option is to double the study sample size and decrease the study period to 15 days. However, because night-time aircraft noise events are rare, this option may not improve the study design. Furthermore, this would seriously diminish the study's power.
The choice for an overall study duration of one year found general approval.

***Participation response rate***
Potential selection and non-response bias is a major concern in this type of study. It was therefore recommended to pay the participants to increase compliance and response.

***Confounding and mediating variables***
It is difficult to see how the many confounders identified in the proposal can be adequately controlled for in the study to allow group comparisons, given the small sample size relative to the number of variables. Thus it may be necessary to prioritize the identified confounders to the ones presumed strongest. Potential covariates not mentioned in the study proposal are daytime noise exposure at work and time exposed to aircraft noise (in years of residence near Schiphol or other airports). Most confounding variables are less important in within-subject analyses.

***Noise levels and measurements***
The discussants agreed with the study proposal to perform a pilot study to assess indoor noise levels. The pilot should consist of indoor noise measurements in a limited number of houses (as much as resources will allow), outdoor measurements and a recording of noise-exposure modifying factors, e.g. the state of the bedroom windows at night. A pilot-study is also necessary to check whether there is sufficient variation in noise exposure.
In order to discriminate between aircraft noise and background noise it was advised to set a threshold level in the noise recordings and to use logs of aircraft movements.

### 3.3.3 Conclusions and recommendations study proposal sleep disturbance and aircraft noise

The project seems feasible given that adequate resources are available and some adaptations are implemented. It will provide information about the current situation of the population and information for the future monitoring system as well as a contribution to the science of noise effects.
The basic design may be improved by including a control group and by increasing the sample size depending on the outcome measure studied. A suggestion was to nest the smaller actimetry study within the larger sleep disturbance questionnaire sample, to enhance the overall study design. The discussants agreed with the proposed core set of sleep disturbance indicators consisting of arousals/awakenings, perceived sleep quality and perceived daily functioning (sleepiness, fatigue etc.) using actimetry and questionnaires.
It was advised to carry out the main study first (with an expansion of the proposed age-group to 25-75 years of age) and subsequently, in case sensitive subgroups are identified, decide about further investigations of these groups.
The proposal to carry out a pilot-study to determine indoor noise levels found general approval.

## 3.4 Air traffic noise and neurobehavioural effects in children

### 3.4.1 Summary proposal

To study the relation between chronic exposure to aircraft noise and neurobehavioural functioning in children, a cross-sectional design is proposed. Two groups of 90 children will be compared, one group living in a high-exposed noise area (>65 dB(A), exposed group) and one group living in a low-exposed noise area (<53 dB(A), control group). The children in the study will be matched by age, sex, school grade en socio-economic status of the parents. Their age will be between 8 and 11 years.
The parents will be asked to fill in a list for the assessment of the children's behaviour (the Child Behaviour CheckList = CBCL) and a questionnaire about sleep disturbances.
The neurobehavioural effects will be tested on a groupwise basis by paper-and-pencil tests and by computerized tests. The selected paper-and-pencil tests are used to measure 'attention', a basic dimension of neurobehavioural functioning. The Neurobehaviour Evaluation System (NES2) is a computerized test battery. The Dutch version of this test battery is used to measure the following dimensions: attention, psychomotor performance, perceptual coding and learning and memory.

A repetition of the study after 3 to 5 years may be indicated to determine whether a more severe pattern of neurobehavioural changes occurs with prolonged noise exposure or, in case of airport expansion, at increased levels of exposure to noise.

### 3.4.2 Discussion

***Theoretical framework***

Several studies have been performed into the effects of chronic and acute exposure to aircraft noise on the neural behaviour of children, for example the Munich and the Los Angeles study[3,4]. To achieve optimal comparability of study results, it is recommended to use identical study protocols and methods as far as possible.

***Design and method***

In the study proposal more clarification is needed of the dynamics of the exposure-response model. It is not clear, for example, whether chronic, acute or both effects are studied in relation to long-term or intermittent aircraft noise exposure. In particular the validity of the exposure and outcome measures and the type of effect that is measured (effect of noise exposure during the previous night versus cumulative developmental effects) need further elaboration.

In the current design only the effect of chronic exposure to aircraft noise can be studied. When acute effects are to be assessed as well, a sound-attenuated mobile laboratory and a different experimental set-up is needed.

Standardized test conditions (especially with regard to noise) are very important in these type of studies. The classroom is not an optimal test environment. It would be better to test the children in a mobile sound-attenuated laboratory in order to reduce variance in (exposure) conditions during the measurements. However, this will be an additional logistic and financial burden.

Based on power considerations and convenience criteria, it was proposed to study two groups of 120 school children in the age range from 8 to 11 years. The discussants agreed that the proposed sample size may be sufficient, though probably minimal, for a pilot-study. The proposed sample size may be too small to detect subtle effects.

The study group is not a representative sample of the general population but represents a potential group at risk. Neurobehavioural effects may develop at a very early age, as observed in a few field studies[3,4]. Also, a disturbed cognitive development at an early age may have an impact on functioning and health in later life. It is not known, however, which age group is the most vulnerable group with regard to noise effects.

To minimize variation due to age differences, it was proposed to restrict the study to children of only 8 years old. Another reason for selecting young children is the possibility for a follow-up study. If a follow-up study is needed i.e. to study the neurobehavioural effects of increased levels of noise exposure due to airport expansion it would be important that the children are retrievable after 3 to 5 years. When the study starts with an age group of 8 years, one might expect that the children are still in the same area, maybe still at the same school, after 3 to 5 years. It will be easier to trace them for the follow-up measurements.

Groupwise testing as opposed to individual testing has some disadvantages. Group dynamics may alter the testing situation to an extent where it is out of the researcher's control. This may create different situations between different groups and may increase the variance. Individual testing with a sufficient number of subjects does not seem feasible, however, both for logistic and financial reasons.

Some doubts were expressed about the ability of parents to assess the behaviour and sleep quality of their children. Assessment of children's behaviour might better be done by their teachers, who are able to compare the behaviour of different children.

In summary, there are a number of uncertainties regarding the feasibility of the proposed method for application in the school environment. It is therefore suggested to perform a pilot study.

***Exposure measurements***

Exposure measurements are not discussed in the study proposal. Individual exposure measurements are preferred instead of comparing two groups (high versus low). A wide range of exposures should be assured. Individuals move throughout the day to different places and the individual chronic exposure will therefore not only be determined by the exposure at school, but also by the exposure at home during the day and during the night. Daily dosimeter measurements were suggested to obtain an estimation of the current daily exposure. Another issue related to noise exposure is the choice of appropriate noise exposure metrics. One can relate outcome measures such as cognitive behaviour to different noise exposure metrics (e.g. average noise exposure or peak exposures). The discussants agreed that more attention should be paid to these issues in the study proposal.

***Outcome measures***

There is no preferred method to test neurobehavioural effects in relation to noise exposure. A combination of methods, testing different aspects of neurobehavioural effects is required. The discussants concurred that, in addition to the proposed tests, a reading test should be added. There is some evidence that deficits in reading achievement are related

to chronic noise exposure. Also, they suggested, if possible, to add the Raven's Progressive Matrices to control for differences in intelligence for the two groups.
In addition, one discussant suggested to use the Logoport method which measures the amount of conversation of a child during the day and gives quantitative information on how people communicate (e.g. short or long sentences, fluent or interrupted speech). The underlying idea is that children from the high exposed group will talk less compared to the children from the low exposed group and therefore, their cognitive behaviour will be different.

In the study proposal two different types of techniques for evaluating the neurobehavioural effects are described: paper and pencil tests and computerized tests. Both can measure attention, but paper and pencil tests require more motivation of children than the computerized tests. In case both types of tests are carried out, one should be aware that the two tests may give different results in relation to the noise exposure.

***Confounding variables***
The proposal should be more specific about the measurement and analysis of potential confounders. In addition to confounders such as social economical status of the parents, sex, school grade, family size and hearing ability, time of the day may also be an important effect modifier. For each child, the time of the day at which the experiment takes place should be noted. In case a follow-up study is considered, measurements should preferably take place at the same time of the day.
To get an indication of the hearing ability of the children, the school doctor may be consulted for the results of the audiometric screening of the children.

### 3.4.3 Conclusions and recommendations study proposal air traffic noise and neurobehavioural effects in children

To achieve optimal comparability of study results, it is recommended to use the same study protocols and methods as in previous studies, if possible. The proposal should be more specific about the type of effect that is measured (acute effect due to noise exposure during the previous night versus chronic effects) and the measurement and analysis of noise exposure and potential confounders.
The discussants agreed that the proposed sample size will be sufficient for a pilot. It should be considered though to increase the sample size for the main study. The overall study design might be enhanced if the study group is restricted to an age group of only 8 years old, thus limiting the interindividual variation. The discussants concurred that, in addition to the proposed neurobehavioural tests, a reading and intelligence test should be added.

Finally, a pilot study should be performed to test the feasibility of the proposed methods for application in the school environment.

## 3.5 Noise measurements

### 3.5.1 Summary proposed measurements

For the questionnaire study, described in chapter 3 of the working document, it is proposed to assess $L_{Aeq,24h}$, $L_{Aeq,day}$, $L_{Aeq,night}$, $L_{dn}$ and Ke, based on a combination of measurements and model calculations.
The proposed noise exposure measures for the field study on sleep disturbance (chapter 4 of the working document) will include aircraft and ambient noise levels in $L_{Aeq}$ and $L_{dn}$. Also peak noise levels ($L_{A,max}$ and SEL) are to be measured, after the identification of aircraft noise events, and outdoor/indoor attenuation will be determined using indoor noise measurements. Information about the exposure level will be collected using data from the noise monitoring system (NOMOS) with the monitor located within 250 meters of the house.
Finally, in the proposal for the field study on neurobehavioural effects in schoolchildren (chapter 5 of the working document) only exposure classes are set for the exposed and control areas based on model calculations.

### 3.5.2 Discussion

***Aim and background***
The overall aims of the proposed noise measurements are to assess aircraft noise exposure indicators for the participants of the different studies, and to determine the quality of these exposure indicators.
Factors which may modify the exposure to ambient noise, have not been mentioned in the separate study proposals. Examples of important modifying factors are:

* The background noise level (varies with time of day),
* Topographical peculiarities (e.g. large buildings) leading to shielding or focusing of noise (e.g. reverberation),
* Rate of onset of noise (due to shielding at close distances from runways),
* Time of day affecting the signal to noise ratio,
* Variability (e.g. variation in flight paths and meteorological conditions),
* The condition of windows (open/closed) and the structure of facade and ceilings.

To determine the outdoor/indoor attenuation in indoor noise measurements it is recommended to:

* Obtain simultaneous (indoor and outdoor) tape recordings to enable certain identification of the sound source,
* Perform measurements of multiple metrics, since attenuation varies depending on the noise metric,
* Specify typical configurations of windows (open/closed),
* Register the positioning of microphones etc.,
* Specify upstairs/downstairs measurements,
* Classify the type of dwelling.

In the overall description of the noise measurements (section 2.5 of the working document) it is not clear whether in addition to Kosten units contours, aircraft $L_{Aeq}$ and $L_{dn}$ contours will be calculated. It is recommended to calculate contours and to include assessment of background noise levels.
With the Noise Monitoring System (NOMOS) aircraft noise levels can be measured at 18-20 locations around Schiphol Airport. It is not clear, however, if these noise levels can be extrapolated to all locations of interest (homes, hospitals, schools). The identification of noise levels by NOMOS is verified by radar.
The discussants concluded that NOMOS offers the potential for a good noise characterization around Schiphol airport, as long as an independent quality control of the measurements or audit is guaranteed. In addition, a pilot is warranted to assess the reliability of the fixed noise monitors and to study the representativeness of NOMOS measurements for the exposure of the population at large. Also, some indoor measurements in a limited number of houses are recommended to study the outdoor/indoor attenuation in noise exposure.

The participants concurred that there are no superior indicators to characterize aircraft noise exposure. They agreed with the study proposal to study different noise metrics.

***Discussion on the separate study proposals***

The aim of the noise exposure assessment in the questionnaire study is to characterize the aircraft noise exposure of the study population and to determine the quality of the exposure indicators used. The relevant noise metrics for the type of effects under study (see 3.2) are: $L_{Aeq,24h}$, $L_{Aeq,day}$, $L_{Aeq,night}$ and $L_{dn}$. The location of the bedroom in relation to the flight path is an important aspect to consider in the assessment of noise exposure. It was recommended to include this aspect in the questionnaire.

The aim of noise exposure measurements in the field study on sleep disturbance is to assess each participant's individual exposure by measuring a number of exposure indicators such as $L_{Aeq,night}$, SEL, $L_{AMax}$ and the number of aircraft noise events.
With regard to the proposed noise exposure measures, statistics of $L_{A,max}$ and/or SEL (mean, SD) are desirable at each subject's location. Furthermore, signal to noise ratios by time of night are desirable. It was suggested to calculate the noise level at each location, and perform additional noise measurements to validate these calculations. The discussants agreed with the proposal to carry out indoor measurements in a subsample and to measure the most important determinants of indoor/outdoor noise attenuation in all houses. The proposed noise metrics should be specified in more detail, e.g. the time period of the proposed $L_{Aeq}$ levels is not specified and it is not clear which statistics of L will be recorded. The number of aircraft noise levels exceeding certain $L_{A,max}$ levels should be measured or estimated at each location.

The aim of noise exposure assessment in the field study on neurobehavioural effects in schoolchildren is to calculate the noise exposure of each study participant, using metrics such as Ke and $L_{Aeq}$. Although in the proposal for the field study on neurobehavioural effects in schoolchildren noise limits are set for the exposed and control areas, no details are given of the process of noise measurements. It is not clear how and where noise levels will be derived or measured. The time period of the proposed $L_{Aeq}$ levels is not specified. Other aspects of noise exposure assessment that should be specified in the proposal are whether the noise exposure is determined at schools and how the children's contribution to noise can be separated from that due to aircraft and traffic, is missing.
The study should include noise measurements at home as well as at school. It was also recommended to measure outdoor/indoor attenuation at each school and/or classroom.

### 3.5.3 Conclusions and recommendations with regard to noise measurements

The participants concurred that there are no superior indicators to characterize aircraft noise exposure. They agreed with the study proposal to study different noise metrics.
All the proposals should clearly specify the noise metrics, the time period the metric concerns and the statistics that will be recorded.
Equal energy measures of noise in the form of contours are necessary for all the studies proposed, and is sufficient for the questionnaire study in which noise annoyance is the main outcome. For the sleep disturbance study validation of model calculations is recommended by measurements of indicators such as $L_{Aeq,night}$, SEL, $L_{A,max}$ and number of noise events exceeding certain $L_{A,max}$ levels. For the neurobehavioural study noise measurements both at home and at school are advised. Outdoor/indoor attenuation should be measured at each school or classroom.

It is advised to take into account acoustical modifiers in the assessment of noise exposure such as background noise level, topographical peculiarities that can cause shielding or focusing of noise, rate of onset, time of day, variability and indoor/outdoor attenuation.

With the existing noise monitoring system around Schiphol the potential for a good noise characterization around Schiphol airport is available, as long as an independent quality control of the measurements or audit is guaranteed. In addition, a pilot is warranted to assess the reliability of the fixed noise monitors and to study the representativeness of NOMOS measurements for the exposure of the population at large. Also, some indoor measurements in a limited number of houses are recommended to study the outdoor/indoor attenuation in noise exposure.

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# ANNEX 1 PROGRAMME, LIST OF SPEAKERS AND DISCUSSION GROUPS

## 1.1 Programme workshop 'Noise and Public Health'

**Lecture meeting 'Sleep, sleep disturbance and health' (October 3rd)**

| *Speaker* | *Subject* |
|---|---|
| D. Schneider-Helmert | Sleep (quality), health and sleep disturbance<br>Presentation of the state of the art knowledge on different issues concerning health and sleep disturbance as well as predictive sleep indicators. |
| A. Muzet | Noise exposure and sleep disturbance. |
| E. Öhrström | Subjective evaluation of sleep disturbance caused by noise. |
| G. A. Kerkhof | Stress, biological rhythm and daily functioning.<br>A survey of rhythm and daily functioning aspects of sleep disturbance with some indications towards disturbance by noise. |
| J. Horne | Noise, annoyance, sleep disturbance and daily functioning. |
| J. Eberhardt | Methods and study design to study sleep disturbance by (aircraft) noise, especially in large populations. Comparative evaluation of the CAA and LUND study. |

Discussion about research priorities and recommendations for further research.

**Expert meeting review study proposals Health Impact Assessment Schiphol Airport (October 4th)**

| *Speaker* | *Subject* |
|---|---|
| B. Staatsen | Introduction 'Health Impact Assessment Schiphol Airport': Presentation of results of the first studies carried out in the framework of the Environmental Impact Assessment Schiphol Airport and introduction to proposals for future research. |
| W. Passchier-Vermeer | Summary of the expert meeting on sleep, sleep disturbance and health on October 3. |

***Presentation by the reviewers***

Comments on the proposals for studies on

1. Questionnaire survey on annoyance, risk perception and perceived health
2. Sleep disturbance in adults around Schiphol airport
3. Aircraft noise exposure and performance among children
4. Noise exposure measurements around Schiphol airport.

Review of the study protocols in small groups.

Presentation of main conclusions from review sessions.

Discussion on the significance, consequences and expected outcome of the proposed studies.

## 1.2 Composition discussion groups

***Questionnaire survey on perceived environmental quality, health status, annoyance and risk perception***

*Chairman*
P. Lercher

*Reviewers*
A. Schuemer-Kohrs
S. Stansfeld

*Rapporteur*
M. Drijver

*Discussants*
J. de Boer
G. van 't Bosch
E. Franssen
L. Hendrickx
R. de Jong
I. van Kamp
H. Miedema
C. Oliva
R. v. Poll

***Field study on aircraft noise and sleep disturbance***

*Chairman*
E. Öhrström

*Reviewers*
A. Muzet
S. Thompson

*Rapporteur*
B. Staatsen

*Discussants*
M. v.d. Berg
N. Carter
G. Doornbos
W. Hofman
J. Horne
C. Jones
A. Kumar
W. Passchier-Vermeer
J. Pieters
L. Reyner
A. Sadeh

***Field study on aircraft noise and neurobehavioural effects in children***

*Chairman*
S. Hygge

*Reviewers*
R. Letz
F. Muller

*Rapporteur*
T. Vrijkotte

*Discussants*
J. Deijen
C. van de Boogaard
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