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# Sleep disturbance and aircraft noise exposure

*Exposure-effect relationships*

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## Summary

The study presented in this report has been carried out in the framework of the research program Health Impact Assessment Amsterdam Airport Schiphol (Gezondheidskundige Evaluatie Schiphol - GES). It consisted of a pilot and main study. The pilot study has been carried out in 1998. It has been undertaken to obtain information to design the main study in detail. The field investigation of the main study has been carried out in the period from November 1999 to April 2001 at locations in the vicinity of airport Schiphol, located near Amsterdam. The objectives of the study are:

a. To assess relationships between night-time aircraft noise exposure and measures of sleep disturbance, health and daily functioning. The effect of the period of the night, especially for the so-called edges of the night (23 to 24 hours and 6 to 7 hours), on these relationships is also of interest;
b. To provide information on the basis of which the prevalence of night-time aircraft noise-induced effects in the population in the vicinity of Schiphol can be estimated.

In this report emphasis is on exposure-effect relationships. In TNO report 2001.205 detailed information is given about subjects and locations. TNO report 2001.206 is a report with tables and figures, supplementary to report 2001.205. TNO report 2002.028 and the identical RIVM report number 441520019 (2002), includes the main results of the study and estimates of the prevalence of effects of night-time aircraft noise in the vicinity of Schiphol and has been written in Dutch.

With a view on the controversies in the relevant literature and black spots in knowledge it was considered necessary that a large-scale study on the effects of night-time aircraft noise in the vicinity of Schiphol be undertaken. The main objective of the study is the assessment of exposure-effect relationships for acute effects during sleep. To be able to perform a large scale study with minimal interference in subjects normal sleep habits, it was decided to focus on the measurement of motility by actimetry. The size of the group of subjects, and the number of nights each subject should participate in order to obtain sufficient data for well-funded conclusions have been estimated from the results of the pilot study. Apart from the choice of actimetry as objective measurement method to assess sleep disturbance, instrumentation also allowed the assessment of behavioural awakenings by pressing a button on the actimeter. Additionally, remembered awakenings have been assessed by means of computerised morning diary.

No (objective) measurements of aspects of somatic health have been included in the present study. Objective parameters to be included in the study would be stress hormone levels or cardiovascular parameters, such as blood pressure and heart rate, during sleep. However, taking into account that the tasks subjects had to perform in the present study were already quite demanding, we abstained from including other exacting requirements.

The data also allow the assessment of exposure-effect relationships on a 24 hours time scale (including a sleep period time) and on a long-term time scale. In those exposure-effect relationships, aircraft noise exposure during sleep period time(s) has been taken as exposure variable.

Relationships between effect variables have also been assessed. In this respect the relationships between motility outcomes and outcomes evaluated by subjects are of particular interest.

## Overview of the field study

In the study 418 adult subjects participated, exposed during their participation in the study to night-time aircraft noise as it usually occurs in their bedroom. Ages of subjects varied between 18 and 81 years, 50% of the subjects was male, and 50% female; 6% lived less than 1 year in the present environment, 44% over 15 years and the remaining 50% between 1 and 15 years.
The study has been carried out successively at 15 locations within a distance of 20 km from Schiphol. The locations have been selected mainly on the basis of night-time aircraft noise exposure, from relatively few aircraft at night up to the highest exposure in residential areas close to Schiphol. At each location the study took place during two subsequent intervals of 11 days (including 11 nights).
To assess night-time (aircraft) noise exposure of subjects, from 22 – 9 hours indoor noise measurements have been performed in the bedroom of each subject and at each location one outdoor noise monitor has been in operation. Identification of aircraft noise events occurred by comparing the noise and time data stored in the indoor and outdoor noise monitors with information obtained from FANOMOS, the flight track monitoring system of the Civil Aviation Enforcement Agency of the Ministry of Transport.
Subjects participated during one interval from a Monday evening starting at 22 hours until a Friday morning 11 days later. After a subject agreed to participate in the study, he/she filled out an extensive questionnaire. Participation in the study included the following tasks during each of the 11 participation days:

- Filling out a morning- and evening diary;
- Performing a reaction time test just before going to bed;
- Filling out a sleepiness strip five times during time awake;
- Wearing an actimeter (weight about 50 grammes) on the non-dominant wrist during 24 hours. An actimeter detects accelerations/movements (motility) and stores in its memory, with the chosen setting, at the end of a 15-s interval a value relative to the accelerations above threshold during the interval. The actimeter is equipped with an event marker, which subjects pressed to indicate that they awoke during sleep period time.

A non-response study has been undertaken to assess whether the results of the study have been biased by selective respons of subjects. A request to fill out a non-response questionnaire was sent at random to a part of the addresses at the locations. In total 451 non-respondents returned the non-response questionnaire to TNO.

## Exposure-effect relationships on three time scales

Relationships between night-time aircraft noise exposure and adverse effects have been be regarded on three time scales:

- On an instantaneous level: measures of instantaneous motility have been related to measures of *aircraft noise events*. The measures of motility used in the analyses are aircraft noise-induced probability of motility and aircraft noise-induced probability of onset of motility. Lmax_i (maximal *indoor* sound level of an aircraft noise event) and SEL10_i (*indoor* equivalent sound level of an aircraft noise event, normalised to one second, assessed over the time the sound level of the aircraft noise event is larger than Lmax_i – 10 dB(A)) have been used as aircraft noise event metrics;
- On a 24 hours level (including one sleep period time): effect measures representative for a sleep period time of a subject or for time awake after a sleep period time have been related to exposure measures representative for *aircraft noise exposure during a sleep period time*. Effect measures are for instance mean motility during sleep, sleep quality rated in the morning diary, number of marker pressings during sleep period time. Equivalent aircraft sound level (Liaspt) and number of aircraft (niaspt) during sleep period time have been used as noise metrics. *Aircraft noise exposure during sleep latency time period* has been expressed in equivalent aircraft sound level and number of aircraft during sleep latency time;
- On a long-term basis: effect variables representative for a long time period have been related to *long-term night-time aircraft noise exposure* measures. Two types of effect variables have been considered: variables aggregated from the data obtained during the 11 nights and days a subject participated in the study, such as mean motility outcomes over 11 sleep period times, and effect variables obtained by questionnaire. Two types of aircraft noise exposure metrics have been used in the analyses: a metric representative for the individual exposure during sleep of a subject (Li), and metrics representative for the long-term night-time aircraft noise exposure at a location. Li is the equivalent indoor aircraft noise sound level, assessed over 11 sleep period times of a *subject*. It has been made plausible that Li is a also representative for the individual aircraft noise exposure of a subject during a longer period of time (one year). At each of the locations, there is a large range of about 30 dB(A) in the Li-values of subjects, due to differences in periods subjects are asleep, differences in ventilation behaviour of subjects, and differences in sound insulation of the bedroom. For the present study RIVM calculated on the basis of data obtained by NLR for the year 2000 the values of various metrics of aircraft noise exposure (such as Lden, Ke, Lbi23-07h) at the 15 locations. Lbi23-07h is the equivalent indoor aircraft sound level from 23 to 7 hours. In most relationships with effect variables obtained from the questionnaire it is used as night-time aircraft noise metric, since it has the strongest relation with these variables.
  The median value of Li at a location (obtained from the individual Li-values of the subjects at a location) is about equal to Lbi23-07h.

## Instantaneous aircraft noise effects

*Exposure-effect relationships*

Aircraft noise events during sleep are able to increase the probability of motility and the probability of onset of motility. In our study aircraft noise-induced increase in probability of motility during a 15-s interval starts on average from Lmax_i of 32 dB(A) or SEL10_i of 38 dB(A), and aircraft noise-induced increase in probability of onset of motility on average from Lmax_i of 32 dB(A) and SEL10_i of 40 dB(A). The effect increases with increasing Lmax_i values: at Lmax_i of 68 dB(A) probability of motility during the 15-s interval at which Lmax_i of an aircraft noise event occurs (the central event interval) and the 15-s interval thereafter is on average about 3 times the probability of motility in the absence of aircraft noise. The average ‘thresholds’ of 32, 38, and 40 dB(A) are about 15 dB(A) lower than estimated from the CAA study in 1992, carried out with subjects living in the surroundings of airports in UK (Ollerhead et al., 1992; Horne et al., 1994).

Aircraft noise-induced increase in probability of motility during sleep is maximal at the central event interval and the interval thereafter, and less in preceding and later 15-s intervals. Also for aircraft with the highest Lmax_i values in the study, the effect of aircraft noise on probability of motility is limited to less than two minutes (7 15-s intervals): two 15-s intervals before the central event interval, the central event interval, and four 15-s intervals after the central event interval.

*Effect-modifiers and confounders*
Four effect-modifiers of the relationship between aircraft noise-induced increase of probability of motility at the central event interval and Lmax_i have been identified: Li, age, time after sleep onset, and clock time.
*Li* has a prominent impact on instantaneous motility response to aircraft noise events. For subjects with a low value of Li (say 5 dB(A)), aircraft noise-induced increase in probability of motility is about a factor 3 larger than for subjects with high values of Li (say 35 dB(A)).
*Time after sleep onset* also modifies probability of motility. Instantaneous aircraft noise-induced motility increases with time after sleep onset. Increase in aircraft noise-induced probability of motility after seven hours of sleep is a factor of about 1.3 higher than at the start of sleep.
*Clock time* is also an effect-modifier. Increase in aircraft noise-induced probability of motility in the period from 6 to 7 hours is about a factor 1.2 larger than in the period from 23 to 6 hours.
*Age* of subjects has a small but statistical significant effect on probability of motility Increase in aircraft noise-induced probability of motility is maximal at an age of about 46 years, and on average somewhat smaller in younger and older subjects.
None of the four effect-modifiers ia a confounder.

The following variables turned out to have no impact on the exposure-effect relationships: type of aircraft noise event ( aircraft descending or ascending), median sound level (L50) in the bedroom during sleep (in the absence of aircraft noise), Lbi23-07h, and a variety of subject related variables, obtained from the questionnaire, such as gender, attitude towards aircraft noise, frequency of awakening by night-time aircraft noise.

## Aircraft noise effects on a 24 hours time scale

*Effects during sleep*
Indoor aircraft equivalent sound level (Liaspt) and number of indoor aircraft noise events (niaspt) during sleep have a statistical significant effect on motility (mean value during a sleep period

time), fragmentation index, number of marker pressings, and number of remembered awakenings due to aircraft noise. Sleep quality is assessed in the morning diary on a 5 points and on a 11 points scale. There turned out to be no statistical significant relationship between Liaspt or niaspt and sleep quality for both ratings. What could be shown is that sleep quality is related to mean motility during sleep: the higher motility, the lower subjects rate their sleep quality after waking up in the morning.
The following variables have an effect on mean motility:

- L50. The higher L50, i.e. the noisier the bedroom, the higher mean motility. Apparently, sounds other than aircraft noise have a substantial effect on motility;
- Lo – Li. The lower Lo – Li (‘sound insulation’ of the bedroom for aircraft noise), the higher motility;
- Difficulty to fall asleep because of aircraft noise;
- Frequency of awakening by night-time aircraft noise, reported by subjects in the questionnaire. For subjects that indicate to awake (nearly) each night due to aircraft noise, mean motility is about 15% larger than mean motility of subjects that indicate to awake never due to aircraft noise.

*Effects during sleep latency time*
Aircraft during sleep latency time has a slight effect on duration of sleep latency time period and on difficulty to fall asleep. If aircraft noise is the reason for difficulty to fall asleep, duration of sleep latency time is increased by about 15 minutes.
Duration of naps during day and evening, number of cups of coffee in the evening and number of alcoholic beverages during evening are determinants of duration of sleep latency time and difficulty to fall asleep. Number of cups of coffee (slightly) increases duration of sleep latency time and difficulty to fall asleep, and number of alcoholic beverages (slightly) decreases these two variables.

Difficulty to fall asleep (evaluated in the morning diary) is an important factor with respect to several aspects of sleep. Compared with duration of sleep latency time and mean motility during sleep, it has twice as much impact on sleep quality, sleepiness during time awake, number of remembered awakenings, and number of marker pressings.

*Night-time aircraft noise and effects next day after sleep*
Only a small effect of night-time aircraft noise on sleepiness at about 10 hours in the morning has been established. In our study, night-time aircraft noise exposure during sleep does not have an impact on sleepiness in the further course of day and evening.
Sleepiness during time awake is associated with difficulty to fall asleep, duration of sleep latency time, sleep quality, number of marker pressings during sleep, number of remembered awakenings during sleep, and mean motility during sleep.

The reaction time test used in our study was a test adapted from a test developed by Wilkinson. It has been especially designed to measure the effect of sleep loss on performance. None of the test results (reaction times and number of mistakes) have been adversily affected by aircraft noise in the course of the night before testing.

## Aircraft noise effects on a long-term time scale

*Aggregated measurement results*

Of 17 effect variables, aggregated over the 11 sleep period times, only four variables (mean motility, mean onset of motility, mean motility level, and sleep latency time) are related to Li. The higher Li is, the higher these effect variables are.

Mean motility and a variety of aggregated effect variables obtained from the diaries and long-term variables obtained from the questionnaire are associated. These variables are: number of times remembered to have been awake during sleep, number of marker pressings during sleep, use of sleeping pills (effective to induce sleepiness), self-reported sleep quality from the questionnaire, number of general sleep complaints, frequency of times awake due to aircraft noise, number of aircraft noise-induced adverse effects a week, and number of health complaints.

Aircraft noise during sleep not only results in increased probability of motility during aircraft noise events, but the exposure induces in addition to this instantaneous effect a long-term increase in motility. This long-term component increases with Li. The present study is not able to assess the underlying mechanism nor to assess this long-term component is permanent, or vanishes (in part) in a subject, after his/her night-time aircraft noise exposure has ended.

*Long-term effect variables obtained by questionnaire*

It is not the aim of the questionnaire to assess general applicable long-term exposure-effect relationships, such as between Lden and percentage of subjects highly annoyed by aircraft noise. Much larger data bases are available than our data base of the questionnaire responses of 418 subjects. Nevertheless, the long-term data from the questionnaire are elaborated to obtain on a small scale a detailed picture of relationships, determinants, effect-modifiers, and confounders.
A variety of effect variables increase with increasing Lbi23-07h: annoyance due to aircraft noise, annoyance due to aircraft noise at night-time, perception of aircraft noise, perception of aircraft noise during night-time, frequency of awakening due to aircraft noise, dissatisfaction with aircraft noise around the house, fear and worries because of aircraft noise, adverse effects of aircraft noise on sleep, and sleep quality. In this study, aircraft noise exposure during day and evening is confounding the relationships.
Of the various demographic variables considered, only age has an important effect on the effect variables obtained by questionnaire. Variables with the strongest impact on effect variables from the questionnaire are satisfaction with the living environment, satisfaction with the insulation of the house against outdoor noises, refraining from ventilating the house because of aircraft noise, noise sensitivity, and an active attitude towards problems and situations.

Number of health complaints (on a scale from 0 to 13) increases by about 1.5 if Li increases from 0 to 35 dB(A).

## Validity and generalization of results

Aspects related to the validity and generalizability of the results of the study have been discussed in the report: possible selection bias, information bias, confounding of the results, and limitations of the study.

*Selection bias*
Exposure-effect relationships are not biased by selective response of subjects, because:
- Invitations to participate in the study have been sent to all addresses at a location. Apart from practical considerations, candidates to participate have been rejected only if they started using strong sleeping pills less than about two months before their possible participation. No candidates have been excluded for any other reason, such as attitude towards aircraft noise or towards the expansion of Schiphol;
- All subjects that started the study completed it;
- The reward given to subjects was only small in comparison to the tasks required of them;
- The non-response study showed only very few and minor differences between the study and non-response population.

*Information bias*
Information bias did not affect the results of the study, because:
- In the detailed design of the study no emphasis was put on aircraft noise;
- In the acoustic measurements the same procedures have been followed for each location and each subject. Therefore the same information on noise exposure has been obtained, irrespective of the degree of aircraft noise exposure at a location. Also, in the analyses the same procedures to assess aircraft noise exposure of subjects has been followed, irrespective of subject and location;
- The main effect variables, probability of (onset of) motility and level of motility during sleep, have been assessed by objective measurements. The analyses showed that motility outcomes are not associated with attitude towards aircraft noise or Schiphol.

*Confounding*
In the study ample attention has been given to the possible presence of confounding factors.
With respect to aircraft-noise induced instantaneous effects, confounders have not been identified.
A small confounding effect of L50 (median sound level in the sleeping room during sleep outside aircraft noise windows) has been established in the case of the relationship between mean motility and Liaspt (equivalent aircraft sound level during sleep period time). This small effect could be quantified.
With respect to the long-term effects on mean motility during sleep, sleep latency time, and health complaints, confounders have not been identified.
Day- and evening-time aircraft noise exposure is a confounder of the relationships between Lbi23-07h and twelve effect variables from the questionnaire considered in the analyses.

*Generalization of results*

About 20 candidates have been rejected because of their start of using sleeping pills and other medication able to induce sleepiness or increase sleep depth within a period of six weeks before the start of the study at their location. Subjects who used sleeping pills and other medication able to induce sleepiness or increase sleep depth for a longer period of time have been included in the study. The only impact of a longer use of sleeping pills etc. turned out to be on sleep quality: people who use sleeping pills etc. rate their sleep quality lower than non-users.

Thirteen subjects were born outside the Netherlands, among them 11 in Indonesia. Presumably subjects with other nationalities are under-represented in the study because difficulties in communicating in Dutch and different lifestyle and privacy considerations refrained people born in other countries from participating. Subjects born outside the Netherlands did not show adverse aircraft noise-induced effects different from the Netherlands subjects. Therefore we consider the results of the study also applicable to people born outside the Netherlands, who live at present in the vicinity of Schiphol.

The study did not consider the effects of noise on sleep of shift workers, children, and ill persons (including persons in hospitals). The results of this study should therefore not be extrapolated to those populations.

*Conclusion*

The considerations given in the report show that the relationships obtained in this study are general applicable with the following limitations. The results of the study should not be extrapolated to the effects of noise on sleep of shift workers, children, and ill persons (including persons in hospitals). Care should be taken in the extrapolation of long-term questionnaire exposure-effect relationships to airports without or with very minor night-time aircraft noise, because effects may be underestimated by using these relationships with L23-07h as exposure metric.

## General observations

- There is a range of about 30 dB(A) in individual aircraft noise exposure during sleep (Li) in subjects living at the same location;
- Individual aircraft noise exposure during sleep (Li) has a large impact on aircraft noise-induced increase in probability of motility during aircraft noise events;
- The threshold of aircraft noise-induced probability of (onset of) probability is on average an Lmax_i value of 32 dB(A), which is lower than assumed until now;
- Aircraft noise during sleep not only results in increased probability of (onset of) motility during events, but the exposure also induces on a long-term basis a higher level of mean motility. The long-term increase in mean motility increases with individual aircraft noise exposure during sleep (Li);
- Aircraft noise during sleep increases number of behavioural awakenings and number of remembered awakenings due to aircraft noise;
- People consider it more difficult to fall asleep when exposed to aircraft noise during sleep latency time period. Duration of sleep latency time period increases with equivalent aircraft sound level during that period;

- Aircraft noise during sleep does not have an effect on sleep quality, assessed on a night-to-night basis by morning diary;
- Aircraft noise during sleep only has a slight effect on sleepiness in the morning (10 hours), and no effect later during day and evening, as evaluated by subjects responses at the sleepiness strip;
- Aircraft noise during sleep does not have an effect on the results of the reaction time test performed the evening after the exposure;
- Age is an important determinant and effect-modifier of many aspects of sleep and many exposure-effect relationships;
- There is a moderate to strong relationship between aircraft noise exposure during sleep and mean motility measures;
- Mean motility is associated with a variety of aggregated effect variables obtained from the diaries and of long-term variables obtained from the questionnaire, such as number of times remembered to have been awake during sleep, number of marker pressings during sleep, use of sleeping pills (effective to induce sleepiness and/or increase sleep depth), self-reported sleep quality from the questionnaire, number of sleep complaints, frequency of times awake due to aircraft noise, number of aircraft noise-induced adverse effects a week, and number of health complaints;
- In this study number of health complaints increases with individual aircraft noise exposure during sleep (Li), but is not related to the yearly average aircraft noise exposure Lbi23-07h, assessed per location.

# 1 Introduction

## 1.1 Framework and objectives of the study

The study has been carried out in the framework of the research program Health Impact Assessment Schiphol (Gezondheidskundige Evaluatie Schiphol - GES). This program is financed by the Ministries of the Environment (VROM), Public Works and Water Management (V&W), and Health (VWS), and it is co-ordinated by the National Institute of Public Health and the Environment (RIVM). The field study has been carried out in the vicinity of airport Schiphol, located near Amsterdam.

The objectives of the study are:

a. To assess relationships between night-time aircraft noise exposure and measures of sleep disturbance, health and daily functioning. The effect of aircraft noise in the so-called edges of the night (23 to 24 hours and 6 to 7 hours) is of special interest;
b. To provide information on the basis of which the prevalence of effects induced by night-time aircraft in the population in the vicinity of Schiphol can be estimated.

The investigation consisted of a pilot and main study. The pilot study has been carried out in 1998 (Passchier-Vermeer et al., 1999). It has been undertaken to obtain information to design the main study in detail. The field investigation of the main study has been carried out in the period from November 1999 to April 2001. The results of the main study have been reported in:

- the present report, containing the statistical analyses of the study (TNO-report 2002.027);
- TNO-report 2001.205 with detailed information about the subject and non-response population, obtained from questionnaires and diaries, and about the locations at which the main study has been carried out;
- TNO-report 2001.206 with tables and figures related to report 2001.205, and with pictures of locations;
- TNO-PG rapport 2002.028, RIVM rapportnummer 441520019: 2002, with the main results of the study and estimates of the prevalence of effects of night-time aircraft noise in the vicinity of Schiphol, written in Dutch.

## 1.2 Findings of prior studies and background of present study

This section describes the rationale for the design of the present study in the context of a brief discussion of findings of prior studies about the effects of noise exposure on sleep.

*Importance of sleep*

Sleep is an active physiological process, and not only the absence of waking. Sleep is a part of a circadian (24 hours) rhythm of activity and rest. “Sleep is viewed as a state of the brain and body governed by diencephalic and brainstem neural systems and characterized by periodic, reversible loss of consciousness; reduced sensory and motor functions linking the brain with the environment; internally generated rhythmicity; homeostatic regulation; and a restorative quality that cannot be duplicated by food, drink, or drug. Sleep is as essential as food and water: the physiological and psychological drive to sleep can overwhelm all other needs" (Aldrich, 1999).

*Sleep and noise during sleep*
Although sensory and motor functions are reduced during sleep, also sleeping people evaluate noise signals. In this evaluation, functions of the central nervous system, including the brain, of the peripheral nervous system, and of the hormonal system are involved. For instance, as a reaction to a noise signal during sleep, sleep stage may change, heart rate and systolic blood pressure may increase temporarily, stress hormones may be released in blood, and the arousal may induce small temporary movements of the body. A more extreme instantaneous reaction to noise is awakening.

*Possible effects of night-time noise*
Possible effects of night-time (aircraft) noise exposure can be distinguished on various time scales: acute effects during sleep (see above), effects and after-effects on the scale of one night, and effects on a long-term time scale. Possible effects and after-effects on the scale of a night are e.g. a reduction in self-reported sleep quality and increase in sleepiness during day-time. Possible long-term effects include night-time noise annoyance and adverse effects on somatic health.

*Key information*
With a view on the controversies in the relevant literature and black spots in knowledge it was considered necessary that a large-scale study on the effects of night-time aircraft noise in the vicinity of Schiphol be undertaken (Fransen et al., 1995). The main objective of the study should be the assessment of exposure-effect relationships for acute effects during sleep. Also, it was considered imperative that assessment of acute sleep disturbance should be based on measurement of physiological functions and not be limited to effects based only on evaluations by subjects.

*Measurement of sleep parameters*
The physiological reactions to noise during sleep can be measured by a variety of measuring methods The sleep polygraph continuously records electroencephalograph (EEG) activity, eye movement (EOG) and muscle tone (EMG). These data are used to classify sleep into various stages, and to assess time of falling asleep and wake-up time. Also, sleep variables such as total sleep time and total time spent overnight in Slow Wave Sleep (SWS, stages of deep(er) sleep) and in the stage of Rapid Eye Movement (REM, also called dream sleep) can be assessed on the basis of sleep polygraph recordings. Polygraphic indicators of responses to individual noise events are changes in sleep from a deeper to a less deep sleep, and EEG-awakening.
Electrocardiography (ECG) continuously records heart rate and measures of blood pressure, and plethysmography (during sleep the recording mechanism is usually worn around a finger) continuously measures heart rate and relative blood pressure. For sleeping persons mean heart rate, mean systolic and diastolic blood pressure, and variability in heart rate are usually assessed.

Indicators of responses to individual noise events are instantaneous changes in (variability of) heart rate and changes in systolic blood pressure.
Collecting assays of overnight urinary catecholamines is a method to study sympathetic nervous activity. The assays represent the total catecholamines released during sleep period time, not taken up by sympathic nerve endings. The method does not allow the detection of peak levels of circulating catecholamines, such as may instantaneously occur in response to noise events during sleep. Overnight and 24 hours cortisol levels may be important indicators of risk of chronic cardiovascular disorders. Previously, sampling of cortisol required blood sampling, but recently a method of assessing cortisol levels in fluvia has been developed, which may provide an adequate non-invasive method of sampling cortisol levels in large groups of people.
Motility is measured with actimeters, in research usually worn on the non-dominant wrist. Measures of instantaneous motility are the probability of motility, and the probability of onset of motility in a fixed time interval. By actimetry total sleep time, time of falling asleep, wake-up time, mean motility and other measures have been assessed. Validated as measures of arousals/awakenings against the sleep polygraph, actimetry has in the last decade been used to monitor sleep disturbance in large numbers of people exposed to noise while sleeping at home (Ollerhead et al., 1992; Horne et al., 1994; Fidell et al., 1995, 1998;. Griefahn et al., 1999).

*Focus on measurement of motility*
To be able to perform a large scale study with minimal interference in subjects normal sleep habits, it was decided to focus on the measurement of motility. The size of the group of subjects, and the number of nights each subject should participate in order to obtain sufficient data for well-funded conclusions have been estimated from the results of the pilot study. Apart from the choice of actimetry as measurement method to assess physiological sleep disturbance, instrumentation also allowed the assessment of behavioural awakenings by pressing a button on the actimeter. Additionally, remembered awakenings have been assessed by means of computerised morning diary.
No (objective) measurements of aspects of somatic health have been included in the present study. Objective parameters to be included in the study would be stress hormone levels or cardiovascular parameters, such as blood pressure and heart rate. However, taking into account that the tasks subjects had to perform in the present study were already quite demanding, we abstained from including other exacting requirements.

*Measurement of motility*
Motility (movement) is measured with an actimeter, in field investigations usually worn on a wrist. In succeeding time intervals, measures of the accelerations associated with movements during the intervals are stored in the memory of the actimeter. Usually the measurement interval is chosen between 2 and 60 s. If the accelerations during an interval exceed a threshold (which is, dependent on the type of actimeter, usually about 0.01 ms-2), a positive value and if there are no accelerations above threshold the value 0 is stored. The threshold is such, that the motility of active people while awake exceeds the threshold in nearly all intervals: the probability of motility in a 15-s interval during time awake is over 0.90. During sleep, motility is strongly reduced. For example, in the present study, motility (over threshold) of all subjects while asleep occurs in

3.66% of the measurement intervals of 15-s, i.e., the probability of motility during sleep is on average in our study population 0.0366. The number of 15-s intervals in the average sleep period of about 7 h and 10 minutes in our study population is 1720. Thus, the number of 15-s intervals with motility over threshold during the average sleep period time is 63, and the number without motility is 1657. Another measure frequently used is the probability of *onset* of motility above threshold. The number of 15-s intervals during sleep with onset of motility above threshold is in our study population equal to 40 (probability is equal to 0.0234). With other measurement intervals, the values of probability of (onset of) motility during sleep change accordingly. E.g., for 30-s intervals the probability of motility and of onset of motility in our study population would have been 0.060 and 0.047 respectively .

Ollerhead et al. (1992) estimates the probability of onset of motility in an undisturbed good sleeper such that it corresponds roughly to 18 EEG awakenings (equal to 40% of 45 times onset of motility) per sleep period time. This number of awakenings is about 15 times higher than the number of awakenings undisturbed good sleepers remember next morning or the number of awakenings assessed by pressing a button.

*Required improvements over earlier studies*
In recent years, acute effects of night-time aircraft noise events have been studied in various field investigations (Ollerhead et al., 1992 (see also Horne et al., 1994); Fidell et al., 1995; Fidell et al., 1998). In 1999 Griefahn et al. reported a large scale study on the effects of road and railway traffic, in which also actimetry has been performed. In Appendix G these studies are reviewed and their results compared with the results obtained with our study.
In 1991 Ollerhead, Horne and colleagues carried out the first extensive field study on night-time aircraft noise, with subjects in the vicinity of civil airports in UK, and established exposure-effect relationships based on motility. Main disadvantage of the UK study is that it has been based on outdoor noise measurements, which, as will be shown in our study, gives only a slight indication of real exposure of subjects. Also, the analyses had to be limited to night-time between 23.30 and 5.30 hours, because of limitations of storage capacity and work memory of computers available at that time. Therefore, in our study emphasis should be on the accurate assessment of individual exposure of subjects to night-time aircraft noise, i.e. aircraft noise as it is present in the bedrooms of subjects.
Fidell and colleagues included, in a larger and a small study, only subjects that live very close to the runways of airports, which implies that all subjects are heavily exposed to night-time aircraft noise. They performed out- and indoor noise measurements and concluded that exposure-effect relationships are stronger with indoor rather than with outdoor aircraft noise exposure metrics. Measurement time has been limited from 23 hours in the evening to 7 hours in the morning. With a view on the selection of subjects, Fidell and colleagues state that their results should not be extrapolated to other populations. In the present study, subjects have been included without or with very few night-time aircraft up to the highest night-time aircraft in the vicinity of Schiphol. With a view on night-time aircraft noise regulations in the Netherlands, the present study should be designed such that it would, in addition to exposure-effect relationships, also give information about possible additional effects of aircraft noise exposure between 23 and 24 hours and between

6 and 7 hours. Noise measurements have been performed from 22 hours in the evening up to 9 hours in the morning. Since it was not feasible to adjust noise measuring times according to the individual sleep patterns of subjects, the period from 22 to 9 hours was considered sufficiently long to include most sleep period times of subjects completely. Subjects wore actimeters during 24 hours.

In each of the studies cited above many data have been collected about factors other than night-time aircraft noise that may have an impact on sleep. These factors have only to a small extend been used in the analyses as possible determinants or effect-modifiers of the instantaneous effect variables. Also, no focus has been on the average effects of aircraft noise exposure during a night, and on the impact of other variables on these average effects. E.g., relationships between mean probability of motility and aircraft noise exposure during sleep, and the impact of age and other noises in the bedroom, are unknown. Also, relationships between the aggregated values of aircraft noise exposure during a night and number of behavioural awakenings, number of remembered awakenings in general, and number of remembered awakenings due to aircraft noise are missing. An additional objective of the present study is to obtain insight in the night-to-night burden of aircraft noise and in the factors that have an impact on night-time aircraft noise effects.

*Additional aspects*
Profound sleep loss has an adverse effect on performance assessed by e.g. reaction time tests. Whether aircraft noise exposure during sleep is able to induce sleep loss sufficient to have an effect on performance, is one of the questions the present study seeks to answer.
Although we had to abstain from objective measurements of somatic health, subjects filled out at the start of their participation in the study a questionnaire which includes several questions about aspects of health. Also, the effect of the use of medication (sleeping pills and other drugs) on sleep can be evaluated on the basis of questionnaires and diaries.
The advantage of measurement of aircraft noise exposure in the bedroom is the possibility to relate aircraft noise-induced effects to the individual aircraft noise exposure of subjects during sleep.

## 1.3 Model of effects of night-time aircraft noise exposure

Figure 1.1 presents the model used in this study to assess exposure-effect relationships. Relationships at three different time scales have been considered:

- At an instantaneous level: *instantaneous* effect variables assessed during sleep period times of subjects are related to measures of *aircraft noise events*;
- At a 24 hours level (including one sleep period time): effect measures representative for a *sleep period time* of a subject or for time awake after a sleep period time are related to exposure measures representative for *aircraft noise exposure during sleep*;
- On a long-term basis: *long-term* effect variables are related to *long-term* aircraft noise exposure measures.

Effects can be divided in self-reported and objective effects. Self-reported effects are assessed by asking an *evaluation* of a subject, for instance about disturbance of activities, sleep quality, sleepiness during time awake, perceived quality of health, and annoyance. Objective effects are obtained from *measurements* of motility and from performance *tests*.

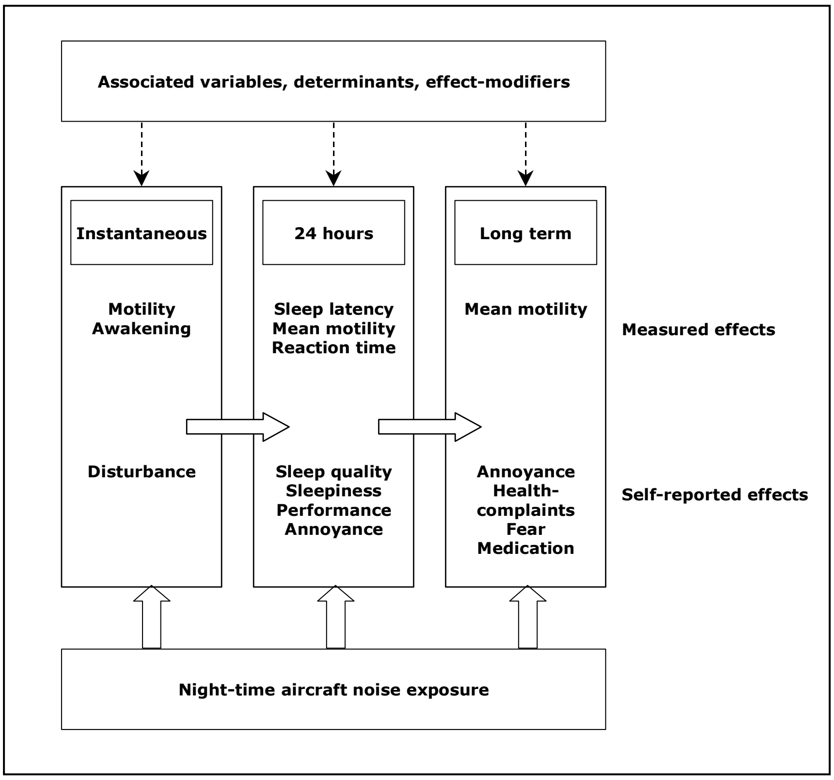



*Figure 1.1: Model of relationships between night-time aircraft noise exposure and adverse effects on sleep, health and performance.*

Exposure-effect relationships have been assessed by using, depending on the type of effect variable, linear and logistic (multi-level) regression models. The most simple regression equation of the relationship between an effect variable y, and an aircraft noise exposure metric A is given by:

$$y(A) = \text{constant} + b1*A$$

in which: b1 is the regression coefficient of A.

An important aspect of the assessment of exposure-effect relationships is the determination of the possible impact of other variables on the effect variables and on the relationships. Variables with an impact on an effect variable are variables either associated with the effect variable, or determinants other than night-time aircraft noise exposure, and effect-modifiers. A variable is associated with an effect variable, if it has an impact on the effect variable and the cause-effect chain is unclear. E.g. if the effect variable is ‘having worries about the impact of airrcraft noise on health’, and the associated variable is ‘attititude towards the expansion of Schiphol’ it is unclear whether 'attitude towards the expansion of Schiphol' has an effect on 'having worreis about the impact of aircraft noise on health' or vise versa. In the case of a determinant, the cause-effect chain is obvious: e.g. gender may be a determinant of night-time aircraft noise annoyance, but night-time aircraft noise is not a determinant of gender. The equation of the relationship between an effect variable y, an aircraft noise exposure metric A and possible associated variables and determinants V2 to Vx is given by:

$$y(A,V2, \ldots,Vx) = constant + b1*A + b2*V2 + b3*V3 + \ldots + bx*Vx$$

in which: b1 … bx are regression coefficients of A, V2, …,Vx.

For a relationship between an exposure and an effect variable, an associated variable or a determinant other than the aircraft noise exposure variable has the same impact on the effect variable, irrespective of the value of the aircraft noise exposure variable: the variable moderates the effect. If the impact on an effect variable of a variable varies with exposure, i.e. there is an interaction between the variable and the exposure variable, the variable is an effect-modifier. The equation of the relationship between an effect variable y, an aircraft noise exposure metric A and an effect-modifier V2 is given by:

$$y(A,V2) = constant + b1*A + b2*A*V2$$

in which: b1 regression coefficients of A;

b2 regression coefficient of A*V2.

For a given relationship between an exposure and effect variable, a variable is a confounder of the relationship, if it has the following characteristics:

- the variable is a determinant of the effect variable;
- there is an association between the exposure variable and the variable;
- the variable is not a factor in the cause-effect chain from exposure to effect.

Therefore, a variable that is a determinant of an effect variable, and is also associated with the exposure variable but not a factor in the cause-effect chain, is a confounder. E.g., assume there is a relationship between night-time aircraft noise exposure and 'fear for aircraft'. Also, assume that day-time aircraft noise exposure is a determinant of the effect variable 'fear for aircraft', that day-time aircraft noise exposure is associated with night-time aircraft noise exposure, and that day-time aircraft noise exposure is not a factor in the cause-effect chain from night-time aircraft noise exposure and fear for aircraft, then day-time aircraft noise exposure is a confounder of the relationship .

More detailed models, each related to a specific time scale, will be presented in the next chapters.

## 1.4 Design of the main study

The study has been divided in three parts: preparation of the (field) study, execution of the field study, analyses of data including the preparation of reports and publications.

### 1.4.1 Preparation

The preparation for the field study has been facilitated by experiences obtained in the pilot study. Before the start of the field study the following activities have been carried out:
- An inception report has been written and discussed with RIVM and Steering Committee GES. In the inception report the detailed lay-out of the study has been given;
- Permission to carry out the study has been requested and obtained from Medical Ethical Committee TNO;
- Equipment has been purchased and prepared for use in the field study. Questionnaires and diaries have been developed and tested;
- Possible locations have been visited and selected;
- Acoustical measurement design has been developed and tested;
- The organisational aspects of the project have been arranged. This included the institution of the Management Team of the project.

### 1.4.2 Field study

*Subjects and their tasks*
In the study 418 adult subjects participated. They were exposed during their participation to night-time aircraft noise as it usually occurs in their bedroom. The study examined subjects in a way that caused minimal interference in their everyday life. Ages of subjects varied between 18 and 81 years, 50% of the subjects was male, and 50% female. Possible candidates had to fulfill the following requirements: they planned to sleep during each of the study nights in their own bedroom, they did not have to nurse a family member extensively during night-time (this does not include the normal activities of taking care of young children), they did not start using strong sleeping pills within two months before their assumed participation in the study. About 20 candidates have been rejected because of the use of sleeping pills. Detailed information about the study population is given in TNO reports 2001.205 and 2001.206.
Candidates for participating in the study have been recruited by mail. The request to participate and a leaflet with information about the tasks of a subject has been sent to about 3000 addresses. About 540 candidates showed interest in participating. About 440 possible subjects have been chosen (see later in this report) for an in-take visit and further consultation. After this in-take visit about 20 persons decided not to take part in the study. All 418 subjects that actually started participation completed the study. At the end of participation subjects received vouchers to the value of € 113. Subjects participated from a Monday evening until a Friday morning 11 days later. After a subject agreed to participate in the study, he/she filled out an extensive questionnaire (the English translation of the questionnaire is given in report 2001.205). Participation in the study encompassed the following tasks at each of the 11 participation days:

- Filling out a morning- and evening diary on a laptop made available to the subject by TNO (the English translations of the diaries are given in TNO report 2001.205);
- Performing a reaction time test on the laptop just before going to bed;
- Filling out a sleepiness strip five times during day and evening and wearing a watch which produced a noise signal at the times the sleepiness strip had to be filled out;
- Wearing an actimeter (CNT, type AW4, weight about 50 grammes) continuously, with the exception of periods of bathing and swimming, during the participation in the study. With the storage interval of the actimeters chosen as 15 s, they were read out three times during the 11 participation days in a personal computer by TNO. The actimeters have an event marker. Times at which the marker is pressed are also stored in the memory of the actimeter. Subjects pressed the marker twice when they intended to go to sleep and after they awoke to get up, and pressed the marker once whenever they woke up during their sleep period times.

*Study locations*
The study has been carried out successively at 15 locations, selected mainly on the basis of night-time aircraft noise exposure. Other selection criteria pertained to exposure to road and railway noise, degree of urbanisation, and type of dwellings. Two locations have been selected because of their presumed absence of night-time (23 – 6 hours) aircraft noise. The other locations have various degrees of night-time aircraft noise exposure, from relatively few aircraft at night up to the highest exposure in residential areas close to Schiphol. The villages and towns where the locations are situated together with their label are given in table 1.1. In figure 1.1 (at the end of this section) the 15 locations are indicated on a map of the surroundings of Schiphol. The map also shows the so-called 20 and 26 dB(A) night-time aircraft noise contours (LAeq,23-06h), calculated by NLR (Nationaal Lucht- en Ruimtevaartlaboratorium: National Aerospace Laboratory) on the basis of aircraft to and from Schiphol in 2000.

*Aircraft noise exposure*
For the present study RIVM calculated on the basis of data obtained from NLR values of various aircraft noise metrics over 2000 at the 15 locations. These metrics are: Lbi23-06h (indoor equivalent sound level from 23 to 6 hours), Lbu23-07h (outdoor equivalent sound level from 23 to 7 hours), Lbu06-07h (outdoor equivalent sound level from 6 to 7 hours), Ke (Kosten Unit), and Lden (day-, evening-, night level: equivalent sound level over 24 hours, with sound levels during evening (19 to 23 hours) increased by 5 dB(A), and sound levels during night (23 to 7 hours) increased by 10 dB(A)). From these metric two other metrics have been calculated: Lday and Lbi23-07h. Lday is the indoor equivalent sound level from 7 to 23 hours, with sound levels from 19 to 23 hours increased by 5 dB(A). Lbi23-07h is the indoor equivalent sound level from 23 to 7 hours, which has been taken 21 dB(A) lower than Lbu23-07h. The last column of table 1.1 presents Lbi23-07h in 2000.
At each location the study has been performed during two subsequent intervals of 11 days. Indoor and outdoor noise measurements have been carried out simultaneously from 22 – 9 hours during the 11 nights in these intervals. Indoor noise measurements have been performed in the bedroom of each subject during each of his/her participation night. At each location one outdoor noise monitor has been in operation. Each (outdoor and indoor) noise monitor stored the equivalent

sound levels over a second and time of measurement. (This implies for 11 night-time periods of 11 hours 435 600 equivalent sound levels per noise monitor). Aircraft noise events have been identified by comparing the stored noise and time data with information obtained from FANOMOS, the flight track monitoring system of the Civil Aviation Enforcement Agency of the Ministry of Transport (Veerbeek et al., 1998).
From the data of the aircraft noise events, for each subject Li - the indoor aircraft noise equivalent sound level during the 11 sleep period times of the subject - has been calculated. In the report it will be shown that Li is representative for the individual long-term indoor aircraft noise exposure during sleep of a subject. Lo is the outdoor aircraft noise equivalent sound level during the 11 sleep period times of a subject, calculated from the outdoor noise levels of the same aircraft that was used in the assessment of Li of the subject.

*Non-respondents*
After the start of the second study interval at a location, a request to fill out a non-response questionnaire was sent at random to a part of the addresses that received the original invitation. In total 451 non-respondents (60%) returned the non-response questionnaire to TNO. Table 1.1 gives the number of non-respondents per location.

### 1.4.3 Analyses and reports

Analyses have been carried out with statistical software packedges SPSS10, SPSS11, and SAS version 8.0. If not mentioned otherwise, program options have been set at default. Hypothesis have been tested one- or two-sided, depending on the type of hypothesis, at a significance level of 0.05.

## 1.5 Contents of the report

The main body of information is given in Appendices A to G. Appendix A provides information about the instrumentation used in the field study and gives an overview of variables and how they have been obtained from the raw data. In Appendix B acoustical aspects of the study are discussed. In the Appendices C to E models and statistical analyses used to obtain exposure-effect relationships are given. Appendix C presents details of the analyses with instantaneous variables, Appendix D gives the analyses of the 24 hours data, and Appendix E of long-term effects. In Appendix F possible differences between subjects and non-respondents have been analysed and the impact of differences has been assessed. In Appendix G an overview of field studies on traffic noise and sleep, performed during the last 10 years, is given and the results of those studies are compared with results of the present study.
Tables and figures are included at the end of each Appendix.

In the main text of the report, results obtained in the Appendices are presented without statistical details.Chapter 2 presents exposure-effect relationships for instantaneous aircraft noise-induced effects, chapter 3 for effects on a 24 hours basis, and chapter 4 for long-term effects. Chapter 5 gives the results about differences between subject and non-respondents. In chapter 6 the overall results are discussed and conclusions are given. Acknowledgements are included in chapter 7. The end of the main text includes references.

*Table 1.1: Name and label of each location, number of subjects, number of persons who filled out a non-response questionnaire (non-respondents), and a measure of indoor night-time aircraft noise exposure (indoor aircraft noise equivalent sound level, Lbi23-07h) on a yearly basis. The outdoor aircraft noise equivalent sound level Lbu23-07h is 21 dB(A) higher than Lbi23-07h.*

| location | label of location | number of subjects | number of non-respondents | Lbi23-07h in 2000 (in dB(A)) |
|---|---|---|---|---|
| Nieuw-Vennep | 31 | 28 | 28 | 26 |
| Rijsenhout | 32 | 27 | 35 | 23 |
| Zwanenburg | 33 | 27 | 35 | 27 |
| Assendelft | 34 | 26 | 27 | 27 |
| Halfweg A | 35 | 27 | 24 | 28 |
| Kaag/Buitenkaag | 36 | 26 | 26 | 27 |
| Leimuiden | 37 | 27 | 29 | 22 |
| Halfweg B | 38 | 28 | 28 | 31 |
| Krommenie | 39 | 24 | 40 | 26 |
| Hillegom **** | 40 | 28 | 31 | 10 |
| Hoofddorp | 41 | 30 | 29 | 19 |
| Spaarndam | 42 | 30 | 31 | 24 |
| Warmond | 43 | 30 | 36 | 26 |
| Haarlem **** | 44 | 30 | 26 | 10 |
| Abbenes | 45 | 30 | 26 | 29 |
| Total | | 418 | 451 | |

**** locations assumed to be without night-time (23 – 6 hours) aircraft noise exposure

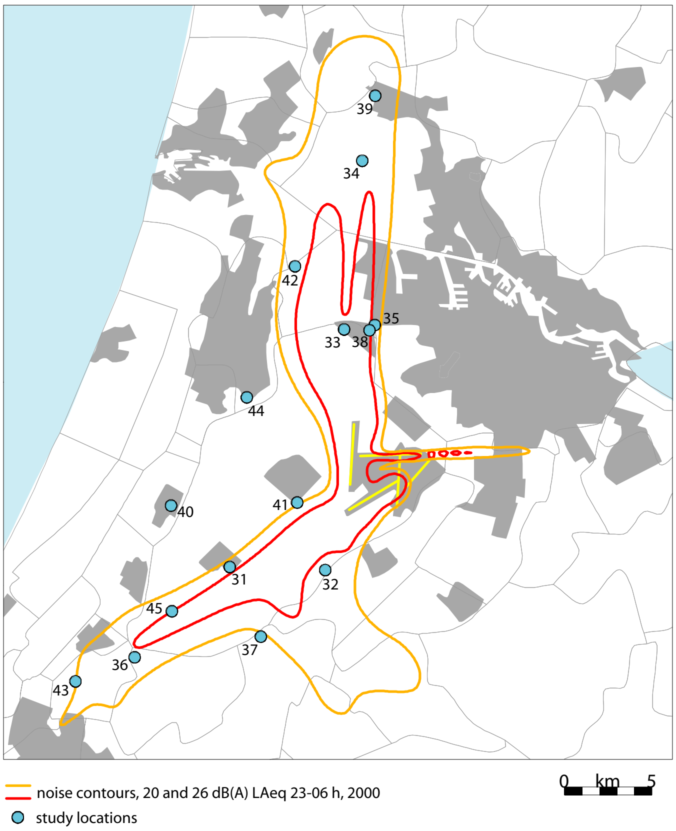



*Figure 1.2:* *Map of the surroundings of Schiphol International Airport. The numbers are the labels of the 15 locations. The map also shows the aircraft noise contours for $L_{Aeq,23\text{-}06h}$ equal to 20 and 26 dB(A). These contours have been calculated on the basis of aircraft to and from Schiphol in 2000.*

# 2 Instantaneous variables

## 2.1 Introduction

This chapter presents in section 2.2 the design of the analyses and in section 2.3 the resulting relationships between instantaneous noise and effect variables. Detailed information about the analyses by which the relationships have been obtained is given in Appendix C. Relationships have been derived from the results of actimetry (motility) and marker presings of subjects and results of (aircraft) noise measurements in the bedroom of subjects during sleep. In section 2.4 the results of the present study are compared to those of earlier studies (Ollerhead et al., 1992; Horne et al., 1994;Fidell et al., 1995). Section 2.5 lists the conclusions of this chapter.

Figure 2.1 gives the model that has been used in the determination of relationships between exposure to aircraft noise events and instantaneous motility outcomees. Detailed information about effect variables, aircraft noise event metrics, and possible other variables with an impact on the effect variables and exposure-effect relationships are given in section 2.2.

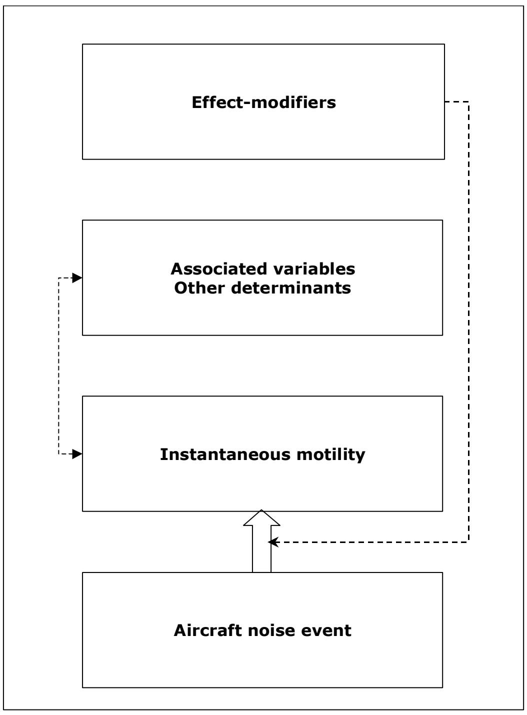



*Figure 2.1: Model for relationships between aircraft noise events and instantaneous effects.*

## 2.2 Analyses

### 2.2.1 Effect variables

Subjects wore an actimeter on the non-dominant wrist during each of the eleven 24 hours periods they participated in the study. This allows the assessment of the following effect variables as a function of time for each of the eleven sleep period times of a subject:

1. for each time interval of 15-s (at the end of the interval) the output of the actimeter (score). Score = 0 if the vibration level (motility) during a 15-s interval is below threshold. The range of score (if unequal to 0) during sleep varies from subject to subject, since subjects have their own but different accelerations while moving their extremities and body. Therefore, analyses are carried out with relscore, the relative value of score equal to score divided by the median value of all values of score (for score unequal to 0) of a subject obtained during all sleep period times the subject participated in the study. Relscore is called motility level;
2. for each time interval of 15-s (at the end of the interval) the indication whether motility occurred during that interval. The binary variable motility (m) is derived from the time series of score. The value of m is 0 or 1 (score > 0: m = 1; score = 0: m = 0). In the relationships the probability of motility (probability of m=1) has been used as effect variable;
3. for each time interval of 15-s (at the end of the interval) the indication whether motility started during the interval. The binary variable motility onset (k) is derived from the time series of m. The value of k is 0 or 1 (k = 1 if m = 1 in a 15-s interval and m = 0 in the preceding 15-s interval; k = 0 in all other cases). In the relationships the probability of onset of motility (probability of k=1) has been used as effect variable;
4. for each time interval of 15-s (at the end of the interval) a value (markpres) which indicates whether the event marker has been pressed or not. The value of markpres is equal to 1 if the marker has been pressed, and 0 if the marker has not been pressed.

### 2.2.2 Aircraft noise event variables

For the following two aircraft noise event metrics exposure-effect relationships have been assessed:

- Lmax_i maximal *indoor* sound level of an aircraft noise event (in dB(A));
- SEL10_i *indoor* equivalent sound level of an aircraft noise event, normalised to one second, assessed over the time the sound level of aircraft is larger than Lmax_i – 10 (in dB(A)).

In the initial analyses, also *outdoor* SEL10 and *outdoor* Lmax have been used as aircraft noise event variables. It turned out that relationships between outdoor aircraft noise metrics and instantaneous motility variables are not statistically significant.
The number of aircraft noise events assessed on the indoor noise monitors during sleep of subjects is equal to 63242.

There is a high correlation between Lmax_i and SEL10_i. The overall correlation coefficient (all 63242 events) is 0.94. The correlation coefficient varies from location to location between 0.85 to 0.95. A correlation coefficient of an *indoor* and an *outdoor* aircraft noise event metric (e.g. Lmax_i and Lmax_o) is about 0.45. In figure 2.2 a scatter plot is given of Lmax_i and Lmax_o. The large scatter explains to some extent the absence of statistical significant relationships of outdoor aircraft noise metrics and instantaneous effect variables, notwithstanding the statistical significant relationships of indoor aircraft noise metrics and instantaneous effect variables.

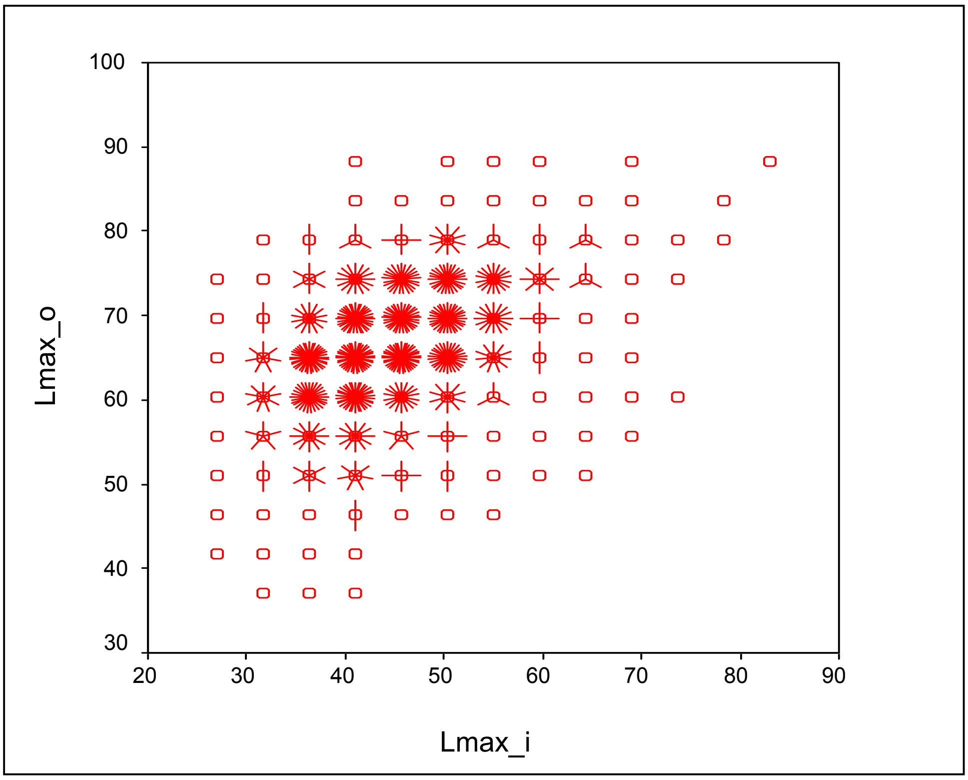



*Figure 2.2: Scatter plot of Lmax_o and Lmax_i. A small bar represents 100 aircraft noise events. A dot without a bar represents 1 to 100 events. Correlation coefficient is equal to 0.43.*

To match on a time basis the actimeter recordings of a subject asleep to the occurrences of aircraft noise events measured by the indoor noise monitor, first the time of an indoor aircraft noise event is specified by the clock time of Lmax_i. This clock time is compared with the clock times of the actimeter outputs (at the end of each 15-s period) and the 15-s interval at which Lmax_i occurs is called the central aircraft noise event interval. For each aircraft noise event, a window around the central aircraft noise event interval has been defined. An aircraft noise event window consists of 20 15-s intervals (et, numbered e1 to e20), 5 before the central interval (e1 to e5), the central interval (at e6) and 14 intervals (e7 to e20) after the central interval.

### 2.2.3 Other variables

Whether subject-, location- or situation-related variables are associated with the effect variables, determinants, effect-modifiers or confounders has been tested by using the effect variable probability of motility at e6 and aircraft noise event variable Lmax_i. The following variables have been considered:

- *Subject related variables:* demographic variables (including age and the combination of age and age*age), 18 variables from the questionnaire (see table C4 in Appendix C), such as attitude towards aircraft noise and towards the expansion of Schiphol, sleep quality, number of complaints about aircraft noise at night;
- *Type of aircraft noise events:* aircraft descending (approaching Schiphol) or ascending (leaving Schiphol);
- *Individual indoor aircraft noise exposure during sleep Li;*
- *L50:* (median sound level in the bedroom during sleep outside aircraft noise windows);
- *Location dependent aircraft noise exposure:* Lbi23-07h;
- *Double-glazing of bedroom window(s);*
- *Time of aircraft noise event after sleep onset*;
- *Clocktime of aircraft noise event*.

### 2.2.4 General approach to obtain relationships

*Probability of (onset of) motility*
First, relationships have been assessed without taking into account that also other variables may have an impact on the effect variables or on the relationships. Then, the impact of other variables has been considered.
Exposure-effect relationships have been specified for probability of (onset of) motility and aircraft noise event metrics Lmax_i and SEL10_i for each of the 15-s intervals e4 to e10 separately. Relationships have been obtained by using random effects logistic regression models with subjects as first level.
By using these models, the probability that m=1 at a 15-s interval et (et from e4 to e10) , denoted by $p_m$, has been specified as a function of Lmax_i and of SEL10_i. In figure 2.3 an example of such a function is given in the left-hand figure. For onset of motility, the probability that k=1, denoted by $p_k$, has been specified as a function of Lmax_i and SEL10_i.These formula's result in the *probability of (onset of) motility* during interval et.
To obtain the *aircraft-noise induced* increase in probability of motility during interval et, the *probability of (onset of) motility that would have occurred if there would have been no aircraft noise event*, should be subtracted from $p_m$ (or $p_k$). The procedure to obtain the estimates of these probabilities of (onset of) motility is outlined in section C3 of Appendix C. In the left-hand figure of figure 2.3 an example of the probability of motility that would have occurred if there would have been no aircraft noise event, denoted by exp_m, is given as a function of Lmax_i.
*Aircraft noise-induced increase of probability of motility*, denoted by resp_m, as a function of Lmax_i or SEL10_i at a given 15-s interval et is obtained by subtracting the function exp_m from the function $p_m$ :

$$\text{resp\_m}(\text{Lmax\_i, et}) = p_m(\text{Lmax\_i}) - \text{exp\_m}(\text{Lmax\_i, et}) \quad [2.1]$$

To SEL10_i and to probability of onset of motility similar functions are appropriate. In the right-hand figure of figure 2.3 an example of resp_m is given.

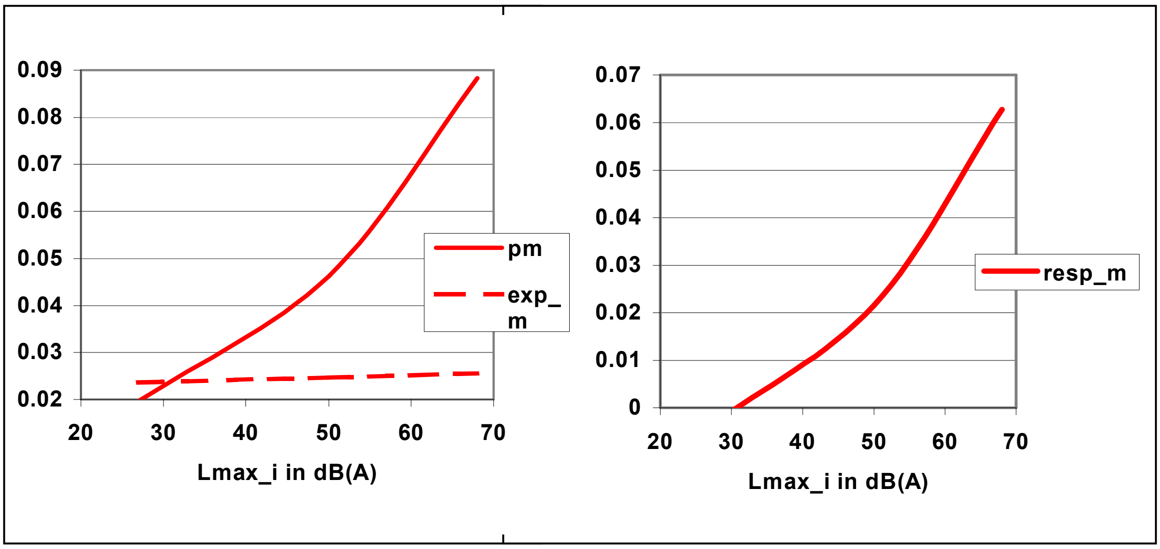



*Figure 2.3:* *Left-hand figure: observed probability of motility $p_m$ (in the figure given by pm) and probability of motility if there would have been no aircraft noise event (exp_m) as a function of Lmax_i. Right-hand figure: aircraft noise induced increase in probability of motility (resp_m), which is the difference between the two functions $p_m$ and exp_m at the left-hand figure.*

*Motility level*

A number of regression models of relscore as a function of Lmax_i and SEL10_i have been tested. The fitting of a model is complicated because of the distribution of the values of relscore (relscore is in about 95% of the cases equal to 0 and in the other 5% of the cases usually between 0.25 and 20). A proper fit could not be established, since all models failed statistical significance. Therefore, in this report no instantaneous exposure-effect relationships with effect variable relscore are given. For further details, see Appendix C.

*Marker pressings*

First an analysis has been performed to assess whether the probability of marker pressings during aircraft noise event windows is larger than outside aircraft noise windows. Then, it has been considered whether probability of marker pressings depends upon Lmax_i or SEL10_i. No attempt has been made to consider the possible impact of other variables on probability of marker pressings.

## 2.3 Results for exposure-effect relationships

Section 2.3.1 concerns probability of motility and of onset of motility, and section 2.3.2 marker pressings.

### 2.3.1 Exposure-effect relationships with resp_m and resp_k as effect variables

This section is structured as follows. First, exposure-effect relationships for resp_m and resp_k are presented for all aircraft noise events and for isolated aircraft noise events. An isolated aircraft noise event is an aircraft noise event for which e4 to e11 does not coincide with any e4 to e11 of another aircraft noise event. Then, confidence intervals, simplified equations for some of the exposure-effect relationships, and results about determinants, effect-modifiers, and confounders are presented. At the end of this section, consequences about the edges of the night are discussed.
In Appendix C, exposure-effect relationships are given for *all* combinations of Lmax_i, SEL10_i, resp_m, and resp_k are given. In this section the results are mainly illustrated with examples that relate to *resp_m* and *Lmax_i*.

**Results for all aircraft noise events**

In figure 2.4 resp_m has been plotted as a function of Lmax_i for all aircraft noise events. Relationships are shown for 15-s intervals e4 to e10. The curves are limited to Lmax_i equal to 68 dB(A), being the value that is not exceeded by 95% of the values of Lmax_i in the database. Resp_m is larger at e7 and e6, the 15-s interval at which Lmax_i occurs, than at other intervals. At the higher values of Lmax_i resp_m increases with interval time from e4 to e6 and e7 and then decreases from e7 to e10. Resp_m is zero at Lmax_i below 32 dB(A).
In figure 2.5 resp_k has been plotted as a function of Lmax_i. At the higher values of Lmax_i resp_k is somewhat larger at e5 than at e6 and e7. Usually aircraft noise events with higher values of Lmax_i are already perceivable in the bedroom at 15-s intervals before e6 and in response to this ‘perception’ motility starts apparently more frequently in the 15-s interval before Lmax_i occurs than at that interval or later.

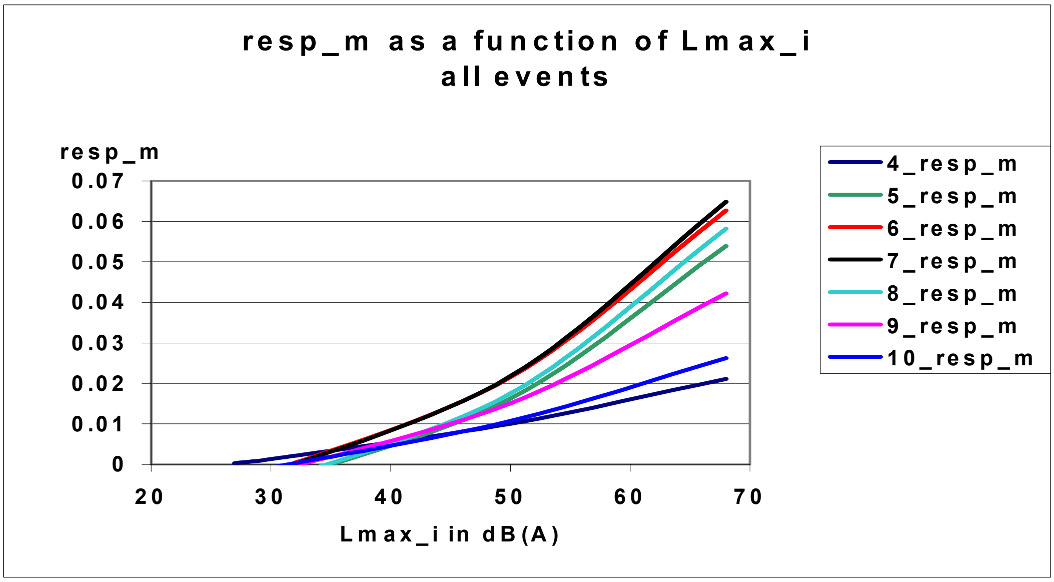



*Figure 2.4: Resp_m as a function of Lmax_i (indoor maximal sound level of an aircraft noise event) for 15-s intervals e4 to e10. The interval during which Lmax_i occurs is e6.*

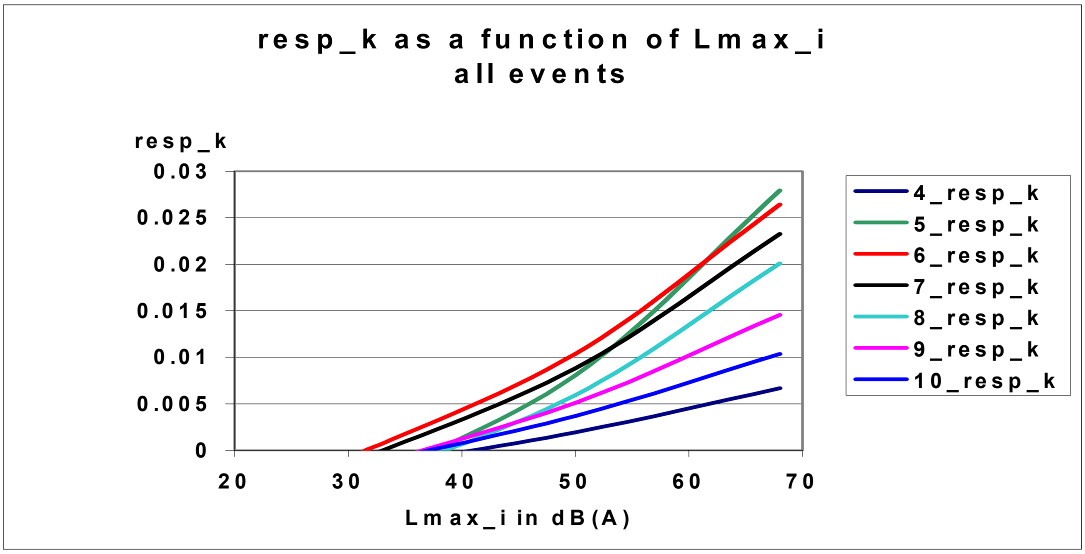



*Figure 2.5: Resp_k as a function of Lmax_i (indoor maximal sound level of an aircraft noise event) for 15-s intervals e4 to e10. The interval during which Lmax_i occurs is e6.*

In figure 2.6 the results presented in figure 2.4 are given in another way: resp_m has been plotted as a function of 15-s interval time for three values of Lmax_i. Interval times are labelled with respect to the interval Lmax_i occurs (e6 = 0, etc.).

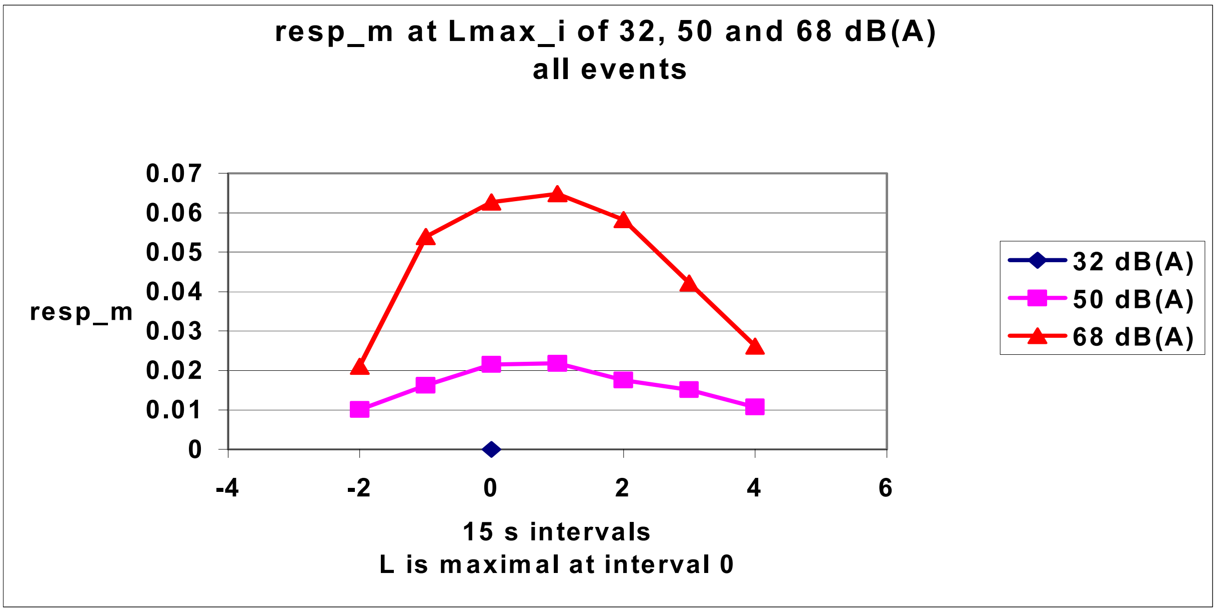
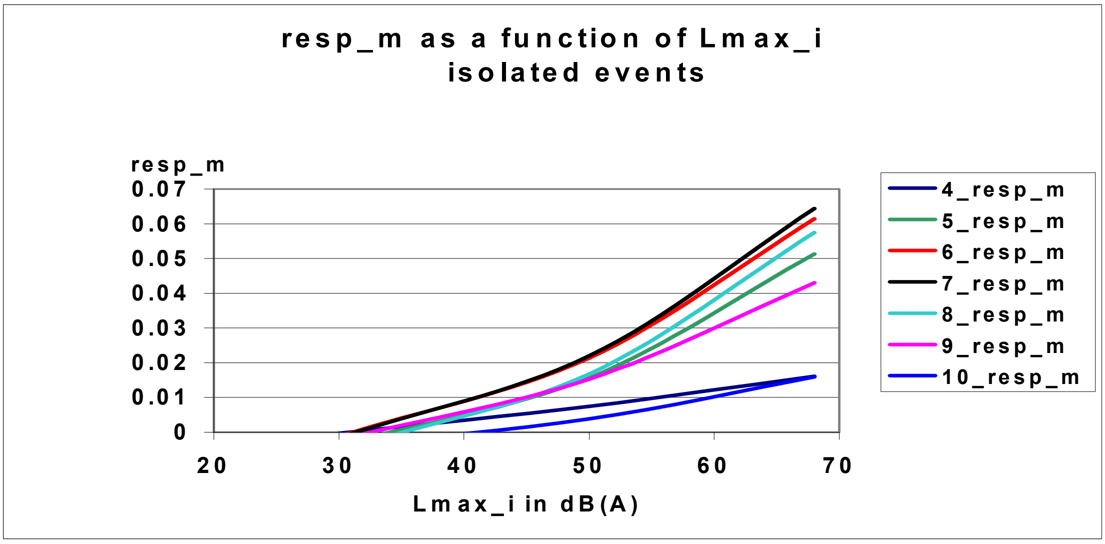



*Figure 2.6: Resp_m as a function of time in 15-s intervals for aircraft noise events with Lmax_i equal to 32, 50 and 68 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0. All aircraft noise events.*

**Results for isolated aircraft noise events**

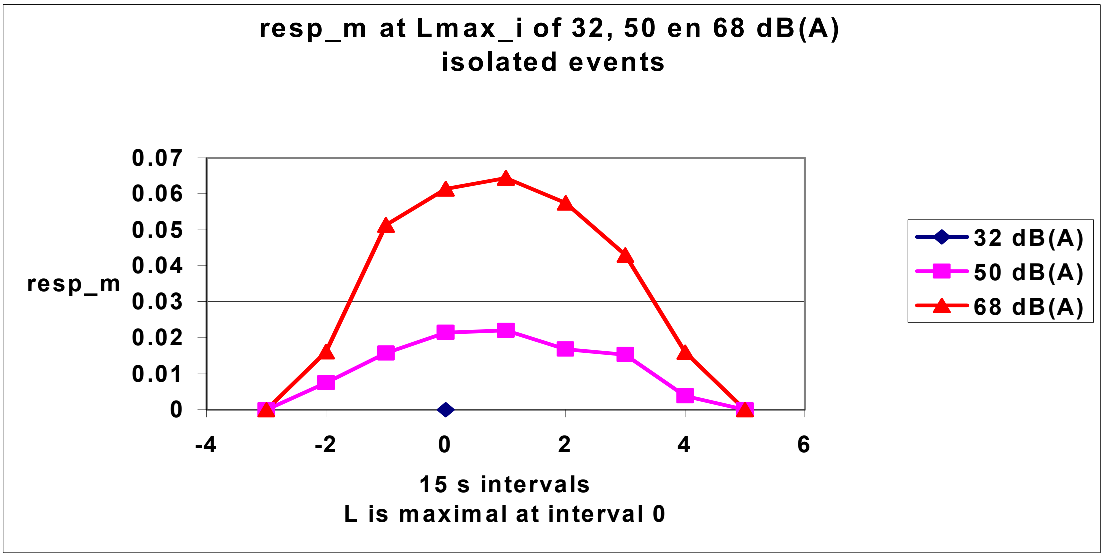
In figure 2.7 resp_m has been plotted as a function of Lmax_i for isolated aircraft noise events. Comparing the results for all events (figure 2.4) with the results for isolated events, it is obvious that the largest differences occur at e10 and e4. The differences in the relationships of resp_m at e5 to e9 for all events and for isolated events are about nil. Apparently, aircraft noise events that are not isolated have an impact on the average value of resp_m at interval e10 and to a lesser extent at interval e4. Such an effect is not unlikely, since for not-isolated aircraft noise events the intervals e6 and e7 of one aircraft noise event (and the resulting increase in probability of motility) may coincide with interval e10 of an earlier aircraft noise event, and the impact of the later aircraft noise event on m at e6 or e7 is included in the effect on m of the earlier aircraft noise event at e10.

*Figure 2.7: Resp_m as a function of Lmax_i (indoor maximal sound level of an aircraft noise event)*




*for 15-s intervals e4 to e10. The interval during which Lmax_i occurs is e6. Isolated aircraft noise events.*

*Figure 2.8: Resp_m as a function of time in 15-s intervals for aircraft noise events with Lmax_i equal*




*to 32, 50 and 68 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0.*

Figure 2.8 shows resp_m as a function of event intervals for three values of Lmax_i for isolated aircraft noise events. The shape of the curves shows that resp_m is zero at e3 (3 intervals before the interval at which Lmax_i occurs) and at e11 (5 intervals after the interval at which Lmax_i occurs). The zero values have been added to the curves.

Further analyses have been carried out with the data of *all* aircraft noise events and with variables at *e6*.

Confidence intervals have been calculated for the relationships between Lmax_i and SEL10_i as independent variables and resp_m and resp_k (at interval e6) as dependent variables. The 95%-confidence intervals for resp_m as a function of Lmax_i are given in figure 2.9.


*Figure 2.9: Resp_m at e6 (interval during which Lmax_i occurs) as a function of Lmax_i for all events. Broken lines represent 95% confidence intervals.*

**Approximations of response functions**

The relationships at e6 between resp_m or resp_k and Lmax_i and SEL10_i are complicated because a number of coefficients specify the relationships and calculation of values implies exponential manipulations. Therefore these functions have been approximated by simple quadratic functions with the following format for resp_m and Lmax_i (similar equations apply for the other combinations):

$$resp\_m = b*(Lmax\_i - a) + c*(Lmax\_i - a)^2$$

The coefficients a, b and c are given in table 2.1. The value of 'a' is the value at which resp_m or resp_k is zero. These curves represent the avarage effects. Later in this section attention will be paid to individual differences in effects.

*Table 2.1* *Coefficients of the quadratic equation of resp_m, and resp_k as a function of Lmax_i and SEL10_i for interval e6 (the interval at which Lmax_i of an aircraft noise event occurs). The equations are applicable to the range of Lmax_i or SEL10_i from at least the value 'a' up to SEL10_i equal to 80 dB(A) or Lmax_i equal to 70 dB(A). At values below 'a', resp_m, and resp_k are zero.*

| | resp_m | resp_k |
|---|---|---|
| aircraft noise event metric Lmax_i | | |
| a | 32 | 32 |
| b | 0.000633 | 0.000415 |
| c | $3.14*10^{-5}$ | $8.84*10^{-6}$ |
| aircraft noise event metric SEL10_i | | |
| a | 38 | 40 |
| b | 0.000532 | 0.000273 |
| c | $2.68*10^{-5}$ | $3.57*10^{-6}$ |

**Other variables with an impact on probability of motility**

In section 2.2.3 the variables have been given which have been considered as determinants or effect-modifiers in the case of aircraft noise-induced increase of probability of motility at 15-s interval e6 and aircraft noise event variable Lmax_i. In first instance, six variables turned out to be determinants, if they were added separately to the logistic regression models. Variables that are determinants of the effect variable in logistic regression models are effect-modifiers of the relationship of the effect variable and Lmax_i. The variable with the largest effect on resp_m is Li. After including Li in each of the five other regression models, the regression coefficient of two other possible determinants in the logistic regression model appeared to be not statistically significant. Therefore the analyses showed that four variables are determinants. It concerns the following variables:

- *Li:* the effect of Li is shown in figure 2.10. At the higher values of Lmax_i subjects with a relatively low value of Li show about a factor 3 higher aircraft noise-induced increase in probability of motility than subjects with high values of Li. In a situation with indoor Lnight equal to 0 dB(A), subjects are e.g. exposed each night to one aircraft with indoor Lmax equal to 35 dB(A) or each week to one aircraft with indoor Lmax equal to 44 dB(A);
- *Clock time:* resp_m increases with clock time of the night. In figure 2.11 resp_m has been plotted as a function of time: 22 means 22 hours etc. At the higher values of Lmax_i, resp_m increases about 25 to 30% if time increases from 22 hours in the evening to 8 hours in the morning. Resp_m from 6 to 7 hours in the morning is about a factor 1.2 larger than from 23 to 6 hours;
- *Time after sleep onset:* resp_m increases with time after onset of sleep. In figure 2.12 resp_m has been plotted as a function of Lmax_i for values of x (number of 15-s interval) in the range of 0 (sleep onset) to 1920 (8 hours after sleep onset);
- *Age:* the combination of age and age*age has a small statistical significant effect on resp_m (see figure 2.13). For a given value of Lmax_I, resp_m of older subjects is somewhat smaller than resp_m for younger subjects and resp_m is maximal at an age of 46 years.

None of the statistical significant determinants in the logistic regression models of resp_m at e6 and Lmax_i are associated with Lmax_i. Therefore, none of these four variables are confounders of the relationship of resp_m with Lmax_i.

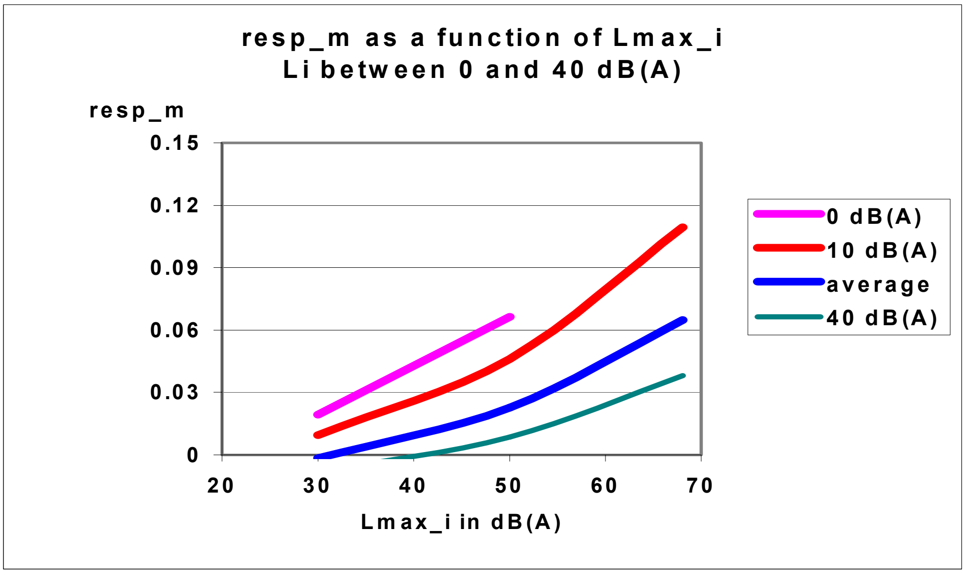



*Figure 2.10: Resp_m as a function of Lmax_i. Average function without Li as determinantand functions for Li equal to 0, 10, and 40 dB(A ).*

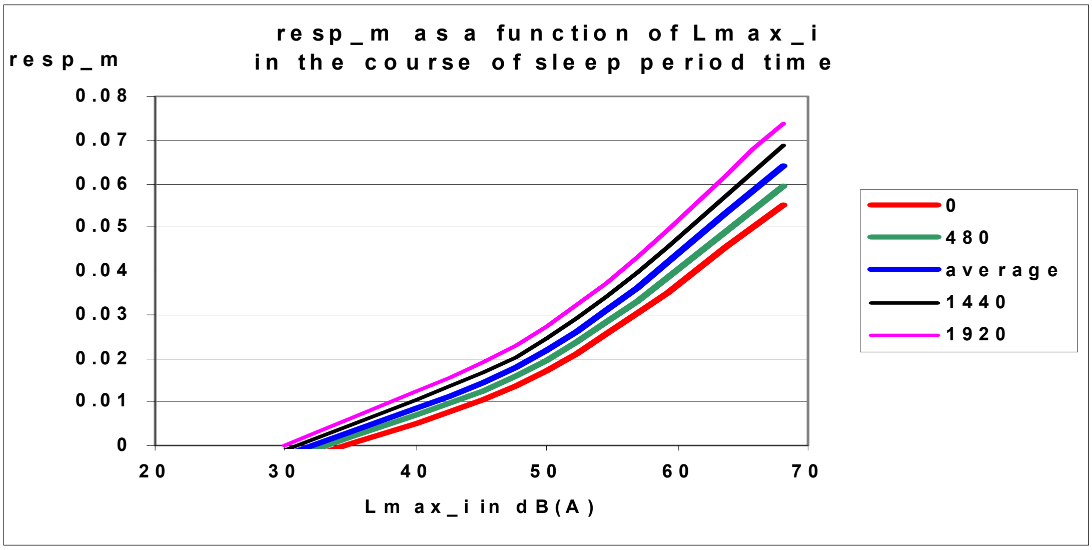



*Figure 2.11: Resp_m as a function of Lmax_i for various values of x (number of 15-s interval after sleep onset. Average function without x as determinantand functions for x equal to 0 (sleep onset), 480 (2 hours after sleep onset), 1440 (6 hours after sleep onset) and 1960 (8 hours after sleep onset.*

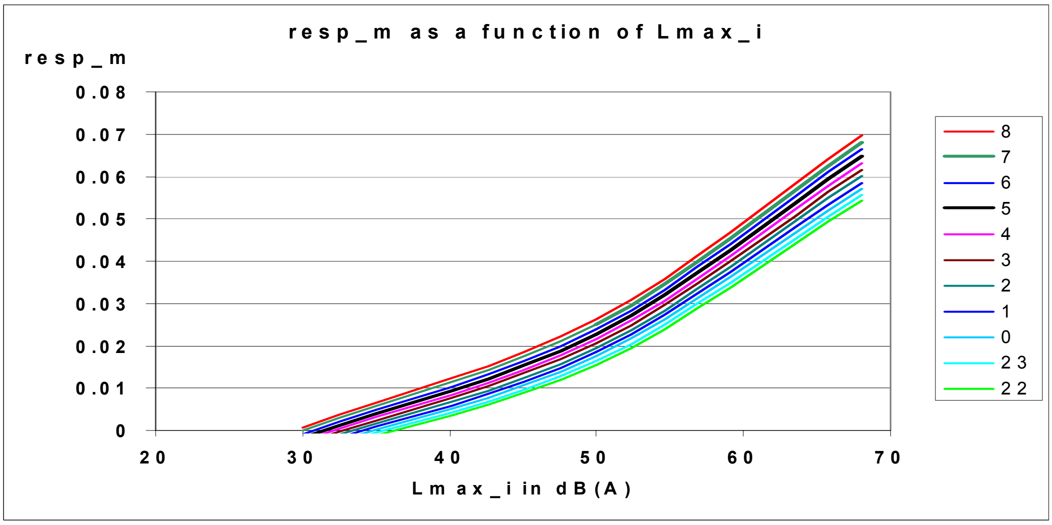



*Figure 2.12:* *Resp_m as a function of Lmax_i for11clock times during night and (early) morning: 22 is 22 hours, etc.*

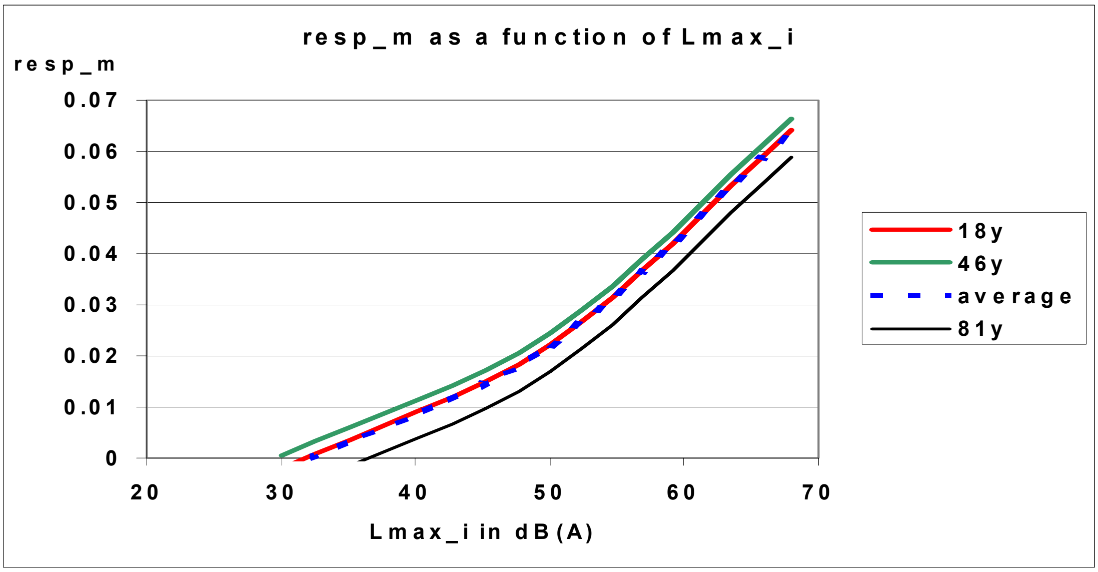



*Figure 2.13:* *Resp_m as a function of Lmax_i for various ages of subjects. Average function without age as determinant and functions for ages 18, 46 and 81 years.*

*Individual differences in aircraft noise induced increase in probability of motility*
At the beginning of this section the 95% confidence intervals of the relationship between resp_m and Lmax_i have been given. The 95% tolerance intervals (which give the range of 95% of the individual effects) are much larger than the 95% confidence intervals. This implies for instance that the threshold of onset of aircraft noise induced effects ('a') varies from 23 to 46 dB(A). This is to a large part understandable from figure 2.10. To subjects with high night-time aircraft noise

exposure different exposure-effect relationships apply than to subjects with low night-time aircraft noise exposure. The range of the 95% tolerance intervals are only somewhat larger than the range between the effects at Li equal to 0 and 40 dB(A).

**Edges of the night**

The distribution of indoor aircraft noise events during sleep of subjects is as follows:

| | | | |
|---|---|---|---|
| before 23 hours | 1.1% | | |
| 23 – 24 hours | 4.0% | 23 – 6 hours | 41.8% (6.0% per hour) |
| 24 – 6 hours | 37.8% | per hour | 6.3% |
| 6 – 7 hours | 26.6% | | |
| after 7 hours | 30.5% | | |

The contribution of indoor aircraft noise events during sleep of subjects on total aircraft noise-induced increase in probability of motility is as follows:

| | | | |
|---|---|---|---|
| before 23 hours | 1.0% | | |
| 23 – 24 hours | 3.5% | 23 – 6 hours | 39.6% (5.7% per hour) |
| 24 – 6 hours | 36.1% | per hour | 6.0% |
| 6 – 7 hours | 27.6% | | |
| after 7 hours | 32.0% | | |

The contribution of aircraft noise between 6 and 7 hours to the total effect on probability of motility is about 28%. If aircraft between 6 and 7 hours would be taken equal to aircraft in an hour between 23 and 6 hours, it would reduce the contribution to the total effect of night-time aircraft noise from 27.6 to 5.7%, i.e. a reduction in the total effect of 21.9%, provided that the aircraft noise events would be postponed until after all subjects would have been awake. This reduction in effect would be reached by a reduction in number of aircraft noise events between 6 and 7 hours from 26.6% to 6.0%, i.e. by a reduction with a factor 4 of number of aircraft between 6 and 7 hours. If the aircraft noise events between 6 and 7 hours would be postponed for one hour, then number of subjects exposed would be reduced by a factor 1.9 and the contribution to the total effect would be 17.2% [5.7+(27.6 – 5.7)/1.9], instead of the original 27.6%, which implies a reduction of 10.4% of the total effect.

### 2.3.2 Number of marker pressings during sleep

Subjects have been requested to press the marker when they woke-up during sleep period time. The total number of marker pressings of all subjects during all sleep period times turned out to be 5951. More than 10% of the subjects did not press the marker during any of the 11 sleep period times, others pressed the marker more than five times during one of the sleep period times. The question is whether subjects press the marker more frequently during aircraft noise events. Table 2.2 shows the results of an analysis to answer this question. There are over 7.86 million 15-s intervals within the sleep period times of all subjects. A total number of marker pressings of 5951 implies that during 0.0757% of the 15-s intervals a marker has been pressed. These marker pressings occur during the 15-s intervals e1 to e20 of aircraft noise windows or outside these windows. The number of marker pressings during the aircraft noise windows is 763 (0.0807%) and outside

these windows 5188 (0.0750%). The percentage of marker pressings during the aircraft noise windows is statistically significant larger than the percentage outside aircraft noise event intervals. The number of expected marker pressings during the aircraft noise windows based on the probability outside these windows would be 709, and the observed number is 763, which is 7.6% higher than expected from the results outside the aircraft noise windows. Marker pressings are even more frequent if the 15-s aircraft noise intervals are limited to the intervals e4 to e10 of the aircraft noise windows. The number of expected marker pressings during e4 to e10 based on the probability outside these intervals would be 330, and the observed number is 357, which is 8.2% higher than expected from the results outside intervals e4 to e10.
It has also been considered whether the probability of a marker pressing during an aircraft noise event depends upon Lmax_i or SEL10_i of the event. No statistically significant relationships have been assessed.

*Table 2.2 Information about marker pressings of subjects during sleep to indicate intermittent awakening.*

| intervals | number of 15-s interval | number of marker pressings | percentage of 15-s intervals with marker pressing |
|---|---|---|---|
| aircraft noise window e1 to e20 | | | |
| total | 7864899 | 5951 | 0.0757 |
| outside window | 6918960 | 5188 | 0.0750 |
| inside window | 945939 | 763 | 0.0807 |
| aircraft noise window e4 to e10 | | | |
| total | 7864899 | 5951 | 0.0757 |
| outside window | 7426275 | 5594 | 0.0753 |
| inside window | 438624 | 357 | 0.0814 |

## 2.4 Comparison with other studies

In Appendix G the relationships between noise-induced increase in probability of (onset of) motility have been compared to the relationships obtained in other studies. Our study shows that instantaneous effects of aircraft noise events on (onset of) motility already start on average at Lmax_i of 32 dB(A) and SEL10_i of 38 to 40 dB(A). These ‘thresholds’ levels are about 15 to 20 dB(A) lower than estimated from the CAA study reported in 1992, carried out with subjects living in the vicinity of airports in UK (Ollerhead et al., 1992). Several factors specified in section G.3.1 have contributed to an under-estimation of the effect on aircraft noise on probability of (onset of) motility. The most important are:

- No indoor noise measurements have been performed in the UK study. Other studies showed that indoor noise event measures have a much stronger relationship with (onset of) motility than outdoors measures (Fidell et al, 1995, 1998; present study).
- The threshold for an aircraft noise event of 60 dB(A) outdoors used in the study implies that all intervals with (aircraft) noise events below 60 dB(A) outdoors are considered as quiet intervals;

- Onset of motility has been considered only in the (30-s) interval during which Lmax_o occurs. However, onset of aircraft noise-induced motility is, especially at the higher aircraft noise event levels, more often in the (15-s) interval before the (15-s) interval during which Lmax occurs. Therefore, in more than 50% of those cases aircraft noise-induced onset of motility is incorrectly assumed to be absent;
- In the analysis, aircraft noise events, which occurred within 5 minutes of a preceding event, were not considered as aircraft;
- Due to limitations of computer facilities in 1992, only aircraft noise events that occurred between 23.30 and 5.30 hours have been considered. However, probability of aircraft noise-induced motility increases according to the present study with sleep onset, which implies an underestimation of the overall effect of aircraft noise exposure.

The study by Fidell et all. (1995) included only subjects who lived at locations close to the runway ends of two airports. Their results compared with the outcomes of the present study with respect to subjects with higher values of Li shows a reasonable good agreement between both studies. The ‘thresholds’ level of aircraft noise-induced motility is estimated in Appendix G as Lmax_i equal to 45 dB(A), which is about the same ‘threshold’ as for subjects in the present study with Li equal to 40 dB(A).

## 2.5 Conclusions

The main conclusions of this chapter are:

- During aircraft noise events probability of motility during sleep is increased. The threshold of Lmax_i and SEL10_i above which probability of motility starts to increase is on average respectively 32 and 38 dB(A). The effect increases with increasing Lmax_i (or SEL10_i): at Lmax_i of 68 dB(A) probability of motility during the 15-s interval at which Lmax_i occurs is on average about 3 times the probability of motility outside aircraft noise windows;
- Aircraft noise-induced increase in probability of motility during sleep is maximal at the central event interval and the 15-s interval thereafter, and less in 15-s intervals before and after these 15-s intervals. The aircraft noise-induced increase in probability of motility is, also at the higher aircraft noise events, on average restricted to about 30 s before until about 60 s after the central event interval;
- Aircraft noise-induced increase in probability of onset of motility during sleep is on average about equal at the central event interval and the two 15-s intervals before and after this interval, and less in the 15-s intervals before and after these three intervals;
- Aircraft noise-induced increase in probability of motility and in probability in onset of motility during sleep have stronger relationships with Lmax_i than with SEL10_i;
- In subjects usually exposed to much night-time aircraft noise, aircraft noise-induced increase in probability of motility is less than in subjects with usually minor or low night-time aircraft noise exposure: for subjects with Li equal to 0 dB(A), aircraft noise-induced increase in probability of motility is at a given value of Lmax_i about a factor 3 larger than for subjects with a value of Li equal to 40 dB(A);

- Aircraft noise-induced increase in probability of motility increases with time after sleep onset and with clock time. The aircraft noise-induced increase in probability of motility at the higher Lmax_i values is from 6 to 7 hours in the morning about a factor 1.2 larger than in the period from 23 to 6 hours;
- Relationships between *outdoor* aircraft noise metrics and aircraft noise-induced increase in probability of motility are not statistically significant.
- Behavioural awakening, evaluated by pressing a marker on the actimeter, is more frequent during aircraft noise event windows than outside these windows. During aircraft noise windows the probability of a behavioural awakening is 0.0075% and during aircraft noise event windows 0.081%.

# 3 Relationships on a 24 hours time basis

## 3.1 Introduction

At 15 locations 418 subjects participated in the study for eleven 24 hours periods, including eleven sleep period times. Consequently, there are 4598 subject nights. Due to various reasons some data is missing: for each variable there are at least about 4500 subject nights.

This chapter is related to data obtained on a 24 hours basis. These data consist of:
- Responses of subjects in a morning- and evening diary (the English translations of the diaries are given in report 2001.205);
- Results of a reaction time test (see Appendix A) performed by subjects just before bed-time;
- Results of the sleepiness strip (see Appendix A) filled out five times during day and evening;
- Results of actimetry, including marker pressings, during sleep period times.

The variables used in the analyses have been given in table A1 of Appendix A.

In TNO report 2001.205 (chapter 4) detailed information is given about the results obtained from the evening and morning diaries. Details of the analyses to obtain relationships are given in Appendix D. A summary and the results of the analyses are given in the next sections.

Exposure-effect analyses have been carried out for the following periods:
. sleep period time;
. edges of the night (23 - 24 hours and 6 - 7 hours);
. sleep latency time.

This chapter has been structured as follows. Section 3.2 gives information about duration of sleep period times, time of sleep onset and wake-up time. In section 3.3 a model related to aperiod of 24 hours (including night-time) is discussed. In section 3.4 exposure-effect relationships are presented: section 3.4.1 concerns sleep period time, section 3.4.2 the edges of the night (23 - 24 hours and 6 - 7 hours), and section 3.4.3 sleep latency time. In section 3.4.4 data of subjects aggregated over the 11 participation nights, have been related to aggregated aircraft noise exposure data. Section 3.5 considers the association between effect variables.

## 3.2 Sleep period time

In this section information is given about the duration of sleep period time, time of sleep onset, and wake-up of subjects. The mean sleep period time of all subjects over all (11) nights is 7 hours

and 13 minutes. In figure 3.1 subjects have been classified according to age in four age classes: A1 < 25 years; A2 25 – 45 years; A3 45 – 65 years; A4 > 65 years. The initial analysis showed that duration of sleep period time, time of sleep onset, and wake-up time of subjects for the five nights starting on Sunday through Thursday night are about the same, but differ from the values for Friday and Saturday night. Therefore the nights have been classified in weekday nights (W1) and weekend nights (W2) with: W1 5 nights, starting on Sunday through Thursday at 22.00 hours and W2 2 nights starting on Friday and Saturday at 22.00 hours. Figure 3.1 shows that during weekdays the youngest and eldest subjects sleep longer than subjects with ages in between. During weekends the duration of sleep is about the same for all age classes. For the eldest and youngest age groups the duration of sleep does not vary much with night of the week.
Mean duration of sleep during weekdays is 7 hours and 7 minutes and mean duration of sleep during weekends is 35 minutes longer (7 hours and 42 minutes).

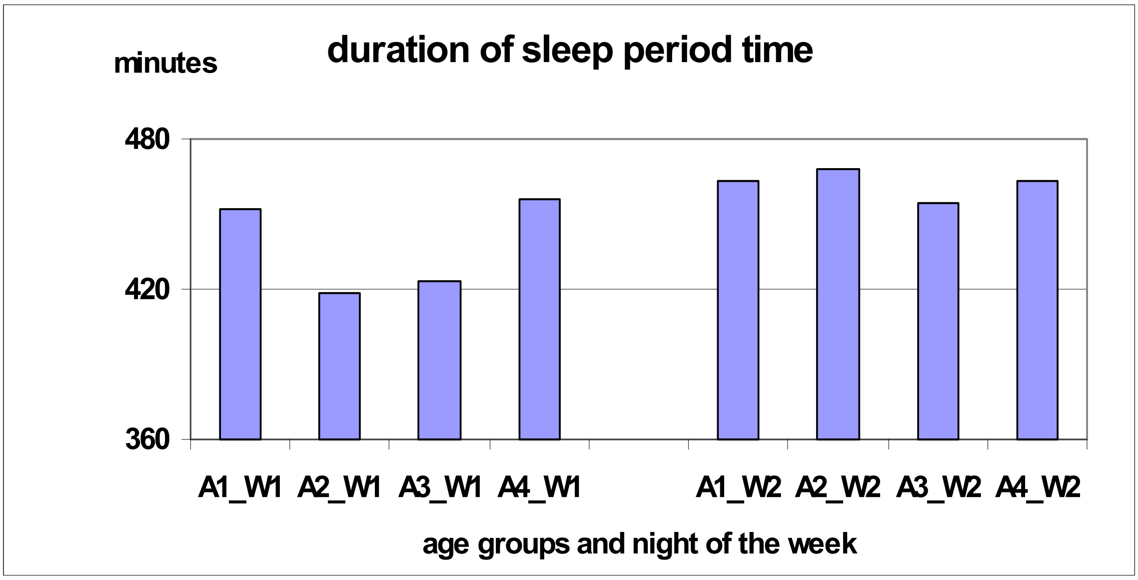



*Figure 3.1* *Duration of sleep period time of subgroups according to age, during weekdays (W1) and during the weekend (Friday and Saturday night) (W2).*

Figures 3.2 and 3.3 give information about sleep onset time and wake-up time. During weekdays, start of sleep is about equal for each age group and during weekends start of sleep of the youngest subjects is about one hour later than for the other age groups. During weekdays, end of sleep is somewhat later for the youngest and oldest age group than for the age groups in between. During weekends the end of sleep becomes earlier if age increases. The average wake-up time during weekends of subjects in the youngest age group is just over nine hours in the morning. If we take into account the distribution of the wake-up times of subjects, 5% of the wake-up times of the youngest subjects is over 750 minutes after 22.00 hours of the night before, which implies after 10.30 in the morning. For the subjects in the other age groups, 5% of the wake-up times are 9.15 and later.

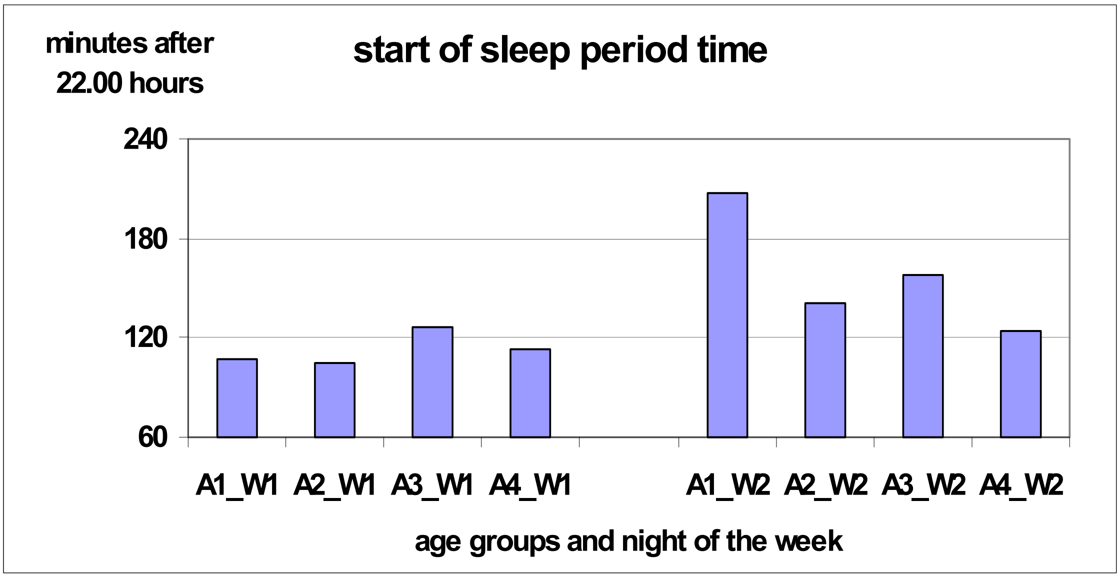



*Figure 3.2:* *Start of sleep period time of subgroups according to age, during weekdays (W1) and during the weekend (Friday and Saturday night) (W2).*

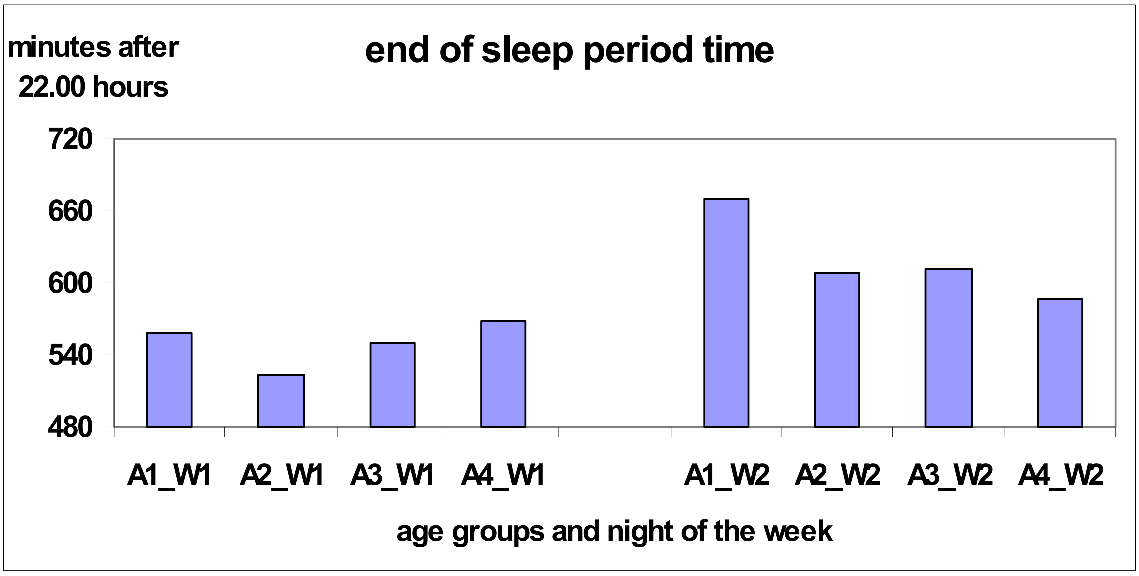



*Figure 3.3:* *Wake-up time of subgroups according to age, during weekdays (W1) and during the weekend (Friday and Saturday night) (W2).*

## 3.3 Model of 24 hours relationships

In figure 3.4 the model is given which is the basis of the analyses to assess exposure-effect relationships. The model shows a 24 hours period starting from left to right end of time awake, sleep latency time, sleep period time, and time awake (usually morning, afternoon, and evening-time). Aircraft noise exposure has been assessed for two distinct periods: sleep latency time and sleep period time.
With respect to aircraft noise during *sleep latency time*, exposure-effect relationships have been considered with effect and exposure variables related to that period.
With respect to aircraft noise during *sleep period time*, various exposure-effect relationships have been assessed with effect variables, not only related to sleep period time (motility, awakening, annoyance, sleep quality), but also to time awake (sleepiness during time awake and performance (of reaction time test)).
Effect and exposure variables are presented in sections 3.4 and 3.6.

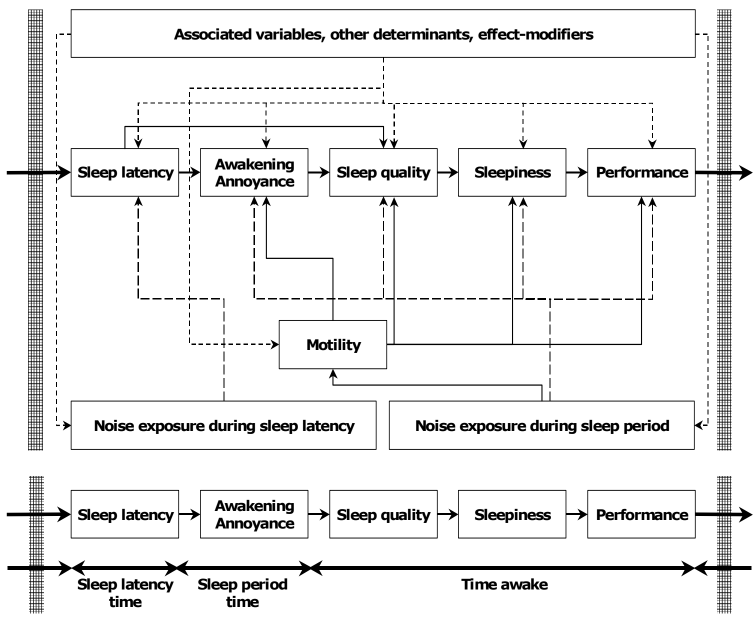



*Figure 3.4: Model of 24 hours relationships between aircraft noise exposure and noise-induced effects on sleep, sleepiness, and performance during time awake.*

In addition to exposure-effect relationships, relations between effect variables have been considered. In principle the effect variable assessed at the earlier stage serves as independent variable and the effect variable assessed at the later stage as dependent variable (e.g. motility as independent variable and sleep quality assessed in the morning diary as dependent variable). Several variables, such as awakening and annoyance during sleep period time, sleep quality, sleepiness during time awake, and performance, have been related to motility.

Variables considered as possible determinants and effect-modifiers in section 3.4 and 3.6 are:

- Demographic variables: age, gender, citizenship, number of persons in household, education, country of birth;
- Variables obtained from the evening and morning diary, such as:
  - number of cups of coffee and number of alcoholic drinks in the evening;
  - number of times smoked during the evening;
  - duration of naps during day and evening-time;
  - use of personal hearing protection;
  - sleepiness before going to bed;
  - use of sleeping pills or drugs able to induce sleepiness or increase sleep depth;
  - reason or not for difficulty to fall asleep (reason_cl: specific reason for difficulty to fall asleep: 1 reason mentioned in the morning diary, 0 no specific reason mentioned);
  - aircraft noise reason or not for difficulty to fall asleep (reason_ac: reason for difficulty to fall asleep is aircraft noise: 1 aircraft noise mentioned in the morning diary, 0 aircraft noise not mentioned);
  - sleepiness during day- and evening-time (in relation to aircraft noise exposure during the preceding sleep period time);
- Variables obtained from the questionnaire, such as:
  - Aircraft noise perception;
  - Aircraft noise annoyance;
  - Night-time aircraft noise perception;
  - Awakening by night-time aircraft noise;
  - Annoyance by night-time aircraft noise;
  - Fear for aircraft noise;
  - Frequency of being afraid of aircraft noise;
  - Dissatisfaction with aircraft noise around the house;
  - Fear for health impact of aircraft noise;
  - Experienced health;
  - Sleep quality;
  - Number of sleep disturbances in general;
  - Number of aircraft noise complaints per week;
  - Health score evaluated over 24 hours;
  - Health score evaluated over night-time;
  - Noise sensitivity;
  - Number of reasons frightened of aircraft noise;
  - Safety: recognising own situation as living under a flight path;
  - Safety: recognising own situation living in the vicinity of a large airport;
  - Worried about living under a flight path;
  - Worried about living in the vicinity of a large airport;

- Lo – Li (difference between outdoor and indoor aircraft noise equivalent sound level over the eleven sleep period times of a subject);
- L50 (median value of the equivalent sound levels during the 15-s intervals of a sleep period time outside aircraft noise windows).

Both age and age*age have been considered as possible determinants. If age*age is a statistical significant variable, an effect at a given value of aircraft noise exposure has a maximum or minimum at a certain age, which is usually between the lowest (18 years) and highest age (81 years) present in the database.

## 3.4 Results for relationships derived for sleep period time

### 3.4.1 Introduction

The following aircraft noise exposure variables have been considered in random effects multi-level regression analyses with subjects as first level:

- Liaspt: equivalent sound level during sleep period time;
- niaspt: number of aircraft noise events detected on the indoor noise monitor during sleep period time.

At most locations Liaspt and niaspt vary considerable from night to night. This is illustrated in figure 3.5. Location 38 is the location with on average more aircraft noise at night than any other location. The average number of aircraft per night during sleep period times of subjects (niaspt averaged over subjects) varies with a factor 3 to 7. This variation allows the assessment of differences in effects due to night to night variation in aircraft noise exposure.

The following effect variables have been considered:

- average probability of motility (mspt), average probability of onset of motility (kspt), and average motility level (rlscspt) over sleep period time;
- sleep quality assessed in the morning diary by using the 5 and 11 points scales;
- fragmentation index (percentage of periods with duration of motility of at most 1 minute (4 15-s intervals) relative to all 15-s intervals with motility);
- number of marker pressings at night;
- number of remembered awakenings;
- number of awakenings due to aircraft noise remembered after sleep;
- results of reaction time test. These results have been related to aircraft noise exposure during the preceding sleep period time;
- sleepiness during day- and evening-time. Sleepiness during time awake has been related to aircraft noise exposure during the preceding sleep period time.

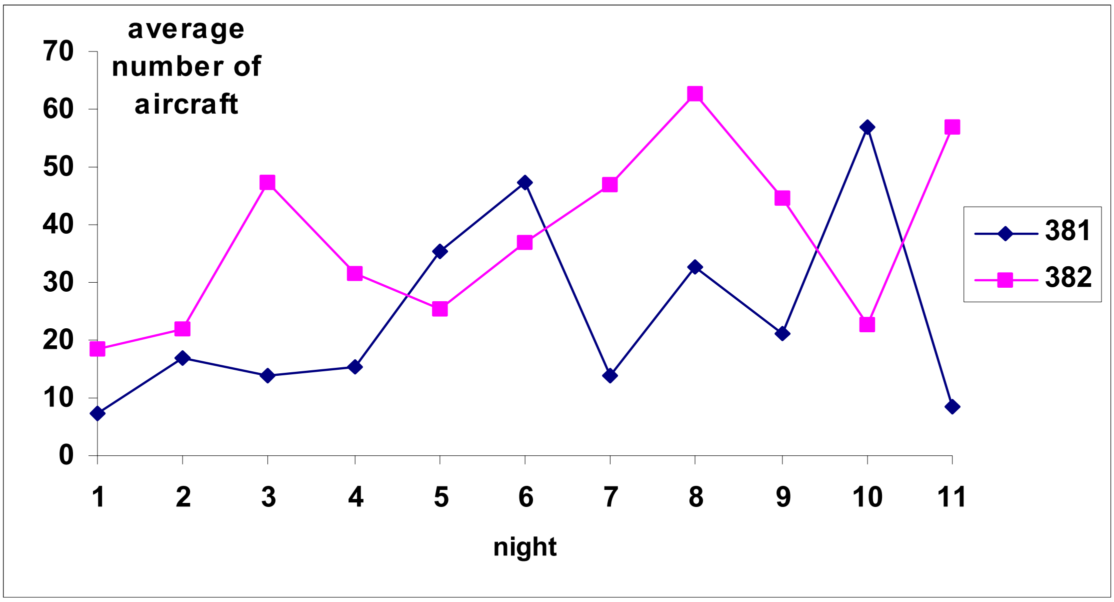



*Figure 3.5:* *Average number of aircraft at night detected on the indoor noise monitors during sleep period time of subjects as a function of participation night (night 1 = Monday, night 2 = Tuesday etc.). Location 38, intervals 381 and 382*

### 3.4.2 Mean motility, mean onset of motility and mean motility level

The following results have been obtained:

- Each of the exposure-effect relationships with mspt, kspt, and rlscspt as dependent variables and Liaspt, and niaspt as independent variables show a statistical significant increase in effect variables with increasing night-time aircraft noise exposure. Of all demographic variables, only age (and age*age) and country of birth are determinants, although the effect of country of birth is small. As an example of an exposure-effect relationship, in figure 3.6 mspt is given as a function of Liaspt with age and age*age as determinants (solid lines: for three ages 18, 81 years and 46 years, the age at which mspt is minimal). Age has a larger effect on mspt, kspt and rlscspt than Liaspt. The interaction term of age and Liaspt added to the regression equation appeared to have a statistically significant coefficient. Therefore age is an effect-modifier. In figure 3.6 also the effect of age as effect modifier is shown (dashed lines). At the age (46 years) at which mspt is minimal, the increase in mspt with aircraft noise exposure is larger than at higher or lower ages. Therefore, although mspt at the age of about 46 years is smaller than at other ages, the effect of aircraft noise exposure on mspt at an age of about 46 years is larger;
- The following variables are determinants:
  - L50. The higher L50, i.e. the noisier the bedroom is in terms of L50, the higher mean motility;

- Lo – Li. The lower Lo – Li (‘sound insulation’ of the bedroom for aircraft noise), the higher motility;
- reason_cl, reason_ac. Twelve times a subject considered it difficult to fall asleep due to aircraft noise on a particular night. During these 12 sleep period times mspt is twice as large as if the reason for difficulty to fall asleep is unknown or another reason is mentioned in the morning diary;
- frequency of awakening by night-time aircraft noise, reported by subjects in the questionnaire. Motility increases with reported frequency of awakening by night-time aircraft noise. This is illustrated in figure 3.7.

To assess whether there are confounding variables, the asscociation between determinants of mspt, kspt, and rlscspt and Liaspt has been considered. Only L50 is statistically significant associated with Liaspt. The association is weak and has hardly any consequence for the relationship between mspt and Liaspt.

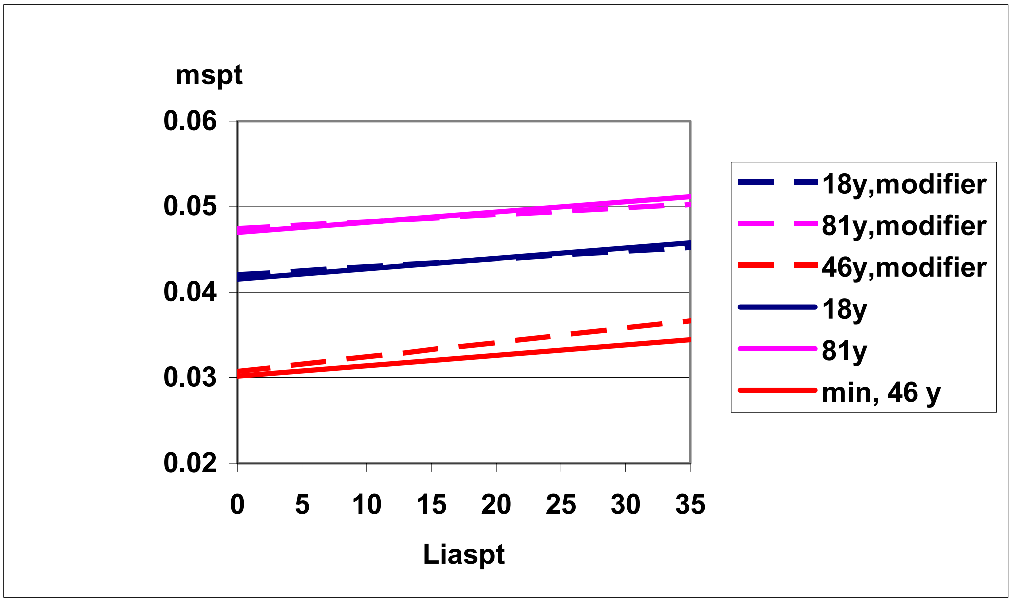



*Figure 3.6:* *Mean motility during sleep period time (mspt) as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18, 81, and 46 years, the age at which mspt is minimal. Solid lines: age and age*age are determinants. Dashed lines: age is effect modifier.*

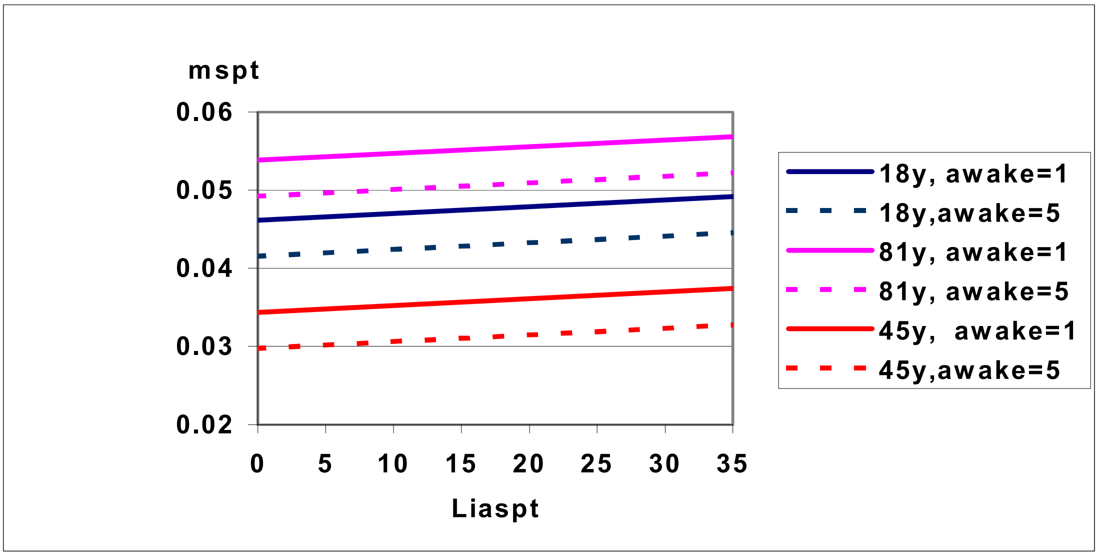



*Figure 3.7:* *Mean motility as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years and for the age at which mspt is minimal, for subjects indicating in the questionnaire to wake up (nearly) each night by aircraft noise (awake = 1) or indicating never to wake up by aircraft noise (awake = 5).*

### 3.4.3 Sleep quality, fragmentation index, remembered awakening and marker pressing during sleep period time, use of sleeping pills, and awakening at the end of sleep period time

There turned out to be no statistical significant relationship between sleep quality and Liaspt or niaspt, for both ratings of sleep quality in the morning diary (by 11- and 5-points scale). The relationships between fragmentation index and Liaspt and niaspt show a small, but statistical significant, increase. The same holds for number of marker pressings and number of remembered awakenings during sleep.

Subjects indicated in the morning diary whether they had been awakened during sleep period time, and if so they were asked to select a reason. If they did choose outdoor noise, they were asked to note what type of noise it was that did wake them up. In total, after 151 subject nights a subject noted at least once to have been awakened during sleep by aircraft noise. The probability of remembering to have been awakened by aircraft noise in the course of sleep period time is a statistical significant increasing function of Liaspt and niaspt. The result with Liaspt as independent variable is given in figure 3.8. The effect is largest at an age of about 65 years. On average the probability of a remembered awakening due to aircraft noise increases with a factor 3.5 if Liaspt increases with 10 dB(A). This implies that the probability of a remembered awakening per aircraft noise event decreases with increasing Liaspt. This can be understood easily, if we consider the simplified situation in which all aircraft noise events have the same SEL10_i value. In that case, if Liaspt increases with 10 dB(A), the number of aircraft noise events increases with a factor 10. Since the probability of a remembered awakening due to aircraft noise increases with a factor 3.5 if Liaspt increases with 10 dB(A), the probability of a remembered awakening due to aircraft noise per aircraft noise event increases by a factor 0.35 (3.5/10). This implies a decrease by a factor 3 (1/3.5) if Liaspt increases by 10 dB(A).

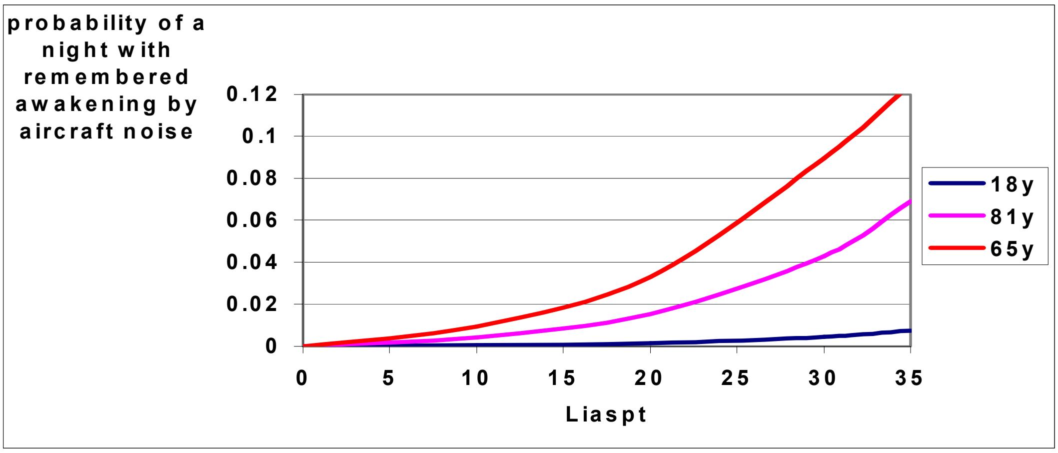



*Figure 3.8: Probability of a night with at least one remembered awakening due to aircraft noise as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18, 81, and 65 years (age at which the effect is maximal).*

In the questionnaire and in the morning diaries subjects indicated whether they used sleeping pills or other medication with a possible sleep-inducing and/or sleep deepening effect. In the study 23 subjects used such pills and/or medication during in total 180 subject nights. A logistic regression model has been applied to assess the effect of Liaspt on the use of sleeping pills or other medication with a sleep-inducing and/or sleep deepening effect. Age is an effect-modifier.

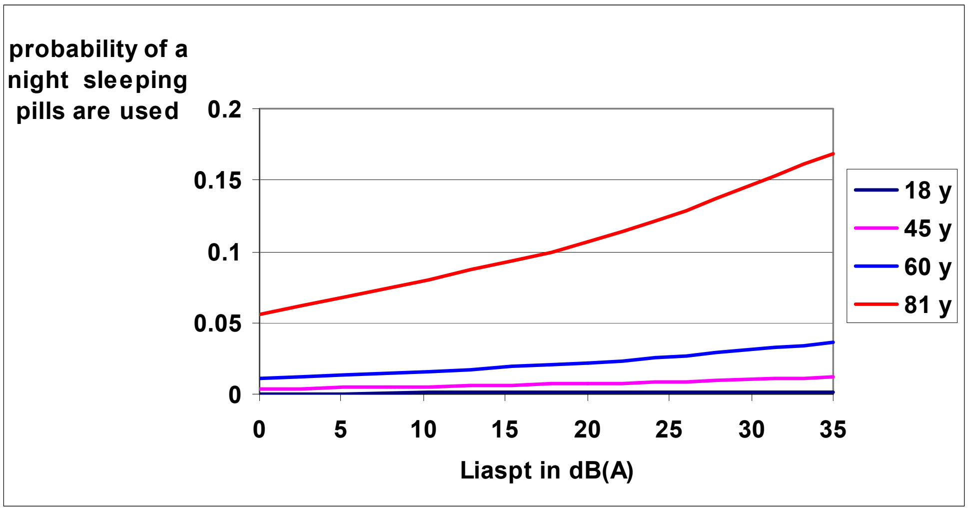



*Figure 3.9: Probability of a night a subject uses sleeping pills or other medication with a sleep-inducing and/or sleep deepening effect as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for four age.*

In the morning diary subjects filled out by which means they have been awakened at the end of sleep period time. For 21 subject nights, subjects mentioned aircraft noise. This number is too small to be used in a further analysis.

### 3.4.4 Sleepiness during time awake and reaction time test

Sleepiness has been assessed on a 9 point scale seven times during day and evening: after getting out of bed (in the morning diary), five times during time awake from 10 hours in the morning to 20 hours in the evening, and once in the evening diary before going to bed. Only sleepiness at 10 hours in the morning increased statistically significant with Liaspt (the increase in sleepiness is 0.2 on a nine points scale, if Liaspt increases from 0 to 35 dB(A)).

The results of the reaction time test have been specified by five variables: number of mistakes (pressing the computer bar too early), median value and value exceeded in 10% of the 90 trials and median value and value exceeded in 10% of the last 45 trials. The relationships between each of these five variables and Liaspt or niaspt turned out to be not statistically significant.

## 3.5 Edges of the night

*23 to 24 hours*
At about one third of the nights, subjects are asleep before 23 hours. Based on the data obtained during these nights it has been analysed whether the aircraft equivalent sound level from 23 to 24 hours has an effect on the relationships between Liaspt and the effect variables mean motility, number of marker pressings, number of remembered awakenings due to aircraft noise. None of these three relationships appeared to be influenced by the aircraft equivalent sound level between 23 and 24 hours. Therefore aircraft between 23 and 24 hours does not have a special effect on the relationships. Aircraft between 23 and 24 hours contributes about 4% to a total effect (such as increase in motility, increase in number of marker pressings, increase in number of remembered awakenings due to aircraft noise) of night-time aircraft noise during a sleep period time (see for data chapter 2, edges of the night). For an hour between 24 and 6 hours the percentage of 6.3% applies.

*6 to 7 hours*
About half the sleep period times (2233: 49%) end after 7 hours. It is therefore possible to use 49% of the subject nights to assess whether the effect of aircraft noise exposure from 6 to 7 hours differs from the effect earlier in the night.
There are no particular locations with relatively high and low aircraft noise exposures between 6 and 7 hours, compared to aircraft noise exposure from 23 to 6 hours. On average the difference between L06-07h and L23-06h is 7.8 dB(A), with a standard deviation of 2 dB(A). The standard error of the mean is 0.52 dB(A). The difference between L06-07h and L23-06h is not a statistically significant function of Lbu23-06h, nor of Lbu23-07h. In the first regression model R= 0.013 and in the second model R= 0.16. This implies that it is not possible to separate locations in locations with relatively high and low aircraft noise exposures between 6 and 7 hours. The consequence is also that there are no particular subjects with relatively high and low aircraft noise exposures between 6 and 7 hours, compared to aircraft noise exposure from 23 to 6 hours.
The available data have been analysed in various ways (see Appendix D.2.2). In this study a statistical significant different effect of aircraft noise exposure between 6 and 7 hours has not been assessed. Therefore the effect of aircraft noise exposure from 6 to 7 hours is not different from the effect earlier in the night.
The contribution of aircraft between 6 and 7 hours to a total effect of night-time aircraft noise is considerable, because from 6 to 7 hours there occurs much more aircraft than in the earlier hours of the night, and about half the nights subjects sleep till after 7 hours. Aircraft between 6 and 7 hours contributes 26.6% to a total effect of night-time aircraft noise during a sleep period time (see chapter 2, edges of the night). This estimate depends on the distribution of aircraft over the night, sleep period times of subjects, and presumably also on the way aircraft approaches and leaves the airport. The estimate therefore may not be applicable to other situations.
If the aircraft noise exposure between 6 and 7 hours of subjects would have been the same as during an hour in the period from 24 to 6 hours, the total effect of aircraft noise would be reduced by 20%, provided that the aircraft noise events would be postponed until all subjects are awake. This reduction in effect would be reached by a reduction in number of aircraft noise events

between 6 and 7 hours with a factor 4. If the aircraft noise events between 6 and 7 hours would be postponed for one hour, then number of subjects exposed to these events would be reduced by a factor 1.9, and the total effect of aircraft noise would be reduced by 10%.

### 3.6 Sleep latency time

The following two aircraft noise exposure variables have been used as independent variables:
- Llaten: equivalent sound level during sleep latency time;
- nlaten: number of aircraft noise events detected on the indoor noise monitor during sleep latency time.

During 15% of the sleep latency time periods, indoor aircraft noise events have been detected on the indoor noise monitors. Therefore, Llaten and nlaten are zero in 85% of all sleep latency time periods.
The following effect variables have been considered:
- sleep latency time (period of time it takes to fall asleep);
- difficulty to fall asleep: score on an 11 point scale in the morning diary (0 not difficult at all, 10 extremely difficult).

Where appropriate, age (and age*age) have been added as intervening variables. In each of the four combinations statistical significant exposure-effect relationships have been established. Age did not have a statistical significant effect on the relationship between Llaten or nlaten and difficulty to fall asleep.

The following variables obtained from the diaries and questionnaire have a statistical significant impact on sleep latency time and difficulty to fall asleep : reason for difficulty to fall asleep (reason_cl), aircraft noise the reason for difficulty to fall asleep (reason_ac), duration of naps during day and evening-time, number of cups of coffee in the evening-time and number of alcoholic beverages during evening-time. Coffee increases (slightly) sleep latency time and difficulty to fall asleep, alcoholic beverages decreases (slightly) these variables. In figure 3.10 the association between sleep latency time and difficulty to fall asleep because of aircraft noise is given. The increase in sleep latency time is about 15 minutes if aircraft noise is the reason for difficulty to fall asleep. It could not be shown that difficulty to fall asleep because of aircraft noise is an effect-modifier of the relationship between sleep latency time and Llaten.

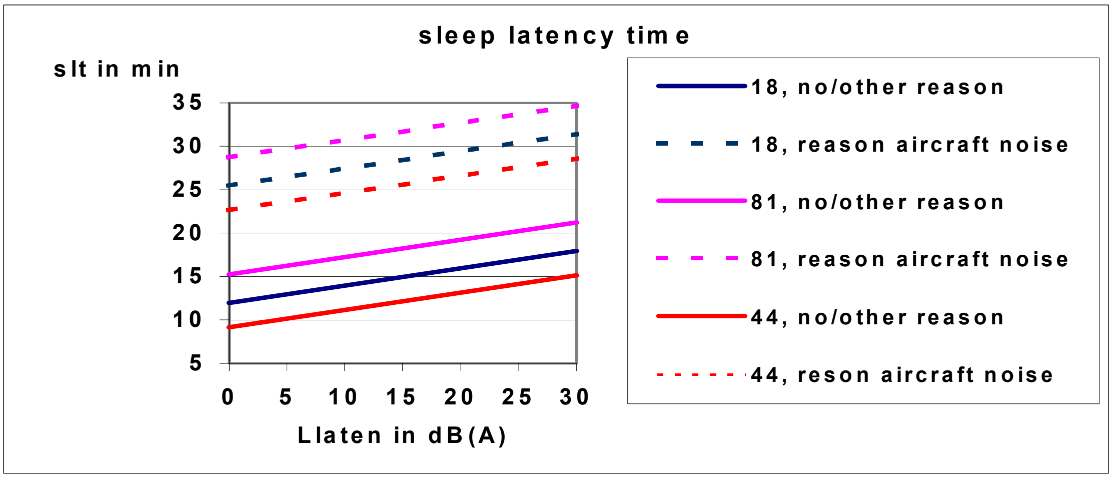



*Figure 3.10:* *Sleep latency time (slt) in minutes as a function of Llaten for age 18, 81 and 44 years (slt being smallest) and whether or not subjects consider aircraft noise the reason for not falling asleep. Subjects indicated this reason in the morning diary after twelve nights.*

## 3.7 Relationships between effect variables

In the specification of relationships between effect variables, the sequence of times to which the variables relate has been taken into account: the earlier of the two effect variable serves as independent variable and the effect variable assessed at a later stage of the 24 hours cycle as dependent variable (e.g. duration of sleep latency as independent variable and sleep quality as dependent variable). The following variables have been considered:
Type 1: Score of difficulty to fall asleep, sleep latency time (2 variables);
Type 2: Mspt, kspt, and rlscspt (3 variables);
Type 3: Number of marker pressings, number of remembered awakenings (2 variables);
Type 4: Sleep quality on a 5 and 11 points scale (2 variables);
Type 5: Sleepiness during time awake (5 variables);
Type 6: Reaction times and number of mistakes during reaction times test (5 variables).

Each of the type 6 variables have been related to the 14 type 1 to type 5 variables. For only one of the possible 70 combinations a result obtained from the reaction time tests is statistical significant related to any of the other effect variables (number of mistakes and mspt during the night before the reaction time test has been performed).
Most of the type 1 to type 5 variables turned out to be statistical significant related to each other with coefficients of the variables in the regression equations in the expected direction. Results are given in Appendix D (e.g. table D8) and some of these results can be summarised as follows. Sleepiness scores during time awake (type 5 variables) have been related to each of the nine type

1 to 4 variables, which were taken as independent variables. From the relationships, that are all statistical significant, the maximal change of sleepiness score has been assessed if the independent variable changes maximal in case of a discrete variable and from the 5% to 95% value if it is a continuous variable. Figure 3.11 gives the result for the nine type 1 to 4 variables (score on the 11 points sleep quality scale has been renumbered from 0 to 10 into 10 to 0). The increase in sleepiness score is the average value of the increases in the five scores assessed during day-time. Obviously, sleep quality on the 5- and 11-point scale has the largest association with sleepiness during time awake, and kspt and rlscspt the smallest. The association of mspt and of duration of sleep latency time with sleepiness score during time awake are about the same.

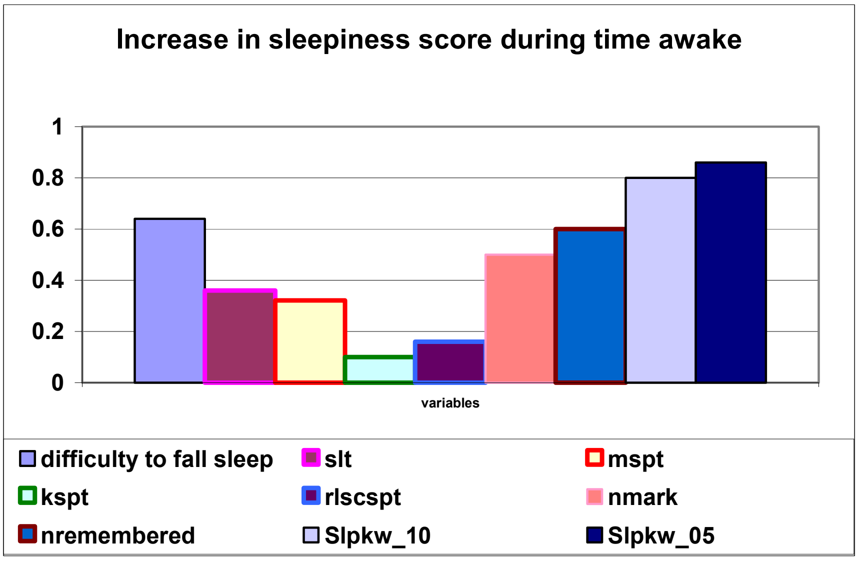



*Figure 3.11: Average increase in the five sleepiness scores (on a 9 points scale) during time awake if a variable increases from its (nearly) lowest to its (nearly) highest observed value.*

The analyses also showed that the two type 1 variables difficulty to fall asleep, assessed by subjects in their morning diary, and sleep latency time, obtained from the actigram, are associated. The linear relationship of sleep latency time with difficulty to fall asleep shows that sleep latency time is on average 9 minutes if subjects considered it not difficult at all to fall asleep and twice as long if they considered it very difficult to fall asleep.

In figure 3.12 the relationship between sleep quality (assessed by subjects in their morning diary on a scale from 0 (very bad) to 10 (very well)) and mspt is given for three ages. Obviously, if motility increases, sleep quality decreases.

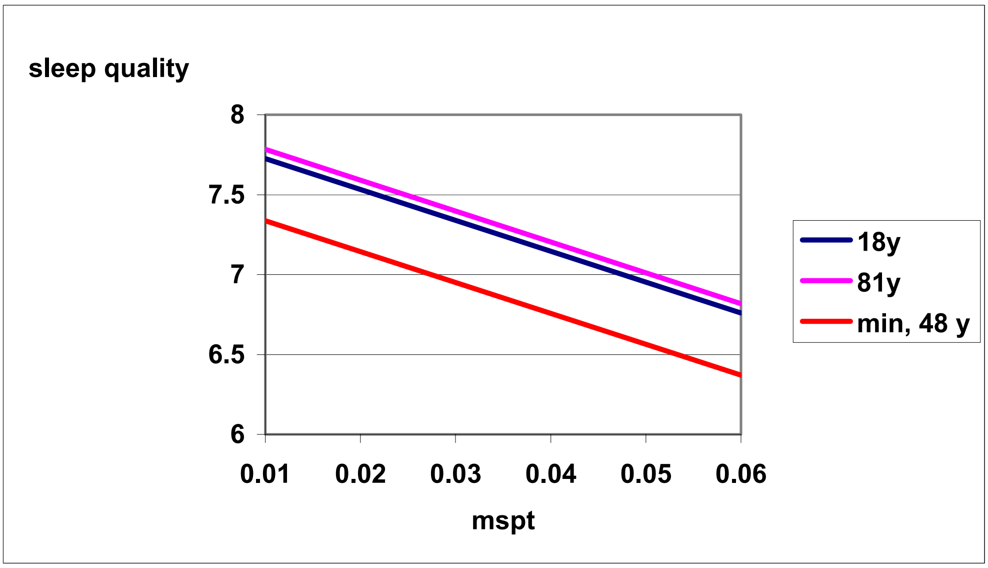



*Figure 3.12: Sleep quality as a function of mspt for three ages.*

## 3.8 Conclusions

The main conclusions are:

- Mean motility , mean onset of motility, mean motility level, mean fragmentation index, mean number of marker pressings, and probability of remembered awakenings due to aircraft noise increase with increasing aircraft equivalent sound level (Liaspt) and number of aircraft noise events (niaspt) during sleep. The probability of the use of sleeping pills effective to induce sleepiness and/or to increase sleep depth increases with increasing Liaspt, especially for older subjects. Sleep quality assessed in the morning diary does not have a statistical significant relationship with Liaspt and niaspt. Sleep quality, however, is related to mean motility during sleep: the higher motility, the lower subjects rate their sleep quality after waking up in the morning;
- Duration of sleep latency time and difficulty to fall asleep both increase with increasing aircraft equivalent sound level during sleep latency time period. Also, difficulty to fall asleep increases with number of aircraft noise events during sleep latency time period;
- Aircraft noise during sleep has only a small effect on sleepiness next day and evening. At about 10 o'clock in the morning, a small increase in sleepiness with night-time aircraft noise has been established, but there is no effect at later times in the afternoon and evening. Sleepiness, however, has a statistical significant relationship with nearly all effect variables related to sleep latency time and sleep period time, such as difficulty to fall asleep, duration of sleep latency time, sleep quality, number of marker pressings, number of remembered awakenings, mean motility, mean onset of motility, and mean motility level;
- Difficulty to fall asleep is an important factor with respect to several aspects of sleep. Compared with duration of sleep latency time and mean motility during sleep period time, it has

not only twice as much impact on other subjective variables such as sleep quality and sleepiness during time awake, but also on number of marker pressings and number of remembered awakenings during sleep;

- None of the test results obtained with the reaction time test have been statistical significant affected by aircraft noise during the night before testing;
- At about one third of the nights, subjects are asleep before 23 hours. Aircraft between 23 and 24 hours contributes about 4% to a total effect (such as increase in motility, increase in number of marker pressings, increase in number of remembered awakenings due to aircraft noise) of night-time aircraft noise during sleep period times of subjects.
  For an hour between 24 and 6 hours the percentage of 6.3% applies.
  The contribution of aircraft between 6 and 7 hours to a total effect of night-time aircraft noise is considerable, because from 6 to 7 hours there occurs much more aircraft than in the earlier hours of the night, and about half the nights subjects sleep till after 7 hours. Aircraft between 6 and 7 hours contributes 26.6% to a total effect of night-time aircraft noise during a sleep period time.
  These estimates depend on the distribution of aircraft over the night, sleep period times of subjects, and presumably also on the way aircraft approaches and leaves the airport. Therefore, these estimates may not be applicable to situations which differ in these respects substantially from the situation in the present study.

# 4 Long-term variables

## 4.1 Introduction

In section 4.2 of this chapter exposure-effect relationships are given. Relationships with two types of effect variables are considered: long-term variables, obtained from the questionnaire subjects filled out in the week before their participation in the study started, and aggregated variables obtained from actimetry, marker pressings, and diaries. In TNO report 2001.205 the English translations of the questionnaire and diaries are given. That report also gives detailed information about the distributions of variables obtained from the questionnaire and from the diaries and about distributions of night-time aircraft noise exposure of subjects at the 15 locations.
In section 4.3 associations between effect variables are considered. Conclusions are presented in section 4.4 and a table in section 4.5.

Appendix E contains information about the statistical analyses and the coefficients of the exposure-effect relationships obtained.

## 4.2 Exposure-effect relationships

Section 4.2.1 provides the model used to assess the relationships and discusses the aircraft noise exposure metrics used in this chapter. Section 4.2.2 gives relationships for effect variables obtained from the questionnaire. Section 4.2.3 presents the relationships for aggregated variables.

### 4.2.1 Model for relationships between long-term variables

Figure 4.1 gives a simple model for the relationships between aircraft noise exposure and effects. Possible associated variables, determinants and effect-modifiers may have an impact on the effect variables and relationships. Confounders can be assessed from the determinants and effect-modifiers.

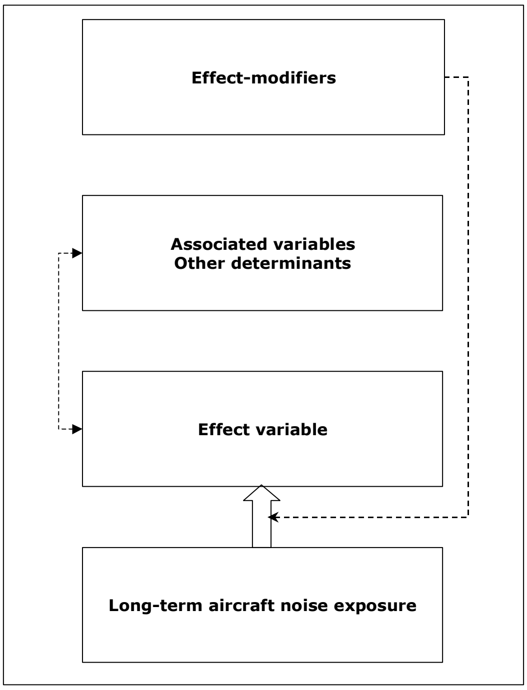



*Figure 4.1:* *Model for relationships between long-term effect variables and long-term night-time aircraft noise exposure*

*Noise exposure variables*

Two sources of information about aircraft noise exposure have been used:

- data from NLR about aircraft noise exposure in the year 2000 at the position of the outdoor noise monitor at each location: Lbi23-06h, Lbi06-07h, Lbu23-07h, Ke and Lden. Ke and Lden are aircraft noise metrics that are related to exposures over the full 24 hours cycle. To obtain Lbi23-07h, 21 dB(A) has been subtracted from Lbu23-07h. The differences between night-time aircraft noise exposures in 2000 and in 1999 at the 15 locations are small: at most 3 dB(A), but for most locations the difference is between –1 and +1 dB(A);
- data obtained from the noise measurements performed outside at a location (Lo) and inside bedrooms (Li) for the 11 sleep period times of a subject. Li of a subject has been calculated from SEL10_i of all aircraft noise events on the indoor noise monitor during sleep of the subject, and Lo has been assessed from SEL10_o of the same aircraft noise events used in calculating Li. Since it was shown earlier that indoor aircraft noise exposure has a stronger relationship with effect variables than outdoor aircraft noise exposure, mainly Li has been used as descriptor of individual night-time aircraft noise exposure.

Lbi23-06h and Lbi23-07h are location dependent variables: each subject at a given location has the same value of Lbi23-06h and of Lbi23-07h, irrespective of the differences in actual aircraft noise exposure during sleep of subjects at the same location.

At a given location, Li varies from subject to subject. In Annex E it has been made plausible that Li is a proper estimate of the individual long-term aircraft noise exposure.

Figure 4.2 presents the median value of Li, calculated from Li of all subjects at a location, as a function of Lbi23-07h. Also the best fitting straight line, obtained by a linear regression analysis, is plotted in the figure. Figure 4.2 also shows the highest and lowest value of Li at each of the locations. There is apparently a large variation in individual aircraft noise exposure at the same location. This variation is mainly due to variation in sleep times, and in sound insulation of the bedroom. The last factor is dependent on building characteristics and bedroom window ventilation behaviour of subjects.
The maximal value of Li at the lowest exposed location is higher than the lowest Li value at the highest exposed location.

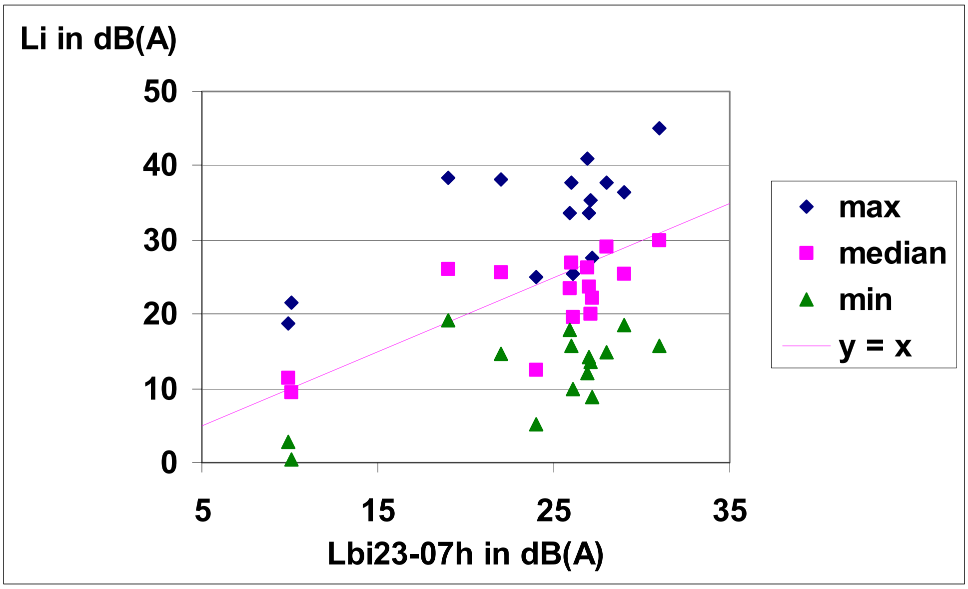



*Figure 4.2: Maximum, median and lowest value of Li at a location as a function of Lbi23-07h. Data points at Lbi23-07h of 24 dB(A) concern location Spaarndam. The straight line is the linear regression line of median Li and Lbi23-07h..*

### 4.2.2 Relationships with questionnaire variables

It is not the aim of the questionnaire to assess general applicable long-term exposure-effect relationships, such as between Lden and percentage of subjects highly annoyed by aircraft noise. Much larger data bases are available than our data base of the questionnaire responses of 418 subjects. Nevertheless, the long-term data from the questionnaire are elaborated to obtain on a small scale a detailed picture of relationships, determinants, effect-modifiers, and confounders.

**Effect variables**

Effect variables from the questionnaire can be classified as follows:
Type 1: night-time aircraft noise specific effect variable, such as awakening by night-time aircraft noise
Type 2: effect variable related to 24 hours aircraft noise exposure, such as fear for aircraft;
Type 3: general effect variable, such as number of health complaints and sleep quality.

Twenty-one self-reported effect variables have been considered. These variables are of the following types:

- Perception of aircraft noise during 24 hours type 2;
- Annoyance by aircraft noise during 24 hours type 2;
- Perception of night-time aircraft noise type 1;
- Awakening by night-time aircraft noise type 1;
- Annoyance by night-time aircraft noise type 1;
- Fear because of aircraft noise type 2;
- Frequency of being afraid of aircraft noise type 2;
- Dissatisfaction with aircraft noise around the house type 2;
- Fear for health impact by aircraft noise type 2;
- Experienced health type 3;
- Sleep quality type 3;
- Number of general sleep disturbances type 3;
- Number of night-time aircraft noise complaints type 1;
- Number of health complaints type 3;
- Use of sleeping pills which induce sleepiness/increase sleep depth type 3;
- Use of medicication type 3;
- Sum reasons frightened of aircraft noise type 2;
- Recognising own situation as living under a flight path type 2;
- Recognising own situation living in the vicinity of a large airport type 2;
- Worried about living under a flight path type 2;
- Worried about living in the vicinity of a large airport type 2;
- Number of effects per week on sleep by aircraft noise type 1.

**Exposure-effect relationships**

Linear regression analyses with the 21 effect variables showed that 8 (type 2 and 3) variables are not statistical significant related to any of the four night-time aircraft noise metric Lbi23-06h, Lbi23-07h, Li, and Lo or related to only one exposure variable, but with a correlation that is just statistical significant. These variables are experienced health, number of general sleep disturbances, use of medication, use of sleeping pills, having fear because of aircraft noise, frequency of being afraid because of aircraft noise, recognising the own situation as living in the vicinity of a large airport and having worries about living in the vicinity of a large airport.

Number of health complaints, assessed with the shortened version of the so-called voeg list with 13 items, is related to Li and Lo, but not to Lbi23-07h and Lbi23-06h. In this study, number of health complaints appeared to be independent of age and increases on average from 2.5 to 4 if Li increases from 0 dB(A) to 35 dB(A).
Most of the remaining 12 effect variables have a slightly higher correlation with night-time aircraft noise metric Lbi23-07h than with the other three night-time aircraft noise metrics. Therefore Lbi23-07h has been selected as night-time noise metric to assess exposure-effect relationships with these 12 effect variables. Frequency of awakening by aircraft noise (a type 1 variable) and recognizing the own situation as living under a flight path of a large airport (a type 2 variable) show the strongest relationships with Lbi23-07h (and with the other exposure variables).

Multi-variate regression analyses have been performed with Lbi23-07h as independent variable, each of the twelve effect variables, which showed a statistical significant exposure-effect relationship with Lbi23-07h (see table 4.1), as dependent variable, and demographic variables including age and age*age as possible determinants. It turned out that age is in nearly all cases a statistical significant determinant. For eight relationships both age and age*age are determinants. In all these eight cases subjects of about 40 to 50 years showed larger adverse effects than younger and older subjects. With respect to other demographic variables (gender, citizenship, number of children, education, country of birth), only some of these variables turned out to be determinants. Moreover, the direction of the effect varied in some cases: the same determinant caused a reduction of some adverse effects and an increase in other adverse effects. Only for country of birth (Netherlands or not) the same direction of impact on effect variables has been observed: subjects born outside the Netherlands (13 subjects, 11 of them born in Indonesia) showed for a few effects larger adverse effects than subjects born in the Netherlands.
In figure 4.3 and 4.4 two examples of statistically significant exposure-effect relationships are given. Note that sleep quality, a type 3 variable, is only slightly affected by night-time aircraft noise exposure. The effect of night-time aircraft noise exposure on frequency of awakening, a type 1 variable, is stronger than the effect on sleep quality.

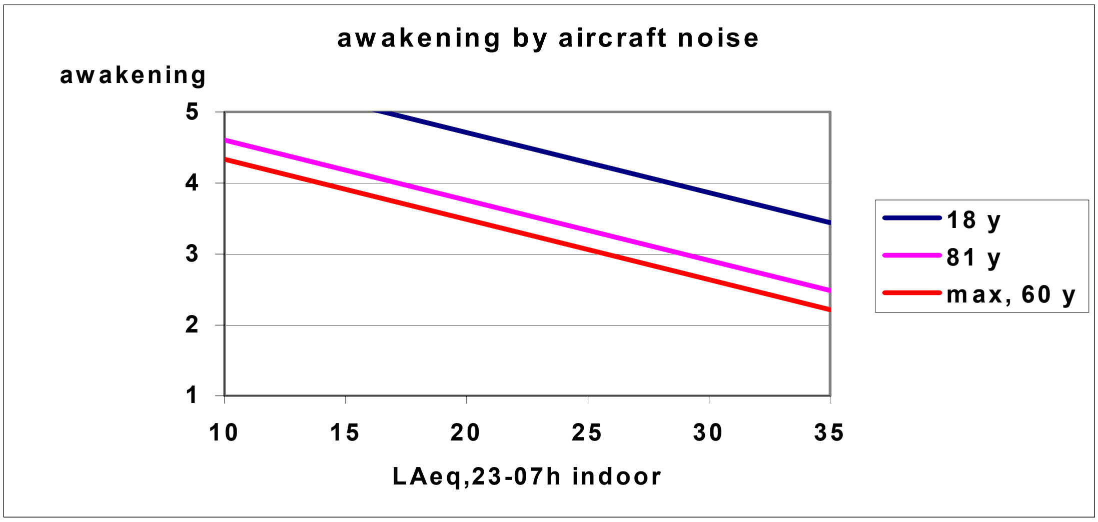



*Figure 4.3: Frequency of awakening due to aircraft noise as a function of Lbi23-07h for three ages: 18, 81 and 60 years, the age at which subjects report in the questionnaire to be awakened most frequently by aircraft noise. Labels of the variable awakening: 5 never, 1 (nearly) each night.*

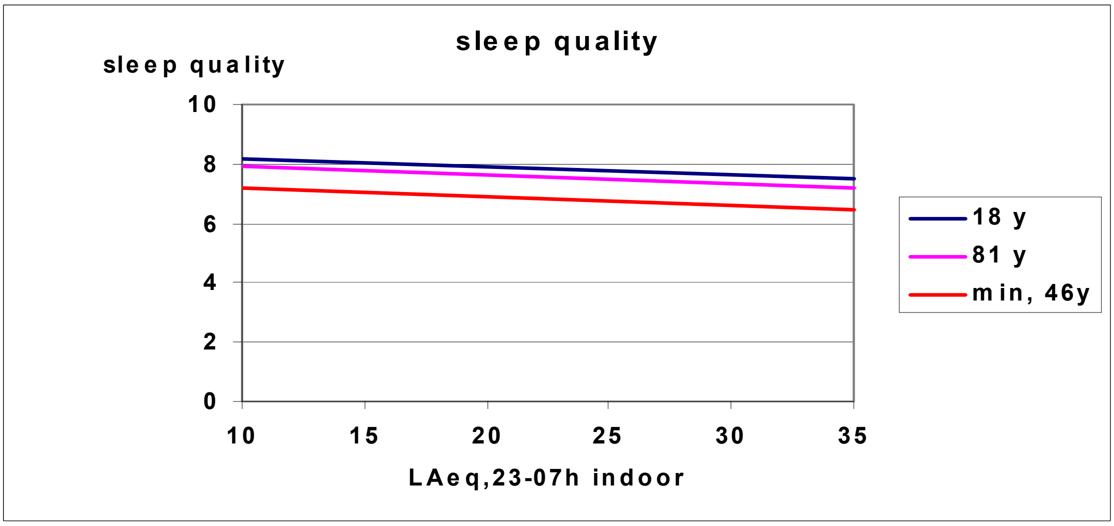



*Figure 4.4: Sleep quality as a function of Lbi23-07h for three ages: 18, 81 and 46 years, the age at which subjects report in the questionnaire the worst sleep quality. Labels of the variable sleep quality: 0 very bad, 10 extremely well.*

By so-called backward linear regression analyses it has been examined which (combination of) variables (obtained from the questionnaire) have a statistical significant impact on the 12 effect variables (where appropriate with demographic variables also included as possible determinants at the start of an analysis). The result is shown in table 4.1. The first column gives the variables

that have an impact on at least one of the effect variables. Such a variable is associated with an effect variable or it is a determinant of the effect variable. As mentioned in chapter 1, in the first case the cause-effect chain is unclear: e.g. it is unclear whether attitude towards the expansion of Schiphol has an effect on worries about aircraft noise on health and/or vise versa. In the second case the cause-effect chain is obvious: e.g. gender is a determinant of night-time aircraft noise annoyance and night-time aircraft noise is not a determinant of gender. The first row gives the effect variables, and the second row the change in the value of the effect variable, if the effect variable changes from the best to the worst classification (range plus direction). The next rows present the type of effect variable and the change in the effect variable if Lbi23-07h increases from 10 to 35 dB(A). E.g., the change (increase) in score of being worried about effects of aircraft noise on health is 2.36, if Lbi23-07h increases from 10 to 35 dB(A). The next rows give the maximal change in an effect variable, if the variable in the first row increases from its lowest to its highest possible value. If a cell is empty, the variable is not associated with or is not a determinant of the effect variable. Since the change due to age and age*age cannot be included in the table in a simple way, these variables have been omitted in the table.
By looking at the values in a column of a certain effect variable, the changes in this effect variable as the result of maximal changes in the variable in the first column can be compared. E.g., the score of being worried about effects of aircraft noise on health is 2.83 higher for subjects having a very negative attitude towards Schiphol and/or aircraft noise compared to subjects having a very positive attitude. Having a job related to Schiphol decreases the score of being worried about effects of aircraft noise on health with 0.5. Changes can also be combined, because all variables in the first column, except the empty cells, are included as independent variables in the final regression equations. E.g., the score of being worried about effects of aircraft noise on health is 5.4 (2.83 + 2.58) higher for subjects that took the maximal observed number of actions against aircraft noise and have a very negative attitude towards Schiphol and/or aircraft noise, compared to subjects who did not take any action and have a very positive attitude towards Schiphol.

Except for age and gender, none of the demographic variables are included in table 4.1, since their regression coefficients did not remain statistical significant after the inclusion of other variables from the first column.

Table 4.1 shows that the following variables have the largest impact on or are most associated with the type 1 as well as on the other types of effect variables:

- satisfaction with the living environment: the more dissatisfied, the higher adverse effects;
- satisfaction with insulation of the house against outdoor noises: the more satisfied, the lower adverse effects;
- required frequency of ventilation less because of aircraft noise: the more frequent subjects abstain from ventilating the house because of aircraft noise, the higher adverse effects;
- self-reported noise sensitivity: the higher noise sensitivity, the higher adverse effects;
- score for an active attitude towards problems and situations (UCL-active): the higher the score, the higher adverse effects.

To our opinion, only noise sensitivity and an active attitude towards problems (UCL) are determinants. We consider the other variables to be associated with the effect variables.

### 4.2.3 Aggregated data

For each subject, the mean value over the eleven sleep period times of the following effect variables have been calculated: mspt, kspt, rlscspt, fragmentation index, number of marker pressings, number of remembered awakenings, sleepiness before going to sleep, sleep quality on the 11- and 5-points scale, use of sleeping pills or drugs effective to induce sleep or increase sleep depth, sleepiness during time awake assessed by sleepiness strip, results obtained with the reaction time test, sleep latency time, and duration of sleep period time.
Multiple linear regression analyses have been performed with each of these effect variables as dependent and Li, age, and age*age as independent variables.
For mspt, kspt, rlscspt and sleep latency time (slt) statistical significant relationships have been assessed, but not for any of the other 13 variables.
It has also been tested whether Lday is a determinant of mspt, kspt, rlscspt and slt. This is not the case. Therefore, Lday is not a confounder in each of these four cases.

In section 4.2.2 it has been shown that most long-term effect variables obtained from the questionnaire have a stronger relationship with Lbi23-07 than with Li. Therefore, also relationships have been assessed with Lbi23-07 as independent variable. In each case it turned out that none of the relationships have statitical significant coefficients. This implies that Lbi23-07is not a confounder of the relationships between the effect variables mspt, kspt, rlscspt and slt and Li.

In chapter 2 relationships have been presented between resp_m and resp_k at the 15-s intervals e4 to e10 of aircraft noise events and aircraft noise event metric Lmax_i. By using these relationships, from the Lmax_i values of all indoor aircraft noise events in the bedroom during all sleep period times of a subject, the increase in mspt and in kspt due to the instantaneous aircraft noise induced increases in probability of (onset of) motility has been calculated. These instantaneous components of mspt and of kspt are small. This is shown in figure 4.5 by the dotted lines. If Li is 0 dB(A) (aircraft noise during sleep is absent), the instantaneous component in mspt is 0 and mspt has, dependent on age, a certain average value. If Li increases, the increase in the instantaneous component at a given value of Li is equal to the value of the dotted line at that value of Li minus the value of mspt at Li=0 dB(A). For Li > 0 dB(A), observed mspt, given by the solid straight lines, is larger than the sum of mspt at Li=0 and the instantaneous component in mspt. This implies that aircraft noise during sleep not only results in increased motility during events, but also that it has induced on a long-term basis in subjects a higher level of motility. It is unknown whether this long-term component is permanent, or whether it is temporary and will vanish after a period of time if night-time aircraft noise exposure is terminated. Obviously, this long-term component increases with Li, since the two straight lines for a given age are divergent.

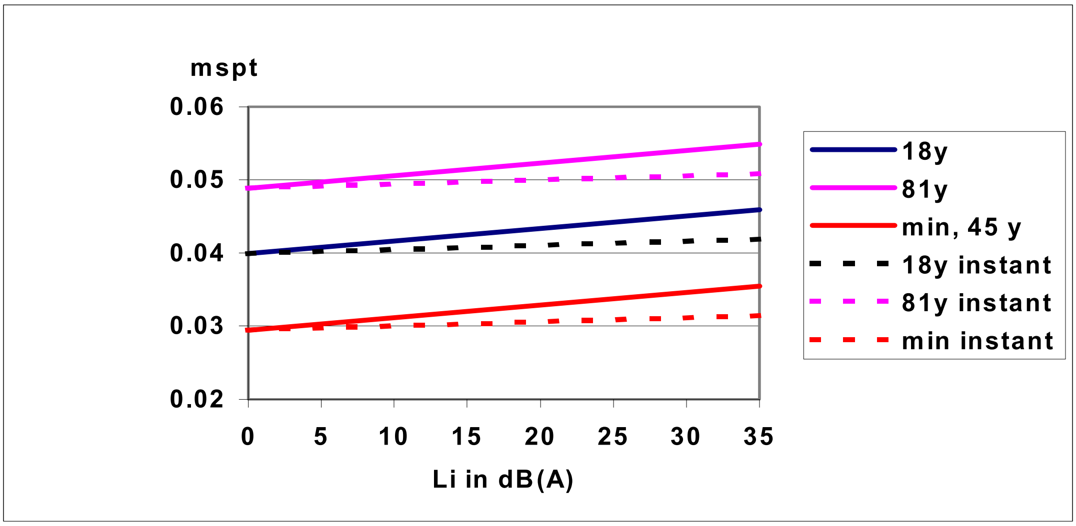



*Figure 4.5: Observed mean motility over sleep period times as a function of Li (solid straight lines) and the expected mspt if motility is only increased by instantaneous increase in motility during aircraft noise events (dashed straight lines).*

## 4.3 Associations between effect variables

### 4.3.1 Self-reported variables obtained from questionnaires and diaries

A few questions in the questionaire are identical to questions in the diaries. In this section, the results of some of these questions are compared. The examples illustrate the overall result, that subjects respond more extreme, if they evaluate their situation in a questionnaire, than if they evaluate their situation on an day to day basis. Also illustrated in this section is the well known phenomenon that persons are less noise annoyed if they are requested to evaluate their situation in general, than if they evaluate annoyance from specific noise sources.

*Comparison of long-term and 24 hours variables*
In the questionnaire and in the morning diary sleep quality is rated on an 11 points scale by using the same question. In figure 4.6 two regression lines are shown: one with the score of sleep quality from the diaries as dependent variable and one with sleep quality obtained from the questionnaire as dependent variable. The ranges of the axes correspond to the lowest and highest scores from subjects. The mean annoyance score is about the same in both evaluations: 6.9 in the diaries and 7.0 in the questionnaire. The figure shows that subjects score more extreme in the questionnaire (from 3 to 10) than in the morning diary (from 5 to 9).

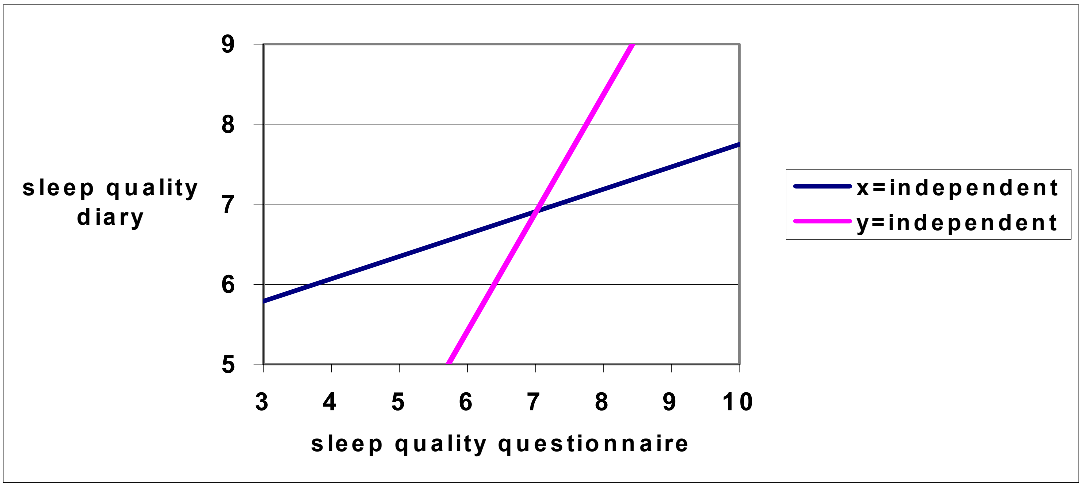



*Figure 4.6: Regression lines of sleep quality on a 11 points scale, obtained from the morning diaries and obtained from the questionnaire. X=independent: the relationship of sleep quality in the diary as dependent variable and sleep quality from the questionnaire as independent variable (on the x-axis). Y=independent: is the relationship of sleep quality from the questionnaire as dependent variable and sleep quality in the diary as independent variable (on the y-axis).*

In the questionnaire, subjects indicate the frequency of awakening due to aircraft noise in five classes. For the subjects in each of these five classes the average number of remembered awakenings due to aircraft noise per night has been calculated and has been plotted in figure 4.7. The responses in the questionnaire conform to the following frequencies:

- (nearly) each night: frequency (nearly) 1;
- at least once a week: frequency at least 0.14;
- at least once a month: frequency at least 0.03;
- at least once this year: frequency at least 0.003;
- never frequency equal to 0.

In the three sub-groups with the lowest frequencies of awakening, there is a good correspondence between the evaluation from night tot night and long-term evaluation. For the two sub-groups with the highest frequencies of awakening, frequency of awakening due to aircraft noise is rated in the questionnaire three times or more higher than actually remembered on a day-to-day basis.

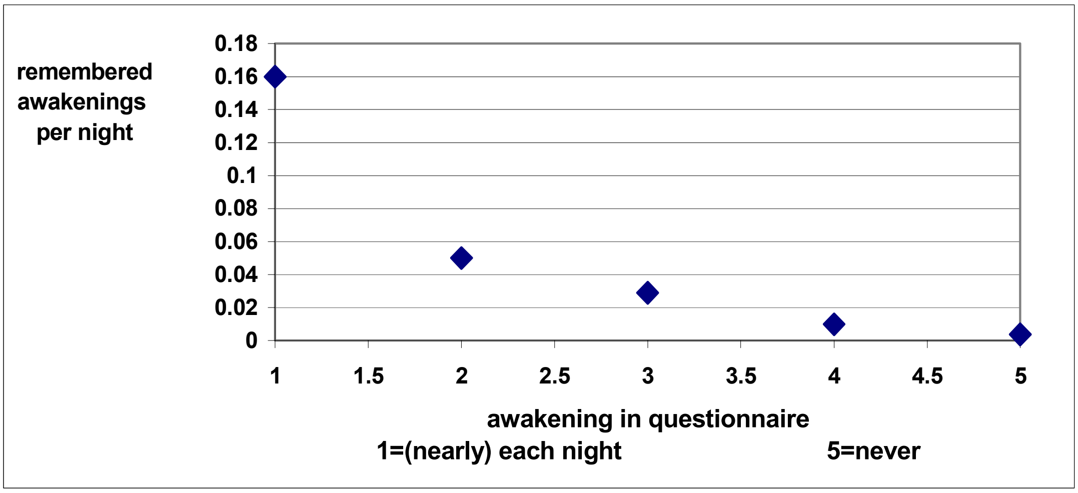



*Figure 4.7: Average frequency per night of remembered awakenings due to aircraft noise as a function of awakening due to aircraft noise in the questionnaire (1: (nearly) each night, 2: at least once a week, 3 at least once a month, 4 at least once last year, 5 never).*

*Comparison of general and noise specific effect variables*

In the questionnaire subjects indicate their noise annoyance, on a scale from 0 to 10, without specifying a noise source and their annoyance related to four specific noise sources (road traffic, aircraft, industry, construction). In figure 4.8 the maximum score for any of the four specific noise sources (usually aircraft noise, in some cases road traffic noise) and general noise annoyance have been related. The source specific annoyance score is from 5 to 10, and the general noise annoyance score from about 0 to 5.

The percentage of subjects highly annoyed (score over 7.2) by aircraft noise is 20.8%, and the percentage of subjects highly annoyed by noise, without the noise source specified, is 5.2%.

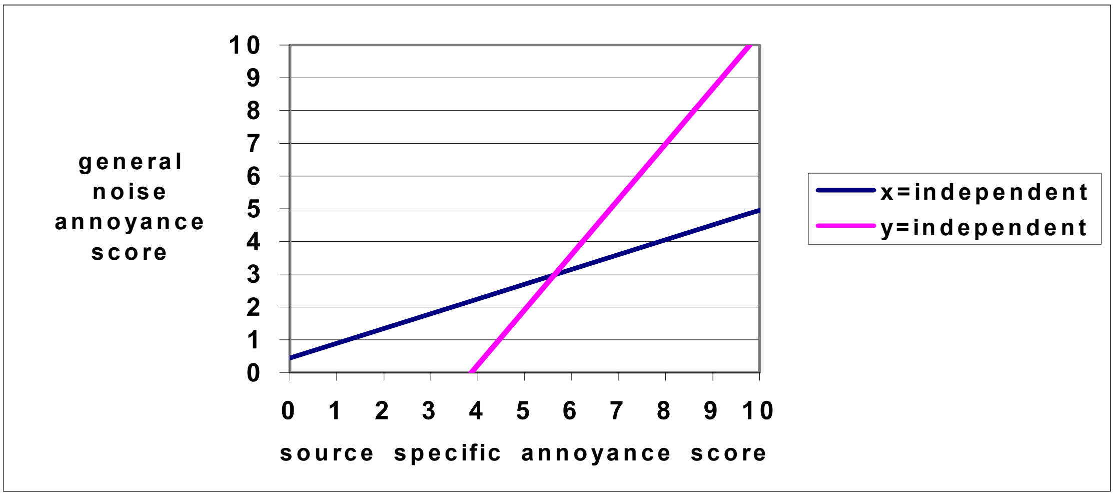



*Figure 4.8:* *Regression lines of noise annoyance in general (daily noise annoyance score) and source specific annoyance scoree. X=independent is the relationship of daily noise annoyance score as dependent variable and noise source specific annoyance independent variable (x-axis). Y=independent is the relationship of noise source specific annoyance score as dependent variable and daily noise annoyance score as independent variable (y-axis).*

### 4.3.2 Associations between aggregated variables

In this section, the associations between motility and long-term variables obtained from the questionnaire and aggregated effect variables obtained by averaging the 24 hours variables are considered. By multiple regression analyses, statistical significant relationships have been established between mean motility during sleep (mspt) and the following variables: number of times remembered to have been awake during sleep, number of marker pressings during sleep, use of sleeping pills (effective to induce sleepiness), self-reported sleep quality from the questionnaire, number of general sleep complaints, frequency of times awake due to aircraft noise, number of aircraft noise-induced adverse effects a week, and number of health complaints. Examples of associations are illustrated in figures 4.9 and 4.10. Although the cause-effect chain is unclear, to illustrate the association mspt has been chosen as independent variable and the other effect variable as dependent variable.

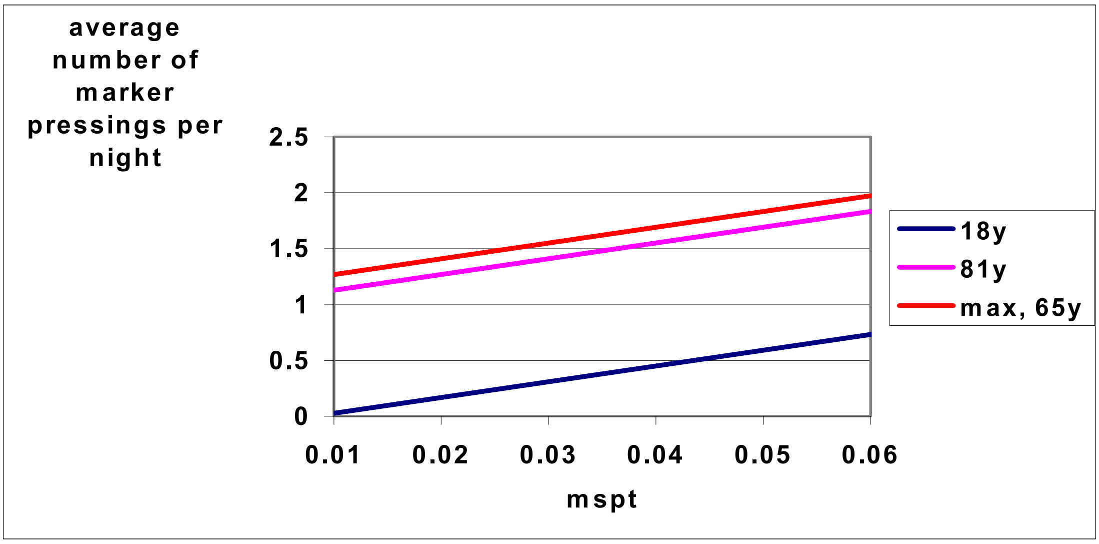



*Figure 4.9:* *Average number of marker pressings per night as a function of mspt (average motility during sleep) for the three ages 18, 81, and 65 years, the age at which the average number is maximal.*

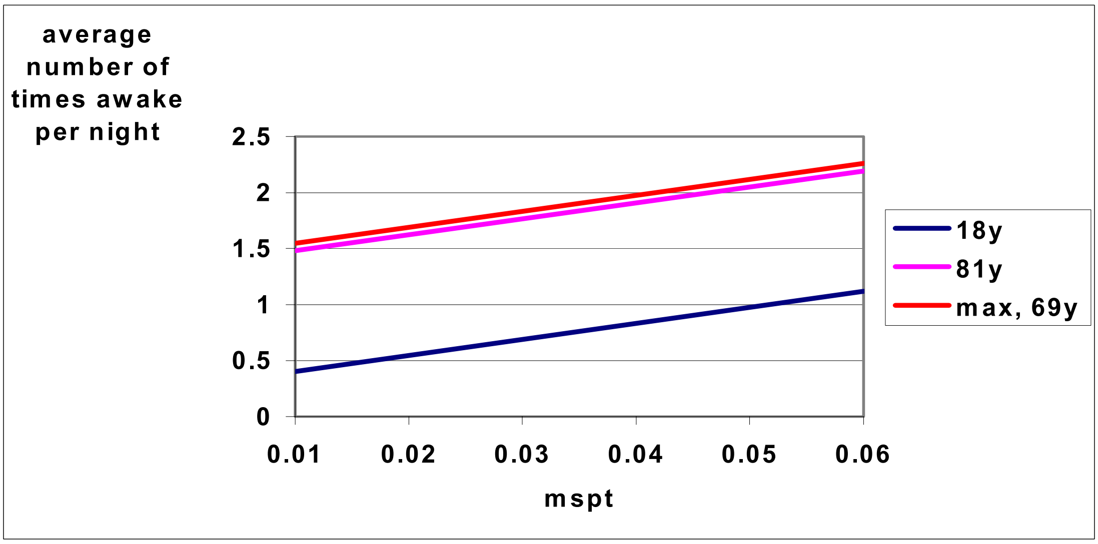



*Figure 4.10:* *Average number of times remembered to have been awake per night obtained from the morning diaries as a function of mspt (average motility during sleep) for the three ages 18, 81 and 69 years, the age at which the average number is maximal.*

## 4.4 Conclusions

The main conclusions in this chapter are:

- On average Li (individual aircraft noise exposure during sleep) at a location is 1.4 dB(A) lower than Lbi23-07h. The difference between Lbi23-07h and Li is a decreasing function of Lbi23-07h: at Lbi23-07h = 10 dB(A), Lbi23-07h - Li = -2 dB(A), and at Lbi23-07h = 31 dB(A): Lbi23-07h - Li = +3 dB(A). Large individual differences in actual aircraft noise exposure during sleep exist: lowest and highest individual values at a location differ by 30 dB(A);
- Correlations of Lbi23-07h with long-term (night-time) effect variables obtained by questionnaire are slightly higher than correlations of Lbi23-06h with these variables;
- Mean motility, mean onset of motility, mean motility level, and sleep latency time are related to Li. The higher Li, the higher these effect variables aggregated over the 11 sleep period times;
- A variety of effect variables increase with increasing Lbi23-07h: annoyance due to aircraft noise, annoyance due to aircraft noise at night-time, perception of aircraft noise, perception of aircraft noise during night-time, frequency of awakening due to aircraft noise, dissatisfaction with aircraft noise around the house, fear and worries because of aircraft noise, adverse effects of aircraft noise on sleep, and sleep quality. In this study, aircraft noise exposure during day and evening is confounding the relationships;
- Of the various demographic variables considered, only age has an important impact on the effect variables obtained from the questionnaire;
- The variables with the strongest impact on effect variables obtained by questionnaire, are satisfaction with the living environment, satisfaction with the insulation of the house against outdoor noises, refraining from ventilating the house because of aircraft noise, noise sensitivity, and an active attitude towards problems and situations. Since the cause-effect chain in case of the first three variables is unknown, these variables are assumed to be associated with the effect variables. Noise sensitivity and an active attitude towards problems and situations are determinants;
- The number of health complaints (on a scale from 0 to 13) increases on average by about 1.5 if Li increases from 0 to 35 dB(A). Day- and evening-time aircraft noise (in n, Ke, Lday) is not confounding the relationship;
- Of the 17 aggregated effect variables, only four variables are statistically significant related to night-time aircraft noise exposure: mean probability of motility, mean probability of onset of motility, mean motility level, and sleep latency time. These four variables are not related to Lbi23-07h;
- Aircraft noise during sleep not only results in increased probability of motility during aircraft noise events, but the exposure induces in addition to this instantaneous effect a long-term increase in motility. This long-term component increases with Li. It is unknown whether this long-term component is permanent, or vanishes (in part) in a subject, after his/her night-time aircraft noise exposure has ended;
- Motility and a variety of long-term variables obtained from the questionnaire and aggregated effect variables obtained from the diaries are associated. These variables are: number of times remembered to have been awake during sleep, number of marker pressings during

sleep, use of sleeping pills (effective to induce sleepiness), self-reported sleep quality from the questionnaire, number of general sleep complaints, frequency of times awake due to aircraft noise, number of aircraft noise-induced adverse effects a week, and number of health complaints.

## 4.5 Table

*Table 4.1 Maximal change in effect variables (variables in the heading of the columns) due to the maximal change in variables in the first row of the table.*

| | Perception aircraft noise | Annoyance aircraft noise | Perception night-time aircraft noise | Awakening night-time aircraft noise | Annoyance night-time aircraft noise | Dissatisfaction aircraft noise around house | Fear for impact of aircraft noise on health | Sum reasons being afraid of aircraft noise | Recognition living under a flight path | Worried about living under a flight path | Sleep quality | Adverse effects due to aircraft noise at night |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Maximal possible change in effect variable, from the best to the worst classification | | | | | | | | | | | |
| | -4 | +11 | -4 | -4 | +11 | +11 | +11 | +10 | +1 | +11 | -11 | +56 |
| Variable type | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 1 |
| Lbi23-07h | -1.08 | 3.24 | -1.40 | -1.59 | 3.33 | 3.49 | 2.36 | 0.90 | 0.73 | 2.83 | -0.72 | 5.42 |
| gender | | | | | -1.03 | | | 0.37 | | 0.31 | | |
| daily noise disturbance | -0.24 | 2.02 | | | 2.19 | | 1.38 | 1.03 | -0.07 | 0.40 | | |
| environment years | | | | 0.95 | | | | | 0.16 | 0.82 | | -1.87 |
| satisfaction with house | | | | | -1.79 | 0.36 | | | | | | -3.48 |
| house owned or rented | -0.25 | 0.96 | -0.34 | | 1.21 | 0.21 | | | 0.09 | | | |
| insulation bedroom window | | -0.44 | | | -0.90 | -0.39 | | | | | | |
| satisfaction living environment | | 1.68 | | | 3.76 | 2.99 | 1.24 | | | -0.42 | | 5.55 |
| satisfaction insulation outdoor noises | 0.28 | -2.55 | 0.65 | 1.14 | -1.91 | -7.34 | -0.39 | | -0.22 | -1.51 | 1.39 | -2.24 |
| required ventilation | | -1.90 | 0.46 | 1.40 | -3.05 | 2.44 | -2.77 | | -0.17 | -1.40 | 0.93 | -5.15 |
| attitude towards Schiphol | | 1.91 | | | 1.28 | -1.20 | 2.83 | 0.37 | 0.17 | 1.89 | | 2.38 |
| actions against Schiphol | | 1.45 | | | 1.73 | -1.79 | 2.58 | | -0.27 | | 0.82 | |
| job related to Schiphol | | | | | | 0.33 | -0.50 | | 0.06 | | | |
| use hearing protection | | | | | | 1.57 | | | -0.32 | | -2.50 | 1.56 |
| sleeping pills | | | | | | | | | 0.18 | | -2.76 | |
| noise sensitivity | | 1.32 | | -1.06 | 1.88 | | | 1.48 | 0.15 | 1.83 | | 3.69 |
| ucl-active | | | | -0.59 | 2.47 | | | 1.19 | | 1.84 | -1.12 | 4.21 |
| ucl-laisser faire | | | | -0.95 | 2.03 | 0.78 | | 0.76 | 0.27 | | | 3.95 |
| ucl-support | 0.29 | | | | | | | | 0.17 | | | |

# 5 Comparison subjects and non-respondents.

## 5.1 Introduction

One of the aims of the study is to provide information on basis of which the prevalence of adverse effects of night-time aircraft noise exposure on the population in the vicinity of Schiphol can be estimated. It is reasonable to assume that for such an estimation information is available at least about the distribution of night-time aircraft noise exposure among the population expressed in Lbi23-07h and about the distribution of age among the population. In chapter 2 to 4 exposure-effect relationships based on subject data have been presented. However, to apply these relationships to the population in the vicinity of Schiphol, the question is whether these relationships have been biased by selective response of subjects. The non-response study has been undertaken to estimate a possible selection bias by first establishing differences in the distribution of variables in the population of subjects and in the population of non-respondents, and then assessing the consequences of the observed differences on exposure-effect relationships.

Non-respondents filled out a questionnaire with a large number of questions that also have been included in the subject questionnaire. The questions which have been included in the non-response questionnaire are given in the headings of the subject questionnaire (see chapter 7 of report 2001.205). From both questionnaires, 67 identical variables have been derived.

## 5.2 Approach

First, it has been established for which of the 67 variables the distribution in the population of subjects is statistically significant different from the distribution in the population of non-respondents. These variables can be one of the effect variables, specified in the first row of table 4.1, or one of the determinants or variables associated with effect variables, specified in the first column table 4.1. An example of the first category is ‘score of worries about effects of aircraft noise on health’, an example of the second category is ‘having a job related to Schiphol’.
For the effect variables, first it has been assessed whether there is a statistically significant difference in exposure-effect relationships for subjects and non-respondents, taking also into account age, and other determinants and variables associated with the effect variable. In case of a difference, exposure-effect relationships for non-respondents have been provided.
If a variable is a determinant or associated with an effect variable, it is assessed whether there is a statistically significant difference in exposure-effect relationships for subjects and non-respondents, with this variable added in the regression model as independent variable. In case of a difference, exposure-effect relationships for non-respondents should be provided.
The exposure-effect relationships for the non-respondents can then be applied to the population in the vicinity of Schiphol. If such a relationship for non-respondents is applied to the population in the vicinity of Schiphol, it is assumed that the results for non-respondents are not biased by

selective response. Whether this is fully correct is incertain, since not 100% but about 60% of the adresses to which a non-response questionnaire was sent returned the completed questionnaire.

## 5.3 Analyses

In total the distributions of 21 of the 67 variables are statistically significant different. Age is one of these variables These 21 variables are given in table F1 of Appendix F.
Four of the variables concern road traffic noise and are not relevant for the present analyses.
For six variables, the difference in distribution between subjects and non-respondents could be explained by the difference in age composition of the group of subjects and the group of non-respondents. Three variables are effect variables. Each of the three exposure-effect relationships turned out to be different for subjects and for non-respondents.
Five of the remaining seven variables have an impact on the effect variables specified in table 4.1 and the difference between subjects and non-respondents may therefore have an impact on exposure-effect relationships. These five variables are citizenship, composition of household, satisfaction with sound insulation against outdoor noises, job related to Schiphol, and use of sleeping pills. It turned out that none of the differences between subjects and non-respondents have an impact on the exposure-effect relationships specified in chapter 4.

## 5.4 Results

The distribution of age of subjects differs from that of non-respondents. Subjects are younger than non-respondents: 29% of the subjects and 17% of the non-respondents are in the youngest age group (< 35 years), and 10% of the subjects and 17% of the non-respondents belong to the oldest age group (> 65 years). Since age has been used in selecting subjects, it is not amazing that age distribution of subjects corresponds closer with age distribution of adult persons in the vicinity of Schiphol than age distribution of non-respondents.
The effect variables of the three exposure-effect relationships that differ among subjects and non-respondents are:

- Score of being worried about impact of aircraft noise on health;
- Number of adverse aircraft noise effects on sleep per week;
- Prevalence of recognising the own situation as living under a flight path of a large airport.

With respect to the first two variables non-respondents show somewhat larger adverse effects: they are somewhat more worried and experience somewhat more adverse aircraft noise effects on sleep. With respect to prevalence of recognising the own situation as living under a flight path of a large airport, at the higher night-time aircraft noise situations subjects experience a larger adverse effect than non-respondents.

An example of the difference between exposure-effect relationships for subjects and non-respondents is given in figure 5.1.

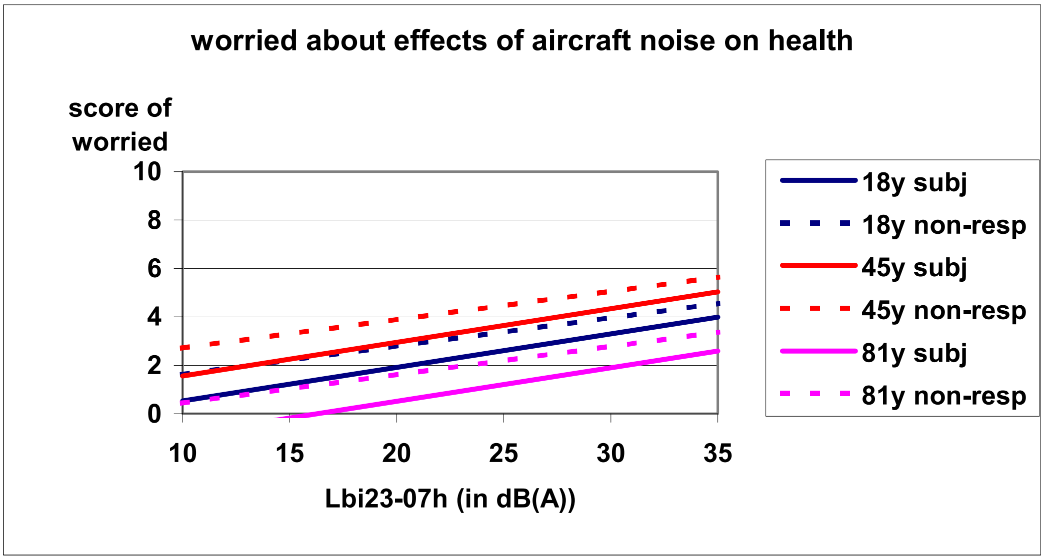



*Figure 5.1: Relationship for subjects and for non-respondents of score of being worried about effects of aircraft noise on health and Lbi23-07h.*

## 5.5 Conclusion

The distribution of age of subjects differs from that of non-respondents. If this difference is taken into account, only three exposure-effect relationships differ somewhat between subjects and non-respondents.

# 6 Discussion and conclusion

## 6.1 Introduction

One of the main aspects of the quality of a study concerns the internal validity and the possibility of generalisation of the results. These items are discussed in sections 6.2 and 6.3. Another important aspect of a study is whether the objectives of the study are met. This is discussed in section 6.4. In section 6.5 conclusions are given.

## 6.2 Validity

### 6.2.1 Introduction

Mainly three aspects are of importance in considering the validity of a study. It concerns selection bias, information bias and confounding of the results. These aspects are discussed in the next sections.

### 6.2.2 Selection bias

To our opinion, exposure-effect relationships are not biased by selective response of subjects, because of the following four reasons:

- Invitations to participate in the study have been sent usually to all addresses at a location. Only at a few of the highest aircraft noise exposed locations all dwellings at some streets have been excluded, because of presumed very high sound insulation of bedrooms after participation of (some of) the dwellings in the acoustic sound insulation program of Schiphol. The only exclusion criteria for subjects has been that he/she did not plan to sleep during each of the study nights in his/her own bedroom, he/she did have to nurse a family member extensively during night-time (this does not include the normal activities of taking care of young children), he/she did start using sleeping pills or other medication/drugs with strong sleep inducing or sleep deepening effects shortly before his/her potential participation in the study. No subject has been excluded for any other reason, such as attitude towards aircraft noise or towards the expansion of Schiphol. Since at nearly each location more than sufficient candidates were interested in participating in the study, subjects have been included on the basis of age, gender, and availibility in one of the two study intervals at a location;
- All subjects that started the study completed it;
- The reward given to subjects was only small in comparison to the tasks required of them. The majority of subjects stated in the evaluation questionnaire that the reward given at the end of their participation had nothing to do with their willingness to participate and with their readiness to complete participation in the study;

- The non-response study showed, apart from age composition, only very few and minor differences between the study and non-response population. Age composition between subjects and non-respondents could be assumed to differ because subjects have been included in the study on the basis of age and no selection based on age was made for non-respondents. With respect to age composition of subjects, we selected as many subjects in the eldest age group as possible, since it is well known that aspects of sleep change with age. (At the end of the study, the percentage of subjects below and over 50 years (respectively 63 and 37%) turned out to be the same as these percentages in the so-called adult study population in the vicinity of Schiphol (about 2 million persons). Within the two age groups, the study population in the vicinity of Schiphol contains more of the youngest persons in the younger age group and more of the eldest persons in the eldest age group. However, since the impact of age is assessed in the exposure-effect relations, age can be taken into account in the estimation of the prevalence of effects in the study population.

### **6.2.3** Information bias

*Emphasis on aircraft noise*
Subjects were well aware of the aim of the study: to assess the effects of night-time aircraft noise on sleep. In the detailed design of the study, however, we tried not to put emphasis on aircraft noise. E.g. subjects have been requested in the morning diary:
- whether they had difficulty to fall asleep,
- whether they did awake in the course of sleep period time,
- what woke them up in the morning,

and if appropriate to select a response possibility. If they selected outdoor noise(s), in an open question it was asked to note which type of outdoor noise(s). Data in TNO report 2001.205 show that in 12 of the nearly 4600 subjects nights subjects noted in the morning diary to have had difficulty to fall asleep because of aircraft noise and 21 times that they had been awakened by aircraft noise at the end of sleep period time. Subjects noted 7172 times to have been awake in the course of sleep, including 159 times (in 151 sleep period times) that the reason for awakening during sleep was aircraft noise. The position of the bedroom window was changed in 121 subject nights. In 13 cases the window was closed because of aircraft noise.
To our opinion, if aircraft noise would have been mentioned explicitely in the various questions, the response rate would have been much higher, also taking into account the willingness of subjects to respond to questions posed to them.

*Measurement of exposure and effect variables*
In the acoustic measurements the same procedures have been followed for each location and each subject. Therefore the same information on noise exposure has been obtained, irrespective of the degree of aircraft noise exposure at a location. Also, in the analyses, the same procedures to assess aircraft noise exposure of subjects has been followed, irrespective of subject and location. The main effect variables, probability of (onset of) motility and level of motility during sleep have been assessed by objective measurements. The analyses showed that motility outcomes are not associated with attitude towards aircraft noise or Schiphol. Although it is not believed that

subjects knew how to manipulate motility outcomes and that they intended to do so on a relevant scale, exposure-effect relationships for motility have not been biased by such possible manipulations.
Therefore we conclude that information bias did not affect the results of the study.

### 6.2.4 Confounding

Confounding can be important, since confounders have a, sometimes not quantifiable, impact on exposure-effect relationships (see section 1.3). In the foregoing chapters, as well as in the Appendices, ample attention has been given to the possible presence of confounding factors. The results for the relationships considered on the three time scales can be summarised as follows:

- Instantaneous effects on probability of (onset of) motility: the four effect-modifiers Li, time of night, time since sleep onset, and age, are each not associated with the aircraft noise event variable Lmax_i. This has been tested by using the effect variable resp_m at 15-s interval e6. Therefore none of these four effect-modifiers are confounders;
- Effects during sleep period time: L50 (median sound level in the sleeping room during sleep outside aircraft noise windows) is somewhat confounding the relationship between mean motility measures (mspt, kspt, rlscspt) and Liaspt (equivalent aircraft sound level during sleep period time). The effect of Liaspt on motility includes about 7% of the effect of L50 on motility;
- With respect to long-term effects: measures of mean motility during sleep, sleep latency time, voegd, voegn and use of sleeping pills are related to Li, and Lbi23-07h nor day-time aircraft noise exposure are confounders of the relationships.
  Lday is a confounder of the relationships between Lbi23-07h and the twelve effect variables from the questionnaire considered in the analyses. These relationships should therefore not be used in situations with a difference between L23-07h and Lday substantial different than observed in this study. In this study Lday – L23-07h ranged from 4 to 17 dB(A) (average value 9.5 dB(A) and standard deviation 3.5 dB(A)). Given this wide range of differences between night- and day-time aircraft noise exposure in the situations studied, these situations cover nearly all situations in the vicinity of Schiphol. Therefore, to our opinion, there is no reason not to use those relationships to estimate the prevalence of effects in the vicinity of Schiphol.

### 6.2.5 Conclusion about validity

To our opinion, the considerations given above show that the results of the study are not impacted by selection or information bias, and that confounding of the exposure-effect relationships by day-time aircraft noise exposure plays only an, insignificant, role in the estimation of the night-time aircraft noise effects with effect variables obtained by questionnaire.

## 6.3 Generalization of results

*Subjects*

The study did not consider the effects of noise on sleep of shift workers, children, and ill persons (including persons in hospitals). The results of this study should therefore not be extrapolated to those populations.

About 20 candidates have been rejected because of their start of using sleeping pills and other medication able to induce sleepiness or increase sleep depth within a period of six weeks before the start of the study at their location. Subjects who used sleeping pills and other medication able to induce sleepiness or increase sleep depth for a longer period of time have been included in the study. The only impact of a longer use of sleeping pills etc. turned out to be on sleep quality: people who use sleeping pills etc. rate their sleep quality lower than non-users.

Thirteen subjects were born outside the Netherlands, among them 11 in Indonesia. Presumably subjects with other nationalities are under-represented in the study because difficulties in communicating in Dutch and different lifestyle and privacy considerations refrained people born in other countries from participating. Subjects born outside the Netherlands did not show adverse aircraft noise-induced effects different from the Netherlands subjects. Therefore we consider the results of the study also applicable to people born outside the Netherlands, who live at present in the vicinity of Schiphol.

*Locations*

The locations selected are a good reflection of situations in the neighbourhood of Schiphol. Locations have been selected based on the following factors:

- Night-time aircraft noise exposure. Locations have been selected with only a few aircraft at night (23 to 6 hours) up to a residential area with the highest night-time aircraft noise exposure in the vicinity of Schiphol. To avoid geographical bias, the two locations with low night-time aircraft noise exposure have been chosen as close as possible to the other locations. This implied that we accepted beforehand the possibility of minor aircraft during sleep of subjects (outside 23 to 6 hours) at these two locations;
- Participation in the second phase of the noise insulation program of Schiphol. In the second phase of this program dwellings are insulated against night-time aircraft noise. The sequence of locations has been chosen such that the field study at a location took place before this phase of the program started at that location. In some instances dwellings of subjects had been insulated in the first phase of the program;
- Degree of urbanisation. Satisfaction with the living environment, health and noise annoyance of residents are among the factors that are related to the degree of urbanisation. Locations have been included from each of the five classes of urbanisation;
- Type of dwelling. In accordance with the type of housing in residential areas with regular planned night-time aircraft, most dwellings are houses in a row and detached houses, but also a few locations with high-rise flats and multi-storey buildings have been included in the study;

- Size of location. Since only one outdoor noise monitor was used in the identification of aircraft noise events, locations have been selected with sufficient addresses in an area of about 500 by 500 m;
- Presence of other night-time noise sources. The GES inventory study from 1996 (TNO and RIVM, 1998) showed that, apart from aircraft noise, local road traffic noise and to a lesser extent railway noise are the main sources of sleep disturbance in the vicinity of Schiphol. Therefore, some locations have been selected with local road traffic or railroad traffic.

*Confounders*
The assessment of confounders resulted in confounding of relationships between Lbi23-07h and effect variables obtained by questionnaire. These relationships should therefore not be used in situations which are not comparable to the situations in the study. In the study Lday – L23-07h ranged from 4 to 17 dB(A) (average value 9.5 dB(A) and standard deviation 3.5 dB(A)). Care should be taken in the extrapolation of long-term questionnaire exposure-effect relationships to airports without or with exceptional night-time aircraft noise (Lday – L23-07h over 17 dB(A)), because effects may be under-estimated by using these relationships with L23-07h as exposure metric.

*Conclusion about generalization of results*
To our opinion, the considerations given above show that the relationships obtained in this study are general applicable with the following limitations. The results of the study should not be extrapolated to the effects of noise on sleep of shift workers, children, and ill persons (including persons in hospitals). Care should be taken in the extrapolation of long-term questionnaire exposure-effect relationships to airports without or with exceptional night-time aircraft noise, because effects may be underestimated by using these relationships with L23-07h as exposure metric.

## 6.4 Objectives of the study

The objectives of the study have been specified in chapter 1:

a. To assess relationships between night-time aircraft noise exposure and measures of sleep disturbance, health and daily functioning. The effect of aircraft noise in the so-called edges of the night (23 to 24 hours and 6 to 7 hours) is of special interest;

b. To provide information on the basis of which the prevalence of effects induced by night-time aircraft in the population in the vicinity of Schiphol can be estimated.

*Exposure-effect relationships*
A wide variety of exposure-effect relationships have been presented in this report at three different time scales. In the Appendices the equations of the relationships have been specified. In addition to these relationships the impact of other variables has been assessed.
The relationships between noise-induced increase in probability of (onset of) motility obtained in the present study have been compared to the relationships obtained in other studies. The present study shows that instantaneous effects of aircraft noise events on (onset of) motility start on

average at aircraft noise event levels Lmax_i of 32 dB(A) and SEL10_i of 38 to 40 dB(A). These 'thresholds' are about 15 dB(A) lower than estimated from the CAA study reported in 1992, carried out with subjects living in the vicinity of airports in UK (Ollerhead et al., 1992). Several factors in the UK study, which are discussed in Appendix G, section G.3.1, have contributed to an under-estimation of the effect on aircraft noise on probability of (onset of) motility.
The study by Fidell et all. (1995) included only subjects who lived at locations close to the run-way ends of two airports. Their results show a reasonable correspondence with the results of the present study for subjects with higher values of Li (individual aircraft noise exposure during sleep).

*Edges of the night*
The effects of aircraft noise between 23 and 24 hours and between 6 and 7 hours have been considered.

With respect to *aircraft noise exposure from 23 to 24 hours*, the following is applicable to the joint situation of the subjects. At about one third of the nights, subjects are asleep before 23 hours. Aircraft between 23 and 24 hours contributes about 3.5 to 4% to a total effect of night-time aircraft noise during the total sleep period time (such as increase in motility, increase in number of marker pressings, increase in number of remembered awakenings due to aircraft noise). For an hour between 24 and 6 hours the percentage of 6 to 6.3% applies. Relevant to the first part of the night is also the finding that aircraft noise during sleep latency time period increases that time period, and increases difficulty to fall asleep and mean motility during sleep.

With respect to *aircraft noise exposure from 6 to 7 hours*, the following observations have been made. From 6 to 7 hours there occurs much more aircraft than in the earlier hours of the night, and about half the nights subjects sleep till after 7 hours. Therefore the contribution of aircraft between 6 and 7 hours to a total effect of night-time aircraft noise is considerable. Aircraft between 6 and 7 hours contributes about 27 to 28% to a total effect of night-time aircraft noise during a sleep period time. This estimate depends on the distribution of aircraft over the night, sleep period times of subjects, and presumably also on the way aircraft approaches and leaves the airport. The estimate therefore may not be applicable to other situations.
If the aircraft noise exposure between 6 and 7 hours of subjects would have been the same as during an hour in the period from 24 to 6 hours, the contribution of aircraft noise between 6 and 7 hours to a total effect would be reduced from 27-28% to 6-6.3%, i.e. a reduction in the total effect of 20-21%, provided that the aircraft noise events would be postponed until all subjects are awake. This reduction in effect would be reached by a reduction in number of aircraft noise events between 6 and 7 hours from 26.6% to 6.0%, i.e. by a reduction with a factor 4. If the aircraft noise events between 6 and 7 hours would be postponed for one hour, then the total effect would be reduced by about 10%.

*Estimation of prevalence of night-time aircraft noise effects in the study population in the vicinity of Schiphol*
In TNO report 2002.028 (written in Dutch) the results of the estimations of prevalences of night-

time aircraft noise induced effects in the population in the vicinity of Schiphol (with over 2.1 million adults) are given. The estimations have been carried out by RIVM on the basis of exposure-effectrelationships provided in this study.

## 6.5 Conclusion

A few results are listed below.

- There is a range of about 30 dB(A) in individual aircraft noise exposure during sleep (Li) in subjects living at the same location. Differences are mainly due to differences in start and end of sleep period times , sound insulation of bedrooms, ventilation of bedroom windows, and position of the bedroom with regard to the flight path of aircraft;
- Individual aircraft noise exposure during sleep (Li) has an important impact on the relationship between Lmax_i and aircraft noise-induced increase in probability of motility;
- The threshold of aircraft noise-induced probability of (onset of) probability is on average an Lmax_i value of 32 dB(A), which is lower than assumed until now;
- Aircraft noise during sleep not only results in increased probability of (onset of) motility during events, but the exposure also induces on a long-term basis a higher level of mean motility. The long-term increase in mean motility increases with individual aircraft noise exposure during sleep (Li). It is unknown whether this long-term component is permanent, or whether it is temporary and will vanish in a period of time after night-time aircraft noise exposure of a subject has ended;
- Aircraft noise during sleep increases number of behavioural awakenings and number of remembered awakenings due to aircraft noise;
- People consider it more difficult to fall asleep when exposed to aircraft noise during sleep latency time. Duration of sleep latency time is also longer at higher equivalent aircraft sound levels during that period;
- In this study, aircraft noise during sleep has only a weak effect on sleep quality, assessed by questionnaire and no effect on sleep quality assessed by morning diary;
- In this study, aircraft noise during sleep only has a slight effect on sleepiness in the morning (10 hours), and no effect later during day and evening, as evaluated by subjects through a sleepiness strip;
- In this study, aircraft noise exposure during sleep period time does not have an effect on the results of a reaction time test, performed at the end of the evening after the sleep period time;
- Age is an important determinant and effect-modifier of many aspects of sleep and many exposure-effect relationships;
- In this study a moderate to strong relationship between aircraft noise exposure during sleep and mean motility measures has been found;
- Motility and a variety of long-term variables obtained from the questionnaire and aggregated effect variables obtained from the diaries are associated. These variables are: number of times remembered to have been awake during sleep, number of marker pressings during sleep, use of sleeping pills (effective to induce sleepinessand/or increase sleep depth), self-

reported sleep quality from the questionnaire, number of general sleep complaints, frequency of times awake due to aircraft noise, number of aircraft noise-induced adverse effects a week, and number of health complaints;

- In this study number of health complaints increase with individual aircraft noise exposure during sleep (Li), but is not related to Lbi23-07h, a location specific aircraft noise metric limited to 23 to 7 hours.

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# Appendix A Instrumentation, initial data handling and tables with variables

## A.1 Instrumentation

### A.1.1 Noise measurements

*Noise monitors*
The acoustical part of the study encompasses identification and quantification of aircraft noise events inside bedrooms. Especially the discrimination between aircraft noise events and other noise events is essential in this study.
The selection of measurement equipment resulted from the pilot-study. The measurement equipment consists of:
- 1 outdoor monitoring system (Larson & Davis Sound Level Meter, model 870), including wind direction, wind speed and precipitation monitoring;
- 14 indoor monitoring systems (Larson & Davis Sound Level Meter, model 820).

The outdoor monitoring system can transmit data to a host system by means of (wireless) telephone communication. The outdoor monitoring station also has the possibility to record noise events on a Sony minidisk. This device can record up to maximal 255 records or maximal 74 minutes, and is controlled by a triggering facility in the Larson & Davis Sound Level Meter, model 870.

In contrast to the pilot study we decided to store the full time history of the noise level assessed on each of the noise monitors. With a recording time from 22 to 9 hours, the time history, in terms of the one-second time-average sound pressure level (LAeq1s), could be stored for a six-night period. Storing of noise data in the computer in a six day period was compatible with the interval necessary for collecting data from the actimeters.

At every installation, the out- and indoor noise monitors have been calibrated with an acoustic calibrator (B&K 4231). Over the entire survey no changes in sensitivity of more than 0.1 dB have been observed.

A very important aspect in the acoustical measurements was a precise time synchronisation of the various noise monitors, since the clock-time of events is an important aspect in the identification of aircraft noise events by comparison with the event times of the Fanomos-system. Therefore, at each time a noise monitor was connected to the host system (installation and data-collection), the clock in the monitor was updated from a radio-controlled clock in the host system. Connection of the outdoor noise monitor with the host system usually was during each workday the equipment was operating, and connection of the indoor noise monitors three times during a measuring interval including eleven nights. Over the entire survey no irregularities in the time registration were observed (accuracies ± 2s).

*Location of outdoor noise monitor*
The outdoor monitor was installed at a location more or less in the middle of the area the dwellings of subjects were located. The outdoor microphone was positioned at approximately 5 m height, in such a way that there were no major influences of the buildings in the vicinity of the microphone on the noise level (no major reflections, no major screening of parts of the flight tracks). The necessity to avoid vandalism was also one of the aspects in the selection of the location of the outdoor monitor. In most cases it was installed in the backyard of one of the subjects that could keep an eye on the equipment.

*Location of indoor noise monitors*
The indoor monitors were situated in the bedrooms of the subjects. The microphone with windscreen was positioned on a tripoid at about 1 m height (i.e. approximately the height of the ears of a sleeping subject). The location was chosen not very close to the bed, to avoid the inclusion of snoring and breathing in the noise signal, on similar positions with respect to the window(s) as the sleeping subjects. Also practical considerations like power supply and specific wishes of the subjects played a role in the location of the indoor noise monitors.

### A.1.2 Actimeters

CNT (Cambridge Neurotechnology Ltd, UK) actimeters, type AW4, with event marker have been used in the study, with the detection interval chosen as 15 s. When in use, an actimeter stores at the end of each 15-s interval a value in a solid-state memory. For the older type used, the solid-state memory of an actimeter is full in somewhat over five 24 hours periods and for the newest type in about nine 24 hours periods. The data are read out in a personal computer for analysis. The agreement between sleep-wake classification using CNT actimeters versus traditional PSG is similar to results obtained with comparable modern actimeters (Babin et al., 1997). The event marker gives the wearer of the actimeter the possibility to record a point in time by pressing the marker. The time at the end of the 15-s interval the marker is pressed is stored in the memory of the actimeter. Subjects have been requested:

- to press the marker twice when they intend to go to sleep and when they awake in the morning with the intention not to fall asleep again;
- to press the marker once whenever they wake up during their sleep.

During the participation of subjects in the field study, actimeters have been read out three times in 11 24 hours periods, which implies a period between read outs of 3 to 4.5 24 hours. Each time before activating an actimeter, the time has been adjusted by means of a radio-controlled clock or precision watch. For a correct coupling of times of the actimeters to times of the noise monitors, it is required that time synchronisations of actimeters and noise monitors meet certain requirements. Time synchronisation of actimeters has been checked in three laboratory experiments in the course of the field investigation. At the start of an experiment the clock times of the actimeters have been adjusted by regulating them according to the time of the radio-controlled clock or precision watch. Then, actimeters were initiated, their markers pressed and each time of pressing the marker according to the time of the radio-controlled clock or precision watch noted down (in s). After at least 5 24 hours the markers have been pressed again and the time of pressing noted down again. Then, the difference in actual time (from the radio-controlled clock or precision watch) has been compared with the difference in marker pressing times stored in the actimeters (at the end of 15-s intervals) and the average duration of a 15-s interval calculated. The total number of actimeter tests was 79. The mean interval time appeared to be 14.9998 s with a standard deviation of 0.0004 s. This standard deviation includes a contribution of the inaccuracy of the marker pressing times which are stored in 15-s intervals. (This implies that real time and stored time can differ up to 15 s). The contribution of the inaccuracy of the marker pressing time registrations to the standard deviation of 0.004 is estimated to be about 0.0002 s. For those actimeters tested two or three times, the correlation between calculated interval times appeared to be low. The results imply that the difference between real time and the time of an actimeter at the end of a 15-s interval is, at the end of an operation time of 4.5 24 hours periods (maximal period between read out of the actimeters), –15 to +10 s (95% confidence intervals). This is considered to be well within the requirements of the study.

At a request of TNO, CNT developed a calibrator checker at the start of the main study. Calibration checks have been performed on a regular basis to see whether the calibration was within the required limits (indicated by the calibration checker). If not, the actimeter was returned to CNT, and adjusted or replaced by another actimeter. An actimeter was also returned to CNT in case of malfunctioning (e.g. when after change of batteries the actimeter did not function properly). All in all 35 actimeters have been used in the course of the study.

In the course of the field study the operation of the actimeters has been studied five times in co-operation with TNO Bouw. To perform tests on the actimeters, a standardised vibrator was used. During tests each of the available actimeters was placed on the vibrator and checks performed. During a test the vibrator moved for at least 4 minutes with a forced sinusoidal acceleration with frequencies 3 and 6 Hz and effective acceleration levels of 1.0 and 1.5 $g/m^{-2}$. The test was repeated on the same day, usually with the vibrator moving with frequency 3 Hz and effective acceleration level of 1.0 $g/m^{-2}$. The output values 'score' (at the end of the 15-s intervals, which implies for a measurement time of at least 4 minutes at least 16 values of score) of each test have been stored in a SPSS data base and analysed. Test retest results on the same day turned out to be perfect: correlation coefficients of over 0.99 were always obtained. The response at 3 Hz turned out to be larger by a factor 5 to 10 than the response at 6 Hz: actimeters do not have a flat spectrum.

Paired test results at 3 Hz and at 6 Hz at effective acceleration levels of 1.0 and of 1.5 $g/m^{-2}$ have been obtained. The average value of score at 3 Hz and an effective acceleration level of 1.0 $g/m^{-2}$ has been compared with the average value of score at 3 Hz and 1.5 $g/m^{-2}$. It turned out that the average value at 1.5 $g/m^{-2}$ was on average 1.485 times the average value at 1.0 $g/m^{-2}$. For the frequency 6 Hz this factor appeared to be 1.43. This implies that if effective acceleration increases with a factor x, score increases with about the same factor: score is a quantity on an interval level.

The test results between the first and last test showed, for those actimeters available at both tests, that the change in score under standardised conditions over a year was in all cases between –3%

and +7%. This implies that a possible slow change in score in the course of the 11 24 hour periods during the participation of a subject in the field study is in the order of –0.1 to +0.2%. This is considered irrelevant for the present study.

### A.1.3 Computerised evening and morning diary

The questions of the evening and morning diaries have been submitted to the subjects through a personal computer. The answers have been stored after completion of the questions and read out by TNO during three visits to the subjects. The English translations of the evening and morning diaries have been given in TNO report 2001.205.

### A.1.4 Computerised reaction time test

The reaction time test (adapted from Wilkinson, 1979) have been carried out on the personal computer by subjects as follows. A figure (three little stars) appears on the screen after which the subject has to press the space bar of the keyboard as soon as possible. After pressing the space bar, the figure remains on the screen for 1.5 s, disappears and is again shown on the screen with a random time lapse of 1 to 10 s. The figure is shown 90 times and the duration of the test is about 10 minutes. If the reaction to an assumed appearance of the figure is earlier than the actual time of appearance, the reaction is counted as a mistake. The reaction times are stored in the computer. The following five measures have been used for the analyses: median reaction times over all 90 trials and over the last 45 trials, reaction times exceeded in 10% of all and in 10% of the last 45 trials, number of mistakes over all trials. The average reaction time was shown on the screen to the subjects at the end of a test.

### A.1.5 Sleepiness strip

The sleepiness strip has been filled out by a subject five times a day during 10 days, starting on Tuesday morning. Subjects wore a watch that produces a noise signal at the times (10, 12.30, 15, 17.30 and 20 hours) the sleepiness strip had to be filled out. The subjects have been requested to indicate by a number from 1 to 9 how sleepy he or she feels at that moment (1 = not sleepy at all and 9 = extremely sleepy). The scoring of sleepiness during time awake has been adapted from Reyner (1995).

### A.1.6 Questionnaire

#### A.1.6.1 Weinstein noise sensitivity list

The list contains 21 statements which the subject rates. A subject has the possibility to rate each statement with 1 to 6, from fully agree to fully disagree. To assess noise sensitivity 13 of the 21 questions have to be re-rated. These questions are: 2, 4, 5, 6, 7, 10, 11, 13, 16, 17, 18, 19, and 21. After re-rating the responses to these 13 questions, the 21 rates are added and divided by 12.6

(21*6/10). This results in a score from 1 to 10, with score equal to 1 ‘very insensitive to noise’ and score equal to 10 ‘very noise sensitive’.

### A.1.6.2 Utrecht Coping List (UCL)

The Utrechtse Coping Lijst (Utrecht Coping List, UCL: Coping with problems and events) concerns coping with problems and events. The full list contains 47 questions about the way how to handle problems. Each item has to be rated on a 4-points scale, representing the frequency with which the subject reacts in the way concerned, when facing a difficult situation.
Seven scales can be distinguished:

- Active approach: looking at the problem from all sides, trying to solve the problem in a focused way and with confidence;
- Palliative reaction: looking for distraction, keeping busy with other matters so that one does not have to think of the problem. Trying to feel better by smoking, drinking or relaxing;
- Avoiding: letting things drift, avoid the situation or wait what is going to happen;
- Seeking social support: looking for comfort and comprehension from others, telling the problems to someone, or asking for help;
- Passive reaction (laisser faire) pattern: completely being absorbed by the problem and situation, being pessimistic, withdrawing while worrying, worrying about the past;
- Expressing emotions: showing irritation, anger, working off tensions;
- Having reassuring and comforting thoughts: reassuring oneself by thinking things will get better.

In the study a shortened version of the UCL has been used with 15 items. With this shortened version three characterisations could be used in the study and they have been coded as follows:
Score_active approach: (stel4 + stel6 + stel8 + stel9 + stel11)/5.
Score_seeking social support: (stel3 + stel10 + stel13 + stel14 + stel15)/5.
Score_laisser faire (stel1 + stel2 + stel5 + stel7 + stel12)/5.

## A.2 Initial data handling

### A.2.1 Introduction

In the course of the study, data have been collected by a variety of methods. These methods and related instrumentation used has been specified in section A.1 of this Appendix. The raw data have been first checked for correctness and completeness, and have then been manipulated to obtain appropriate data for the assessment of exposure-effect relationships. The labels and the description of resulting variables are given in table A1 and A2 in section A.3.
Table A1 presents variables obtained from data on subjects: from actimetry, morning and evening diary, sleepiness strip, reaction time test, and questionnaire. Most labels have been translated from Dutch. No attempt has been made, however, to translate labels of variables that have not been mentioned elsewhere in the report. Table A2 gives an overview over (aircraft) noise exposure metrics used in the analyses.

For key variables, their assessment from the raw data is given in section A.2.2.

### A.2.2 Specification of variables

*Sleep latency time*
Sleep latency time is the period the subject tries to try to fall asleep. The subject is supposed to press the marker twice at the time he/she decides to go to sleep (start of sleep latency time). In the morning diary the subject indicates at what time he/she started to try to go to sleep. It is also asked whether he/she pressed the marker at that time and if so whether it was at the right time, too early (if yes how many minutes too early), or too late (if yes, how many minutes too late). If the marker has been pressed, the (corrected) time of pressing has been compared to the time the subject indicated in the morning diary as start of sleep latency time. If these times are within 10 minutes, the (corrected) time the marker has been pressed is taken as time the subject started to try to fall asleep. If thetwo times differ by more than 10 minutes, the actigram has been visually inspected and a decision about the start of sleep latency time has been taken. In such a decision, the activity level of a subject around the presumed start of sleep latency time and the fact that subject is awake while pressing the marker are taken into account. If the marker has not been pressed, the start of sleep latency time indicated by the subject in the morning diary is taken as the actual start, unless a comparison with the actigrams of other nights shows that a subject is still relatively too active to assume the start of sleep latency time. In these exceptional cases, start of sleep latency time is, based on the actigram, set at a later time and only used in the procedure to assess sleep onset time. The information is, in these cases, not used to assess duration of sleep latency time.

*Sleep period time*
Sleep period time of a subject during a specific night is assessed by first automatically analysing the actimetric test signal from the start of sleep latency time. By convention, sleep onset time is taken as the middle of the first period of 10 minutes without motility with score over 10. Then, wake-up time is assessed by comparing the time the event marker is pressed in the morning with the wake-up time mentioned by the subject in the morning diary. If these times are within 10 minutes, the earlier time minus 5 minutes is chosen as wake-up time. If the difference is larger than 10 minutes, a visual inspection of the actimeter signal is undertaken and based on this inspection a decision is taken about wake-up time. In difficult cases, the time the morning diary was filled in (stored automatically in the laptop of the subject) has been taken into account and the method the subject stated to have been awakened. Thus, sleep period time of the subject during a specific night is assessed as the period between sleep onset time and wake-up time. All sleep period times have been visually inspected from figures produced on the computer screen and in rare cases (usually when event marker pressing in the morning and wake-up time in the morning diary differed less than 10 minutes) the sleep period time has been adapted.

*Classification of sleeping pills and drugs effective to increase sleep depth and sleepiness*
The classification has been used:

- in the selection of subjects. Candidates for participation have not been included in the study, if they, at the time they showed interest in participating in the study, recently (within six weeks) started using specific types of sleeping pills, tranquilizers, or other drugs . Which sleeping pills, tranquilizers, and drugs will be specified below;
- in the analyses of questionnaire data. Subjects indicated in the questionnaire which type (including trade mark) of sleeping pills or tranquilizers they used;
- in the analyses of data obtained by diaries. Subjects indicated in the morning diary which type (including trade mark) of sleeping pills, tranquilizers, drugs, and common and garden means they used last night and evening.

To classify sleeping pills, tranquilizers, or other drugs effective in increasing sleep depth and/or inducing sleepiness, use has been made of ‘Farmacotherapeutisch Kompas 1999’ (Van der Kuy, 1999). In a section of this publication sleeping pills (hypnotics, I/A) and tranquilizers (anxiolytica, I/C) are discussed. Of main importance are the benzodiazepines, since the only other relevant type of medication (barbiturates) are at present hardly ever used by patients outside hospitals etc. in the Netherlands. The effectiveness of benzodiazepines to induce (deep) sleep is usually decreasing in the course of time after the patient uses the medication. Already some weeks after the start of the use of benzodiazepines, the effectiveness to induce sleep is significantly reduced. For this reason, only candidates have been excluded from participation that started using sleeping pills or tranquilizers less than six weeks before the start of the study at a location.

Benzodiazepines are on the market with different trade marks and user names. The Farmacotherapeutisch Kompas 1999 lists trade marks and user names of sleeping pills and tranquilizers, at present allowed on the Netherlands market. Tables consulted are on page 60 and 73 of the Farmacotherapeutisch Kompas 1999. Classification of each type of sleeping pill, tranquilizer or other drug used by subjects or candidates occurred by dr S.A. Reijneveld, physician and epidemiologist, member of the Management Team of the project.

Apart from sleeping pills and tranquilizers, also some other medication is able to induce sleepiness. Examples are opiates (used to reduce pain) and antihistaminica (used e.g in case of allergy and COPD). Subjects noted in the evening diary if they used any medication during day and evening-time, and if so what type (user name, trade mark) of medication.

*Processing of noise data*

The raw data (noise versus time registrations in combination with Fanomos data) have been processed in order to identify and quantify aircraft noise events. A program was developed to link the noise data obtained with the out- and indoor noise monitors to the Fanomos data. The Fanomos data include for each measuring night (from 22 hours in the evening to 9 hours next morning) a calculated value of the maximal sound level (Lmax_f) of each aircraft and the time the aircraft is at closest distance (slant range) to the outdoor noise monitor. The Fanomos time of an aircraft noise event has been used to set a time-window, from 20 seconds before to 20 seconds after that time, in which the indoor aircraft noise events are assumed to occur. The maximum of the one second time-average sound pressure levels within this window ($L_{max}$), and its clock-time, is then attached to this window. These times are compared with the sleep period times and sleep latency time periods of a subject, and only windows within these time periods have been processed.

The indoor clock-time of $L_{max}$ in a 40 s window has been used to calculate the durations between the 5, 10, 15 and 20 dB-down points and the corresponding SEL values over these durations. Figure A1 (at the end of this section) gives a graphical presentation of the procedure.

This part of the program produces raw $L_{max}$ and SEL values. The second part of the program determines which data are ‘reliable’. Selection criteria have been developed to determine whether an aircraft noise event has been captured in a window and which SEL values of an aircraft noise event are reliable. The set of criteria has been developed on an empirical basis, starting from the characteristics of aircraft noise events on the outdoor monitor, on which aircraft noise events are clearly recognisable and hardly disturbed by other noises, also because it concerns aircraft noise events during the night. The criteria have been optimalised for all locations; they are applied to give an optimal succession of aircraft noise events that have been reliably quantified. The assessment of reliable aircraft noise event data contains the following steps.

Step 1. If a SEL-value has been determined over a period larger than 60 seconds before and/or 60 seconds after the time of $L_{max}$ in a time window, the value has been rejected. It is assumed that the event has not significantly emerged from the background to assess SEL properly or the time window did not include the aircraft noise event, because the actual time at which the maximal sound level of an aircraft noise event occurred was outside the window because it differed more than 20 s with the Fanomos clock-time of an aircraft noise event.

Step 2. The following criterion, empirically developed from the data at the first locations, has been applied to assess whether a SEL value is reliable :

$$L_{max} + 7 < SEL \leq L_{max} + 13 \text{ (dB(A))}$$

In fact, this selection criterion is based on the typical duration and time characteristics of aircraft noise events at the measurement locations, the time scale of the aircraft noise event being in the order of one minute. Ambient noises like cars passing by, barking dog, etc., have a shorter duration and have therefore been rejected by this selection criterion (the difference between $L_{max}$ and SEL is less than 7 dB(A)). On the other hand, the selection criterion serves as a filter for an aircraft noise event which has been ‘polluted’ by other noises in the time window, such as snoring and children crying.

Step 3. If none of the SEL values proved to be reliable, the procedure could not detect an aircraft noise event in the time window, and the data have been excluded from further analyses in which aircraft noise events have been used. If, after step 2, the SEL5-value appeared to be the only value which is not rejected, then the duration between the 5 dB down points should be longer than 15s for the event considered to be an aircraft noise event. If not, the emergence of the event is considered too low to be a recognisable aircraft noise event. The remaining time windows are assumed to include an unpolluted aircraft noise event and Lmax_i and SELx_i values have been assigned to these aircraft noise events.

SEL5_i proved to be very sensitive to small variations in aircraft noise levels itself as well as to background noise, because sometimes emergence was below 10 dB. SEL20_i could rarely be determined, because the emergence of the event above background was usually less than 20 dB(A). Consequently, SEL10_i and SEL15_i are the better results to quantify aircraft noise events. In the study SEL10_i has been used as indoor aircraft noise event metric (see Appendix B). Also, for each aircraft noise event detected on an indoor noise monitor, the corresponding values of the outdoor aircraft noise metrics have been assessed.

Step 4. The final output of the program is a list of all values within sleep latency times and sleep period times of each subject per aircraft noise event per position, with the unreliable values flagged. Another list has been provided with the best available reliable values per aircraft noise event per position.

*Quality of noise data*
Taking into consideration the identification on the basis of the Fanomos clock-time in combination with a filtering on the basis of aircraft noisecharacteristics, the quality of data of the aircraft noise events measured in- and outdoors is to our opinion excellent and no “false” aircraft noise events have been included in the database.

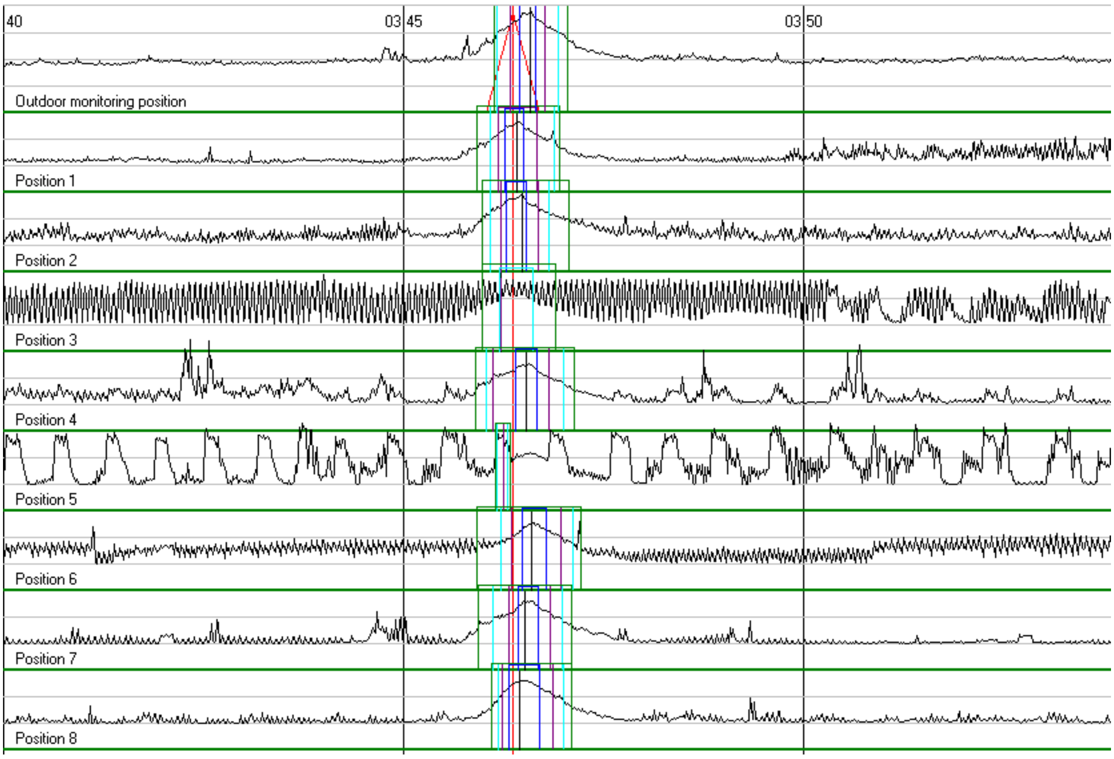


*Figure A1: A graphical presentation of an aircraft noise event, measured on 8 noise monitors. Upper curve: outdoor noise monitor, lower 7 curves: indoor noise monitors. Position 3 shows the effect of heavy snoring on the sound level in the bedroom. Time interval between vertical lines: 5 minutes.*

## A.3 Description of variables

*Table A1 Effect and intervening variables.*

| | Label of variable | Description variable |
|---|---|---|
| General | actonr | Number of subject (311001 – 452418) |
| General | loc | Location (31 – 45) |
| General | interval | Measuring period at a location consisting of 11 consecutive days and nights (311 – 452) |
| General | exp_nair | Location classified according to presumed night-time aircraft noise exposure (1= yes: 13 locations, 2= no: location 40 and 44) |
| General | night | Number of night of participation (1 – 11) |
| General | slp | Sleep period time (in s) |
| General | sleep_start | Time at which a subject falls asleep according to the actigram |
| General | slt | Sleep latency time: period (in minutes) between sleep onset time and the time subject starts to try to fall asleep |
| General | resp_m(L, et) | The difference between the two functions $p_m$(L, et)and exp_m(L, et) |
| General | resp_k(L, et) | The difference between the two functions $p_k$(L, et)and exp_k(L, et) |
| General | resp_rlsc(L, et) | The difference between the two functions relscore(L, et)and exp_rlsc(L, et) |
| Instantaneous | x | Number of 15-s interval after sleep onset time |
| Instantaneous | score | Value of the actimeter output at the end of a 15-s interval |
| Instantaneous | m | Motility (dichotomy: m=1 motility, m=0 no motility) |
| Instantaneous | k | Onset motility (dichotomy k=1 if m=1 and m=0 in preceding interval; k=0 otherwise) |
| Instantaneous | relscore | Motility level at a 15-s interval: score/score50 with score50 the median value of all score values > 0 of a subject during all sleep period times |
| Instantaneous | aircraft noise window | Twenty 15-s intervals during the period of an aircraft noise event with the maximal indoor sound level at the sixth 15-s interval (e6) |
| Instantaneous | other noise window | Period of at least twenty 15-s intervals with the first (or only) ‘other noisy event’ at the sixth interval and the last ‘other noisy event’ 14 intervals before the last noisy interval |
| Instantaneous | e1 … e20 | Twenty consecutive 15-s intervals during an aircraft noise window, starting with e1 |
| Instantaneous | isolated aircraft noise event | An aircraft noise event for which there is no overlap at its 15-s intervals e4 to e11 with e4 to e11 of any other aircraft noise event |
| Instantaneous | exp_m | The expected value of probability of m during a 15-s interval of sleep period time in the absence of aircraft noise |
| Instantaneous | exp_k | The expected value of probability of k during a 15-s interval of sleep period time in the absence of aircraft noise |
| Instantaneous | exp_rlsc | The expected value of relscore during a 15-s interval of sleep period time in the absence of aircraft noise |
| Instantaneous | marker_x | 15 s interval the marker was pressed during sleep period time |
| Instantaneous | instant_sensi | Individual instantaneous aircraft noise sensitivity indicator |
| 24 hours | mspt | Mean value of m during sleep period time |
| 24 hours | kspt | Mean value of k during sleep period time |
| 24 hours | rlscspt | Mean value of relscore during sleep period time |
| 24 hours | fragm | Fragmentation index obtained from the actigram during sleep period time: percentage of movement periods of at most 1 minute related to all movement periods |

| | | |
|---|---|---|
| 24 hours | nmark | Number of marker pressings during a sleep period time |
| 24 hours | strip1_bn | Sleepiness at 10 hours before a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | strip2_bn | Sleepiness at 12.30 hours before a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | strip3_bn | Sleepiness at 15 hours before a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | strip4_bn | Sleepiness at 17.30 hours before a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | strip5_bn | Sleepiness at 20 hours before a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | sleep_ev | Sleepiness at the end of the evening (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | strip1_an | Sleepiness at 10 hours after a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | strip2_an | Sleepiness at 12.30 hours after a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | strip3_an | Sleepiness at 15 hours after a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | strip4_an | Sleepiness at 17.30 hours after a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | strip5_an | Sleepiness at 20 hours after a sleep period time (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | duurdut | Duration naps during day- and evening-time in minutes |
| 24 hours | bijzpos | Very positive experience during day or evening-time |
| 24 hours | bijzneg | Very negative experience during day or evening-time |
| 24 hours | hinddag | Noise annoyance score for day-time (11 points scale, 0 not at all – 10 very much) |
| 24 hours | hindav | Noise annoyance score for evening-time (11 points scale, 0 not at all – 10 very much) |
| 24 hours | day_worries | Serious worries during day-time (5 classes) |
| 24 hours | gedaanav | Activities during the evening (coded: more than one of 15 possibilities) |
| 24 hours | times_smoked_ev | Number of times smoked after 17 hours |
| 24 hours | coffee_ev | Number of cups of coffee after 17 hours |
| 24 hours | alcohol_ev | Number of glasses of alcoholic beverages after 17 hours |
| 24 hours | med_ev_cl | Effect of drug/medication used during the day and/or evening on sleep (0 no effect, 4 important effect) |
| 24 hours | sleep_mor | Sleepiness 15 minutes after awakening (9 points scale, 1 not at all – 9 very sleepy) |
| 24 hours | medsl_cl | Effect of drug/medication used during the night on sleep (0 no effect, 4 important effect) |
| 24 hours | slesl_cl | Effect of sleeping pill on sleep (0 no effect, 4 important effect) |
| 24 hours | sleepeff | Use of effective sleeping pills or drugs, obtained from evening and morning diary and questionnaire |
| 24 hours | in_sleep | Difficulty to fall asleep last night (11 points scale, 0 not difficult at all, 10 very difficult) |
| 24 hours | reason_in | Reasons for difficulty to fall asleep (0 irrelevant, 8 aircraft noises) |
| 24 hours | reason_cl | Reason for difficulty to fall asleep (1 reason specified, 0 irrelevant or reason not specified) |
| 24 hours | reason_ac | Aircraft noise reason for difficulty to fall asleep (1 reason aircraft noise, 0 irrelevant, and other reason specified) |
| 24 hours | oordop | Use of hearing protection (1 no, 2,3 yes) |

| | | |
|---|---|---|
| 24 hours | slpkw_10 | Sleep quality (11 points scale, 0 very bad, 10 very good), assessed in the morning diary |
| 24 hours | nremembered | Number of remembered awakenings during a sleep period time, obtained from the morning diary |
| 24 hours | redenwak | Reason for awakening during sleep period time (0 irrelevant, 9 aircraft noise) |
| 24 hours | wakvlieg | Aircraft noise reason for awakening during sleep period time (0 other reason, irrelevant, 1 aircraft noise) |
| 24 hours | wakhoe | Awakening in the morning (1 spontaneous, 5 aircraft noise) |
| 24 hours | vliegmor | Awakening in the morning by aircraft noise (0 not by aircraft noise,1 by aircraft noise) |
| 24 hours | redenop | Reason for getting out of bed |
| 24 hours | slpkw_05 | Sleep quality from the morning diary (5 points scale, 1 very good, 5 very bad) |
| 24 hours | stand | Position of bedroom window before going to sleep (1 fully closed, 5 fully opened) |
| 24 hours | verander | Change of position of bedroom window during sleep period time |
| 24 hours | fouten_bn | Number of mistakes made during a reaction test before a sleep period time |
| 24 hours | p10l90_bn | 10-th percentile of 90 reaction times during a test before a sleep period time |
| 24 hours | gem90_bn | Median value of 90 reaction times during a test before a sleep period time |
| 24 hours | p10l45_bn | 10-th percentile of the last 45 reaction times during a test before a sleep period time |
| 24 hours | gem45_bn | Median value of the last 45 reaction times during a test before a sleep period time |
| 24 hours | fouten_an | Number of mistakes made during a reaction test after a sleep period time |
| 24 hours | p10l90_an | 10-th percentile of 90 reaction times during a test after a sleep period time |
| 24 hours | gem90_an | Median value of 90 reaction times during a test after a sleep period time |
| 24 hours | p10l45_an | 10-th percentile of the last 45 reaction times during a test after a sleep period time |
| 24 hours | gem45_an | Median value of the last 45 reaction times during a test after a sleep period time |
| questionnaire | a1 | Gender (1 male, 2 female) |
| questionnaire | a2 | Age in years |
| questionnaire | a3 | Citizenship (1 married or living together, 2 single) |
| questionnaire | a4k | Size of household (2 classes, one person 1, more than one person 2) |
| questionnaire | a5k | Number of children in the household |
| questionnaire | a6k | Country of birth (Netherlands 1, outside Netherlands 2) |
| questionnaire | a7k | Level of education (5 classes, 1 none, 4, university, 5 different, set at missing) |
| questionnaire | a8k | Type of daily activity (4 classes, 1 job, 2 retired, 3 studying, 4 different) |
| questionnaire | a9 | Work shift at night (1 yes, 2/3 no) |
| questionnaire | a10 | Daytime exposure aircraft noise (11 points scale, 0 not at all, 10 very much) |
| questionnaire | a11k | Daily noise exposure at work (4 classes, >4 h 1, not 4) |
| questionnaire | a12 | Annoyance due to noises (11 points scale,0 not at all, 10 very much) |
| questionnaire | huistevr | Satisfaction with dwelling/house (5 points scale, 1 very satisfied, 5 very unsatisfied) |
| questionnaire | omgtevr | Satisfaction with living environment (5 points scale, 1 very satisfied, 5 very unsatisfied) |
| questionnaire | buurtj | Number of years living in present neighbourhood (5 classes, <1 y 1, >25 y 5) |
| questionnaire | huisj | Number of years living in present dwelling/house (5 classes, <1 y 1, >25 y 5) |
| questionnaire | b3k | Type of dwelling (4 classes, house in a row 1, different 4) |
| questionnaire | huurkoop | House bought or rented (1 rented, 2 bought, 3 else) |
| questionnaire | huisjaar | Year house has been built (1 before 1980, 2 1980 or later) |
| questionnaire | insolsl | Double glazing bedroom window (1 yes, 0 no) |
| questionnaire | b7a | Insulation program (1/2/3/4/ type of program, 5 no program) |
| questionnaire | b8 | Satisfaction insulation against outdoor noise (11 points scale, 0 very dissatisfied, 10 |

| | | |
|---|---|---|
| | | very satisfied) |
| questionnaire | b9 | Satisfaction insulation against neighbour noise (11 points scale, 0 very dissatisfied, 10 very satisfied) |
| questionnaire | ventilation | Ventilation of house (5 points scale, 5 much more often, 0 never) |
| questionnaire | c1a | Perception road traffic noise (5 points scale, 1 each day, 5 never) |
| questionnaire | c1b | Perception aircraft noise (5 points scale, 1 each day, 5 never) |
| questionnaire | c1c | Perception industrial noise (5 points scale, 1 each day, 5 never) |
| questionnaire | c1d | Perception construction/demolition noise (5 points scale, 1 each day, 5 never) |
| questionnaire | c2a | Annoyance road traffic noise (11 points scale,0 not at all, 10 very much) |
| questionnaire | c2b | Annoyance aircraft noise (11 points scale,0 not at all, 10 very much) |
| questionnaire | c2c | Annoyance industrial noise (11 points scale,0 not at all, 10 very much) |
| questionnaire | c2d | Annoyance construction/demolition noise (11 points scale,0 not at all, 10 very much) |
| questionnaire | d1a | Perception night-time road traffic noise (5 points scale, 1 (nearly) each night, 5 never) |
| questionnaire | d1b | Perception night-time aircraft noise (5 points scale, 1 (nearly) each night, 5 never) |
| questionnaire | d1c | Perception night-time industrial noise (5 points scale, 1 (nearly) each night, 5 never) |
| questionnaire | d1d | Perception night-time construction/demolition noise (5 points scale, 1 (nearly) each night, 5 never) |
| questionnaire | d2a | Awakening by night-time road traffic noise (5 points scale, 1 (nearly) each night, 5 never) |
| questionnaire | d2b | Awakening by night-time aircraft noise (5 points scale, 1 (nearly) each night, 5 never) |
| questionnaire | d2c | Awakening by night-time industrial noise (5 points scale, 1 (nearly) each night, 5 never) |
| questionnaire | d2d | Awakening by night-time construction/demolition noise (5 points scale, 1 (nearly) each night, 5 never) |
| questionnaire | d3a | Annoyance night-time road traffic noise (11 points scale,0 not at all, 10 very much) |
| questionnaire | d3b | Annoyance night-time aircraft noise (11 points scale,0 not at all, 10 very much) |
| questionnaire | d3c | Annoyance night-time industrial noise (11 points scale,0 not at all, 10 very much) |
| questionnaire | d3d | Annoyance night-time construction/demolition noise (11 points scale,0 not at all, 10 very much) |
| questionnaire | d4_sum | Number of night-time indoor noises perceived |
| questionnaire | d5_sum | Number of awakenings by night-time indoor noises |
| questionnaire | d6_sum | Total annoyance score of night-time indoor noises |
| questionnaire | e1_3n | Safety: recognising own situation as living under a flight path |
| questionnaire | e1_6n | Safety: recognising own situation as living at a busy street |
| questionnaire | e1_7n | Safety: recognising own situation as living in the vicinity of a large airport |
| questionnaire | e_3 | Worries about living under a flight path (0 – 10) |
| questionnaire | e_6 | Worries about living at a busy street (0 – 10) |
| questionnaire | e_7 | Worries about living in the vicinity of a large airport (0 – 10) |
| questionnaire | wonen | Safety: recognising other situations |
| questionnaire | oord_wn | Worries about living at other situations |
| questionnaire | f1 | Use of aircraft from and to Schiphol |
| questionnaire | f2 | Reasons for not flying from and to Schiphol (6 possibilities) |
| questionnaire | f3 | Attitude towards Schiphol (11 points scale, 0 very positive, 10 very negative) |
| questionnaire | f4_sum | Number of activities performed against Schiphol (1 to 10) |
| questionnaire | f5 | Job related towards Schiphol (1 yes, 2, no) |
| questionnaire | f6a | Ever afraid of aircraft noise (2 points scale, 1 yes, 2 no) |

| | | |
|---|---|---|
| questionnaire | f6b | Frequency of being afraid of aircraft noise (5 points scale, 1 each day, 5 never) |
| questionnaire | f6b_zoja | Frequency of being afraid of aircraft noise (1 daily, 4 once this year, 5 never) |
| questionnaire | f6b_sum | Sum of reasons being afraid of aircraft noise (7 points scale, 0 no reason, 6 six reasons) |
| questionnaire | f7 | Dissatisfaction with aircraft noise around the house (11 points scale, 0 not at all dissatisfied, 10 very much dissatisfied) |
| questionnaire | f8 | Afraid of health impact by aircraft noise (11 points scale, 0 not at all, 10 very much worried) |
| questionnaire | gez1 | Subjective experienced health ((5 points scale, 1 very good, 5 very bad) |
| questionnaire | voegd | Health score during daytime (0 – 13) |
| questionnaire | voegn | Health score during night-time (0 – 13) |
| questionnaire | neg_exp | Negative experience last year (1 no. 2 yes) |
| questionnaire | gehoorp | Hearing problems |
| questionnaire | protect | Use of personal hearing protection (6 points scale: 1 never, 6 (nearly) each night) |
| questionnaire | recmedal | Number medicin prescribed |
| questionnaire | vrijmdal | Number medicin free |
| questionnaire | medall | Total number medicin |
| questionnaire | slaapm1 | Frequency of use of sleeping pills (1 (nearly) each night, 4 never) |
| questionnaire | slaapm2 | Duration of use of sleeping pills (1 less than 6 weeks, 3 more than 12 months) |
| questionnaire | slaapm3 | Purchase of sleeping pills |
| questionnaire | slelt_cl | Classification of sleeping pills (4 classes, sleep arousing additional 1, sleep arousing main effect 4) |
| questionnaire | raamopen | Position of bedroom window (5 points scale, 1 always opened, 5 always closed) |
| questionnaire | sleep qua | Sleep quality obtained from questionnaire (11 points scale, 0 very bad, 10 very good) |
| questionnaire | slsom | Number of complaints about general sleep quality (0 – 10) |
| questionnaire | vliegsom | Number of aircraft noise complaints per week (0 - 56) |
| questionnaire | sensi | Noise sensitivity according to Weinstein list |
| questionnaire | uclact | UCL_active attitude |
| questionnaire | uclste | UCL_supportive attitude |
| questionnaire | uclafw | UCL_laissez_faire attitude |

*Table A2* *Noise exposure variables*

| period | Variable | Description |
|---|---|---|
| instantaneous | LAeq1s | Measured equivalent sound level over 1 s (in dB(A)) |
| instantaneous | L | Equivalent sound level over an interval of 15-s (in dB(A)) |
| instantaneous | Lmax_i | Maximum value of LAeq1s of an aircraft noise event, assessed indoors (in dB(A)) |
| instantaneous | Lmax_o | Maximum value of LAeq1s of an aircraft noise event, assessed outdoors (in dB(A)) |
| | SEL | Equivalent sound level of a noise event, normalised to 1 s (in dB(A)) |
| instantaneous | SEL10_i | Equivalent indoor sound level of an aircraft noise event, normalised to 1 s, assessed over the uninterrupted period the sound level of the aircraft noise event exceeds Lmax_i – 10 dB(A) (in dB(A)) |
| instantaneous | SEL10_o | Equivalent outdoor sound level of an aircraft noise event, normalised to 1 s, assessed over the uninterrupted period the sound level of the aircraft noise event exceeds Lmax_o – 10 dB(A) (in dB(A)) |
| instantaneous | tSEL10_i | The period over which SEL10_i is assessed (in s) |
| instantaneous | tSEL10_o | The period over which SEL10_o is assessed (in s) |
| sleep period time | L50 | Median value of the LAeq15s values of a sleep period time of a subject with aircraft noise windows excluded (in dB(A)) |
| sleep period time | Liaspt | Indoor aircraft equivalent sound level during a sleep period time calculated from all SEL10_i values of aircraft noise events and duration of sleep period time (in dB(A)) |
| sleep period time | Loaspt | Outdoor aircraft equivalent sound level during a sleep period time calculated from all SEL10_o values of aircraft noise events and duration of sleep period time (in dB(A)) |
| sleep period time | niaspt | Number of indoor aircraft noise events during a sleep period time |
| 6 – 7 hours | Lia06 | Indoor aircraft equivalent sound level for 6 – 7 hours of a sleep period time for subject asleep the full hour |
| 6 – 7 hours | nia06 | Number of indoor aircraft noise events during a sleep period time for subjects asleep during 6 – 7 hours |
| 23 – 24 hours | Lia23 | Indoor aircraft equivalent sound level for 23 – 24 hours of a sleep period time for subject asleep the full hour |
| 23 – 24 hours | nia23 | Number of indoor aircraft noise events during a sleep period time for subjects asleep during 23 –24 hours |
| sleep latency period | Llaten | Indoor aircraft equivalent sound level during a sleep latency period calculated from all SEL10_i values of aircraft noise events during that period, taking into account the duration of the sleep latency period (in dB(A)) |
| sleep latency period | nlaten | Number of aircraft noise events during sleep latency period |
| long-term | Lbu23-07h | Outdoor equivalent sound level during night-time (23 – 7 hours) representative for aircraft noise exposure at a location during a year (in dB(A)). Values calculated by RIVM on the basis of data obtained from NLR |
| long-term | Lbi23-07h | Indoor equivalent sound level during night-time (23 – 7 hours) obtained by subtract-ing 21 dB(A) from Lbu23-07h |
| Long-term | Lbu06-07 | Outdoor equivalent sound level during night-time (6 – 7 hours) representative for aircraft noise exposure at a location during a year (in dB(A)). Values calculated by RIVM on the basis of data obtained from NLR |
| long-term | Lbi23-06h | Indoor equivalent sound level during night-time (23 – 6 hours) representative for aircraft noise exposure at a location during a year (in dB(A)). Values calculated by RIVM on the basis of data obtained from NLR |
| long-term | Ke | Metric of outdoor aircraft noise exposure representative for 24 hours aircraft noise exposure at a location during a year. Values calculated by RIVM on the basis of data |

| | | |
|---|---|---|
| | | obtained from NLR |
| long-term | Lden | Outdoor equivalent sound level over 24 hours, with sound levels during 23 to 7 hours increased by 10 dB(A), and sound levels during 19 to 23 hours increased by 5 dB(A), representative for 24 hours aircraft noise exposure at a location during a year (in dB(A)). Values calculated by RIVM on the basis of data obtained from NLR |
| long-term | Lday | Outdoor equivalent sound level over 16 hours (from 7 to 23 hours), with sound levels during 19 to 23 hours increased by 5 dB(A), representative for aircraft noise exposure at a location during a year (in dB(A)). |
| location interval period | Li | Indoor equivalent sound level of all aircraft noise events calculated from all Liaspt values obtained for a subject, taking into account the durations of sleep period times of the subject (in dB(A)) |
| location interval period | Lo | Outdoor equivalent sound level of all aircraft noise events calculated from all Loaspt values obtained for a subject, taking into account the durations of sleep period times of the subject (in dB(A)) |

# Appendix B Aircraft noise

## B.1 Introduction

In this chapter various aspects of aircraft noise is considered. Section B.2 concerns aircraft noise events, section B.3 aircraft noise exposure measures representative for a sleep period time, and section B.4 long-term aircraft noise exposure measures. In section B.5 the sound insulation of aircraft noise is discussed with a view on double glazing of the bedroom window and participation of dwellings in an aircraft noise insulation program.

## B.2 Aircraft noise event measures

### B.2.1 Theoretical considerations

SEL of a noise event is a theoretical quantity and equal to the equivalent sound level of the event normalised to one second. SEL is based on all sound energy of an event.

$$SEL = 10*\int lg(10^{L(t)/10})dt \qquad [B1]$$

Aircraft noise events have a shape that looks like a triangle: its sound level increases until it reaches its maximum and then decreases. For an event with a perfect triangle shape, the sound level increases linear with a dB(A) per second until it reaches its maximum (Lmax), after which the sound level decreases with –a dB(A) per second. For such a theoretical event the following equations apply:

$$SEL = Lmax - 10*lg\ a + 9.4 \qquad [B2]$$

$$SELx = Lmax - 10*lg\ a + 9.4 + 10*lg[1-10^{(-x/10)}] \qquad [B3]$$

with: t time, in s;

$a = x/t$, in dB(A)$s^{-1}$;

SELx equal to the equivalent sound level normalised to one second assessed over the period the sound level is above Lmax – x, in dB(A).

Therefore, for a theoretical aircraft noise event:

$$SELx - SELy = 10*lg[1-10^{(-x/10)}] - 10*lg[1-10^{(-y/10)}] =$$

$$10*lg[1-10^{(-x/10)}]/[1-10^{(-y/10)}] \qquad [B4]$$

This implies:

SEL – SEL10 = 0.46 dB(A) [B5]

SEL15 – SEL10 = 0.3 dB(A) [B6]

SEL10 – SEL5 = 1.2 dB(A) [B7]

The time (tSELx) the sound levels of the event are between the two Lmax – x values is equal to 2x/a s.

For a perfect triangle shaped event the two durations tSELx and tSELy have the following relationship:

tSELy/tSELx = y/x [B8]

This implies

tSEL15/tSEL10 = 15/10 = 1.5 [B9]

tSEL10/tSEL5 = 10/5 = 2.0. [B10]

### B.2.2 Actual noise measurements

#### B.2.2.1 Instantaneous indoor aircraft noise event measures

Each second an indoor noise monitor measures and stores LAeq1s. From this signal Lmax_i and the time Lmax_i occurs are assessed for each indoor aircraft noise event occurring in the bedroom during sleeping period and sleep latency times of subjects. In practical situations, where background noise levels in the bedroom usually hamper the assessment of SEL, SELx is measured or calculated. In Draft International Standard ISO 1996-part 1 (2002) and ISO 389 (Description of aircraft noise heard on the ground) preference is given to SEL10. In line with these International Standards, in this study indoor aircraft noise events are specified by SEL10_i and outdoor aircraft noise events by SEL10_o.

In practice, usually aircraft noise events have a shape that deviates somewhat or much from the triangle shape. Also, if background noise levels present in a bedroom are from time to time during an aircraft noise event higher than Lmax_i – 10 dB(A) of the event, it is not possible to assess SEL10_i from the measurements without including sound energy from background noise in the bedroom.

For the initial analysis of the noise signals (see Appendix A) an algorithm has been developed that specified which of the following three SELx_i values could be assessed reliable: SEL10_i, SEL15_i and SEL5_i. For the aircraft noise events for which only SEL5_i could be assessed reliable, it is necessary to estimate SEL10_i from this value. To obtain these estimates, the indoor aircraft noise event data of locations 31 to 36 have been used. For those aircraft noise events with SEL10_i (or SEL15_i) as reliable noise measure, the mean value of the differences between SEL10_i and SEL5_i (and the mean value of the differences between SEL15_i and SEL10_i) and the mean value of the factor tSEL10_i/tSEL5_i (and of the factor tSEL15_i/tSEL10_i) have been assessed. The following differences and factors have been obtained:

$$SEL15\_i - SEL10\_i = 1.5 \text{ dB(A)} \qquad [B11]$$

$$SEL10\_i - SEL5\_i = 3.2 \text{ dB(A)} \qquad [B12]$$

$$tSEL15\_i/tSEL10\_i = 15/10 = 1.7 \qquad [B13]$$

$$tSEL10\_i/tSEL5\_i = 10/5 = 3.1 \qquad [B14]$$

If for an aircraft noise event only SEL5_i has been labelled as a reliable measure, SEL10_i and tSEL10_i have been estimated by using formula B12 and B14. The results are all indicated by SEL10_i and tSEL10_i. These variables and Lmax_i of each aircraft noise event have been used to establish relationships between aircraft noise and instantaneous motility variables.

#### B.2.2.2 Correlations and relationships between Lmax_i and SEL10_i

For each location separately and for all locations together the cumulative distributions of Lmax_i and SEL10_i have been assessed. The results are given in figures B1 and B2 and in tables B1 and B2. Table B3 presents correlation coefficients and the coefficients of the linear regression equation with Lmax_i as independent and SEL10_i as dependent variable. The results have been plotted in figure B3 over the ranges of Lmax_i observed at the various locations.

The correlation between Lmax_i and SEL10_i is very high. This implies that aircraft noise events with a given Lmax_i value have about the same duration tSEL10_i. This is explored in the next analysis. Let SEL10_i = Lmax_i + k*10*lg(tSEL10_i). For each aircraft noise event k has been calculated. The average value of k has been assessed for the aircraft noise events at all locations together and for each location separately. The results are given in table B4.

#### B.2.2.3 Correlations and relationships between outdoor and indoor aircraft noise event metrics

The relationships between the two outdoor and two indoor aircraft noise event metrics have been assessed on the basis of data of 63242 aircraft noise events, assessed during sleep period times of subjects. Relationships and correlation coefficients are:

$$SEL10\_i = 16.40 + 0.877*Lmax\_i \ (r = 0.941) \qquad [B15]$$

SEL10_o = 23.05 + 0.822*Lmax_o (r = 0.934) [B16]

Lmax_i = 13.6 + 0.464*Lmax_o (r = 0.432) [B17]

Lmax_o = 48.2 + 0.403*Lmax_i (r = 0.432) [B18]

SEL10_i = 11.29 + 0.567*SEL10_o (r = 0.472) [B19]

SEL10_o = 55.8 + 0.394*SEL10_i (r = 0.472) [B20]

A comparison of B17 and B18 and of B19 and B20 shows that, due to the relatively low correlation between outdoor and indoor aircraft noise event metrics, the relationship between an outdoor and an indoor aircraft noise metric differs substantially from the relationship between these indoor and outdoor aircraft noise metrics. An example is given in figure B4.

In section C.6 of Appendix C it will be shown that the relationships between probability of (onset of) motility and *outdoor* aircraft noise events metrics have no statistical significant regression coefficients. The discrepancy of this result with the results obtained for *indoor* aircraft noise metrics is explained by the low correlation between outdoor and indoor aircraft noise event metrics. B17 to B20 show that the correlation coefficient between Lmax_i and Lmax_o is only 0.43 and between SEL10_i and SEL10_o only 0.47.

The ranges of the various aircraft noise event metrics in the data base are:
SEL10_i: 38 – 90 dB(A);
SEL10_o: 54 – 94 dB(A);
Lmax_i: 26 – 84 dB(A);
Lmax_o: 38 – 87 dB(A).

In the CAA study (Ollerhead et al. ,1992), the relationship between SEL_o and Lmax_o has been specified as:

SEL_o = 23.9 + 0.81*Lmax_o [B21]

SEL has been defined in the CAA study as given in formula B1, and in the report no comments are given about the limitations to determine SEL of aircraft noise events in practice.

In the CAA study no indoor measurements have been performed. Lmax_o in the CAA study is at least 60 dB(A) and maximal about 90 dB(A). If we calculate SEL_o from equation B16 and B21, then the following results are obtained:

| CAA study | | present study | |
|---|---|---|---|
| Lmax = 60 dB(A) | SEL = 72.5 dB(A) | Lmax = 60 dB(A) | SEL10 = 72.4 dB(A) |
| Lmax = 90 dB(A) | SEL = 96.8 dB(A) | Lmax = 90 dB(A) | SEL10 = 97.1 dB(A) |

Apparently, the agreement between the relationships of Lmax_o and SEL_o obtained in the CAA study and those obtained in the present study is excellent.

## B.3 Aircraft noise measures for a sleep period time

### B.3.1 Equivalent sound level during sleep period time and sleep latency time

The indoor equivalent sound level due to aircraft noise over a sleep period time (Liaspt) has been calculated from the SEL10_i values of the individual aircraft noise events as follows:

$$\text{Liaspt} = 10*\lg 1/T(\sum 10^{\text{SEL10\_i}/10}) \qquad [B22]$$

With T duration of sleep period time in s

∑ summation over all SEL10_i values during sleep period time

For Loaspt, Llaten corresponding formulas apply.

A question is what the difference is between the theoretical equivalent sound level due to aircraft noise during sleep period time and Liaspt. In theory, the difference between SEL and SEL10 (and consequently the difference between the theoretical equivalent sound level due to aircraft noise and Liaspt) is 0.46 dB(A) (formula B5). In reality the following complication exist:

- If aircraft noise events do not exceed the noise levels in the bedroom by more than 5 to 10 dB(A), SEL10_i overestimates the contribution to the theoretical equivalent sound level due to aircraft noise;
- If aircraft noise events exceed the noise levels in the bedroom by about 10 to 15 dB(A), SEL10_i provides a correct contribution to the theoretical equivalent sound level;
- If aircraft noise events do exceed the noise levels in the bedroom by 20 dB(A) or more, SEL10_i provides an underestimation of the contribution to the theoretical equivalent sound level due to aircraft noise. Formula B11 shows that the difference between SEL15_i and SEL10_i is 1.5 dB(A). Therefore it is estimated that for these aircraft noise events the difference between SEL_i and SEL10_i is about 2 dB(A).

In table B5 the distribution of aircraft noise events according to their difference between L50 and Lmax_i is given. Assume that L10 of the background noise present in the bedroom is about 5 dB(A) higher than L50. This implies that for up to 42% of the events the theoretical equivalent sound level is overestimated by using SEL10_i, for about 46% the contribution is more or less correct and for 12% of the events it is an underestimation of the theoretical equivalent sound level of about 2 dB(A). The last 12% aircraft noise events constitute the highest values and due to the exponential addition of SEL values, they have more impact on equivalent sound level than the lower SEL values. Assume that SEL10_i of these 12% aircraft noise events are 10 dB(A) higher than SEL10_i of the 46% aircraft noise events which give a correct contribution to the theoretical equivalent sound level and 20 dB(A) higher than SEL10_i of the 42% aircraft noise events with the lowest SEL10_i values, then it is estimated that the theoretical equivalent sound level during sleep period time is about 1.8 dB(A) (say 2 dB(A)) higher than Liaspt.

The relationships between Liaspt and Loaspt are given in figure B5.

## B.4 Long-term aircraft noise exposure

For each subject Li and Lo have been calculated from the 11 Liaspt and Loaspt values of a subject obtained during the study. The following formula applies for Li:

$$Li = 10*\lg(\sum Tj*10^{Li\_j/10})/(\sum Tj) \quad [B23]$$

With Li_j Li during sleep period time j

Tj duration of sleep period time j in s

∑ summation over all j values

For Lo a corresponding formula applies.

The relationships between Li and Lo are given in figure B6.

For each location, also yearly averages of aircraft noise metrics have been obtained from RIVM. RIVM calculated these aircraft noise exposure values on the basis of information obtained from NLR. It concerns the values of Lbu23-07h, Lbu06-07h, Lbi23-06h, Lden and Ke. In this study, Lbi23-07h has been calculated by subtracting 21 dB(A) from Lbu23-07h.

In figures B7 and B8 Lo and Li, based on the individual subject data, have been plotted as a function of respectively Lbu23-07h and Lbi23-07h. Correlation coefficients are respectively 0.82 and 0.57. The relationships are:

$$Lo = -2.0 + 1.01*Lbu23\text{-}07h \quad [B24]$$

$$Li = 4.3 + 0.76*Lbi23\text{-}07h \quad [B25]$$

In figure B9 and B10 the 95% tolerance intervals (including 95% of the individual Li or Lo data) of the relationships are given.

For each location, the median value of the Li values of the subjects at that location has been calculated. This value has also been related to Lbi23-07h. The equation is the nearly identical to equation B25. In section B.3.1 it has been made plausible that real Liaspt, and therefore also ‘real Li’, is about 2 dB(A) higher than Li calculated from SEL10_i. In the equation of the median value of real_Li as a function of Lbi23-07h, the constant in the equation is not statistical significant. The equation without a constant is:

median value of real_Li = 0.99*Lbi23-07h [B26]

This implies for the 15 locations that considered the real value of Li is on average equal to Lbi23-07h calculated on basis of the data obtained from NLR.

The average value of Li – Liaspt is equal to 3.8 dB(A). The fact that this difference is positive is understandable from the exponential averaging of the Liaspt values to obtain Li: the higher Liaspt values count more heavily that the lower Liaspt values. The regression equations are:

Li = 11.8 + 0.56*Liaspt [B27]

Liaspt = -3.1 + 0.97*Li [B28]

The relationship between Liaspt and Lbi23-07h is given by:

Liaspt = 0.3 + 0.77*Lbi23-07h [B29]

In figure B11 the 95% tolerance intervals (including 95% of the individual Liaspt data) of the relationship are given.

## B.5 Sound attenuation of aircraft noise

The difference between Lmax_o and Lmax_i is a measure of the actual sound attenuation of aircraft noise by the dwelling of a subject. This actual sound attenuation differs from the sound attenuation assessed in building acoustics (with windows closed, and the measuring equipment at standardised positions), since in the actual sound attenuation bedroom windows may be opened or closed. The following data give the position of the bedroom window obtained from the morning diary for bedrooms with or without double glazed windows:

| | no double glazing (42%) | double glazing (58%) |
|---|---|---|
| Fully closed | 47.3 | 40.6 |
| Small opening | 21.7 | 27.9 |
| Opened at hand’s breath | 23.2 | 22.6 |
| Half opened | 5.6 | 4.3 |
| Fully opened | 2.1 | 4.6 |

In practice double glazing of the bedroom window will provide substantial extra sound insulation only if the windows are fully closed. This is the case in only 40.6% of the double glazed windows. The distribution of the difference between Lmax_o and Lmax_i for the aircraft noise events classified according to double glazing of bedroom windows is given in table B6. The mean difference between Lmax_o and Lmax_i for double glazed windows and windows without double glazing is less than 1 dB(A) and at the same time both distributions are shifted by 1 dB(A), with a larger difference for bedrooms with double glazed windows.

In the questionnaire subjects indicate whether their dwelling took part in an acoustic insulation program, and which type of program (against aircraft noise, against road traffic noise, or against railway noise). The sound insulation program against aircraft noise at a particular dwelling may not have included special insulation of the bedroom, if the participation was in the phase of the Ke-insulation. The percentage of dwellings that participated in an aircraft sound insulation program is 15%. Table B6 shows for each location the number of subjects with aircraft noise insulated dwellings. The locations with the highest percentage of insulated dwellings are Rijsenhout and Zwanenburg

## B.6 Tables

*Table B1 Cumulative distributions of Lmax_i for each location and all locations together.*

| Percentage | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | all |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 32 | 33 | 32 | 33 | 37 | 36 | 34 | 34 | 33 | 31 | 37 | 34 | 33 | 32 | 36 | 34 |
| 10 | 33 | 35 | 33 | 35 | 39 | 37 | 36 | 37 | 35 | 33 | 40 | 35 | 35 | 33 | 38 | 35 |
| 20 | 35 | 37 | 35 | 38 | 42 | 40 | 38 | 39 | 38 | 34 | 42 | 37 | 37 | 35 | 40 | 38 |
| 30 | 37 | 39 | 36 | 40 | 44 | 42 | 40 | 42 | 40 | 36 | 44 | 39 | 39 | 37 | 42 | 40 |
| 40 | 38 | 40 | 38 | 41 | 46 | 43 | 42 | 43 | 42 | 37 | 46 | 41 | 41 | 39 | 44 | 42 |
| 50 | 39 | 42 | 39 | 43 | 48 | 45 | 44 | 45 | 44 | 38 | 47 | 42 | 42 | 40 | 45 | 44 |
| 60 | 40 | 43 | 40 | 45 | 49 | 46 | 46 | 47 | 45 | 40 | 49 | 44 | 44 | 42 | 47 | 46 |
| 70 | 42 | 44 | 42 | 47 | 51 | 48 | 48 | 49 | 48 | 42 | 50 | 45 | 46 | 44 | 49 | 48 |
| 80 | 43 | 46 | 44 | 49 | 53 | 51 | 50 | 52 | 50 | 43 | 52 | 48 | 48 | 45 | 51 | 50 |
| 90 | 46 | 49 | 48 | 52 | 55 | 55 | 53 | 58 | 53 | 45 | 56 | 50 | 52 | 49 | 54 | 54 |
| 95 | 49 | 51 | 55 | 55 | 56 | 58 | 55 | 62 | 56 | 48 | 58 | 54 | 55 | 51 | 56 | 57 |
| lowest | 26 | 26 | 26 | 26 | 26 | 28 | 28 | 27 | 26 | 28 | 28 | 28 | 27 | 27 | 29 | 26 |
| highest | 68 | 69 | 84 | 75 | 70 | 74 | 79 | 72 | 70 | 67 | 71 | 59 | 72 | 59 | 71 | 84 |
| number of aircraft noise events | 3105 | 3271 | 6045 | 3009 | 6732 | 4514 | 3299 | 8690 | 6596 | 548 | 3874 | 589 | 6423 | 475 | 6072 | 63242 |

*Table B2 Cumulative distributions of SEL10_i for each location and all locations together.*

| Percentage | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | all |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 44 | 44.2 | 44 | 45 | 49 | 48 | 46.5 | 47 | 45 | 44 | 49 | 45.1 | 45 | 43 | 48 | 45.2 |
| 10 | 45 | 46 | 45 | 47 | 51 | 49 | 48.2 | 48.2 | 46 | 45 | 52 | 47 | 47 | 44.2 | 49.2 | 47 |
| 20 | 47 | 48.2 | 46.2 | 49 | 54 | 51 | 50.5 | 50.2 | 49 | 46 | 54 | 48.5 | 49 | 46.2 | 51.2 | 49.2 |
| 30 | 48 | 50 | 47.5 | 51 | 55.5 | 53 | 52 | 53 | 51 | 47.2 | 56 | 50 | 50.2 | 48 | 53 | 51 |
| 40 | 49 | 51 | 49 | 53 | 57 | 54 | 54 | 54.2 | 53 | 48.2 | 57.5 | 52 | 52 | 49.7 | 54 | 53 |
| 50 | 50 | 53 | 50 | 54 | 59 | 56 | 55 | 56 | 55 | 49.5 | 59 | 53.2 | 53.5 | 51.2 | 55.5 | 55 |
| 60 | 51 | 54 | 51 | 56 | 60 | 57 | 57 | 58 | 56.5 | 51 | 60.2 | 55 | 55 | 53 | 57 | 56.5 |
| 70 | 52.2 | 56 | 52 | 58 | 61 | 59 | 59 | 60 | 58 | 52.1 | 62 | 57 | 57 | 54 | 59 | 58.2 |
| 80 | 54 | 57.2 | 55 | 60 | 63 | 62 | 61 | 63 | 61 | 54 | 63 | 59 | 59 | 55.5 | 60.2 | 61 |
| 90 | 57 | 60 | 58.5 | 63 | 65 | 65 | 64 | 69 | 64 | 56 | 66 | 61 | 63 | 58 | 63 | 64 |
| 95 | 59 | 62 | 63.5 | 65 | 66.1 | 68 | 66 | 72 | 66 | 58 | 69 | 64.1 | 65 | 62 | 66 | 67 |
| lowest | 39 | 38 | 38 | 38 | 40 | 39 | 41 | 40 | 40 | 39 | 41 | 42 | 39 | 40 | 42 | 38 |
| highest | 77 | 76 | 90 | 86 | 84 | 83 | 87 | 80 | 76 | 73 | 80 | 71 | 84 | 71 | 77 | 90 |
| number of aircraft noise events | 3105 | 3271 | 6045 | 3009 | 6732 | 4514 | 3299 | 8690 | 6596 | 548 | 3874 | 589 | 6423 | 475 | 6072 | 63242 |

*Table B3* *Association between Lmax_i and SEL10_i. Correlation coefficients, constant and slope of the linear regression line with Lmax_i as independent and SEL10_i as dependent variable.*

| Percentage | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | all |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| correlation coefficient | 0.87 | 0.89 | 0.92 | 0.93 | 0.93 | 0.95 | 0.92 | 0.95 | 0.94 | 0.85 | 0.92 | 0.90 | 0.94 | 0.89 | 0.94 | 0.94 |
| constant | 20.2 | 17.5 | 17.6 | 17.1 | 18.5 | 16.4 | 18.6 | 15.8 | 15.8 | 21.3 | 17.7 | 16.3 | 17.1 | 16.5 | 17.9 | 16.4 |
| slope | 0.77 | 0.85 | 0.83 | 0.87 | 0.84 | 0.88 | 0.84 | 0.90 | 0.89 | 0.74 | 0.87 | 0.88 | 0.86 | 0.86 | 0.83 | 0.88 |
| number of aircraft noise events | 3105 | 3271 | 6045 | 3009 | 6732 | 4514 | 3299 | 8690 | 6596 | 548 | 3874 | 589 | 6423 | 475 | 6072 | 63242 |

*Table B4* *Information about k.*

| Location | Mean value of k | Number of events | Standard deviation in k | Median value of k | Std. error of mean k |
|---|---|---|---|---|---|
| 31 | 1.81 | 3105 | 0.67 | 1.77 | 0.012 |
| 32 | 1.79 | 3271 | 0.68 | 1.71 | 0.012 |
| 33 | 1.71 | 6045 | 0.65 | 1.62 | 0.008 |
| 34 | 1.77 | 3009 | 0.65 | 1.68 | 0.012 |
| 35 | 1.68 | 6732 | 0.59 | 1.61 | 0.007 |
| 36 | 1.67 | 4514 | 0.53 | 1.62 | 0.008 |
| 37 | 1.87 | 3299 | 0.66 | 1.82 | 0.012 |
| 38 | 1.71 | 8690 | 0.63 | 1.57 | 0.007 |
| 39 | 1.70 | 6596 | 0.63 | 1.57 | 0.008 |
| 40 | 1.84 | 548 | 0.75 | 1.77 | 0.032 |
| 41 | 1.86 | 3874 | 0.60 | 1.84 | 0.010 |
| 42 | 1.80 | 589 | 0.68 | 1.74 | 0.028 |
| 43 | 1.74 | 6423 | 0.59 | 1.66 | 0.007 |
| 44 | 1.69 | 475 | 0.65 | 1.62 | 0.030 |
| 45 | 1.51 | 6072 | 0.52 | 1.43 | 0.007 |
| all | 1.72 | 63242 | 0.62 | 1.62 | 0.002 |

*Table B5* *Information about the distribution of Lmax_i relative to L50.*

| Lmax_i - L50 in dB(A) | Lmax_i - L10 in dB(A) | Number of events | Percentage of events | Cumulative percentage of events |
|---|---|---|---|---|
| <=10 | <= 5 | 9337 | 14.6 | 14.8 |
| 10 - 15 | 5 - 10 | 17089 | 27.7 | 41.8 |
| 15 - 20 | 10 - 15 | 17388 | 27.5 | 69.3 |
| 20 - 25 | 15 - 20 | 12041 | 19.0 | 88.3 |
| 25 - 30 | 20 - 25 | 5604 | 8.9 | 97.2 |
| >30 | > 25 | 1783 | 2.8 | 100.0 |
| all | | 63242 | 100.0 | |

*Table B6 Cumulative distribution of Lmax_o – Lmax_i for single and double glazed windows.*

| | Double glazing of bedroom window | |
|---|---|---|
| | no | yes |
| mean difference | 21.3 | 22.2 |
| 10% | 13 | 12 |
| 20% | 16 | 16 |
| 30% | 18 | 18 |
| 40% | 20 | 20 |
| 50% | 22 | 23 |
| 60% | 23 | 25 |
| 70% | 25 | 27 |
| 80% | 27 | 28 |
| 90% | 30 | 31 |

*Table B7 Participation in the past in the Schiphol aircraft noise insulation program as indicated by subjects in the questionnaire. Four responses are missing.*

| | Number of subjects with their dwelling in an insulation program or not | | |
|---|---|---|---|
| | Not in a program | In program | Total |
| Nieuw-Vennep | 21 | 7 | |
| Rijsenhout | 17 | 10 | 27 |
| Zwanenburg | 17 | 10 | 27 |
| Assendelft | 21 | 3 | 24 |
| Halfweg A | 22 | 5 | 27 |
| Kaag | 23 | 3 | 26 |
| Leimuiden | 26 | 1 | 27 |
| Halfweg B | 25 | 3 | 28 |
| Krommenie | 18 | 4 | 22 |
| Hillegom | 27 | 1 | 28 |
| Hoofddorp | 26 | 4 | 30 |
| Spaarndam | 28 | 2 | 30 |
| Warmond | 26 | 4 | 30 |
| Haarlem | 27 | 3 | 30 |
| Abbenes | 28 | 2 | 30 |
| Total | 352 | 62 | 414 |

## B.7 Figures

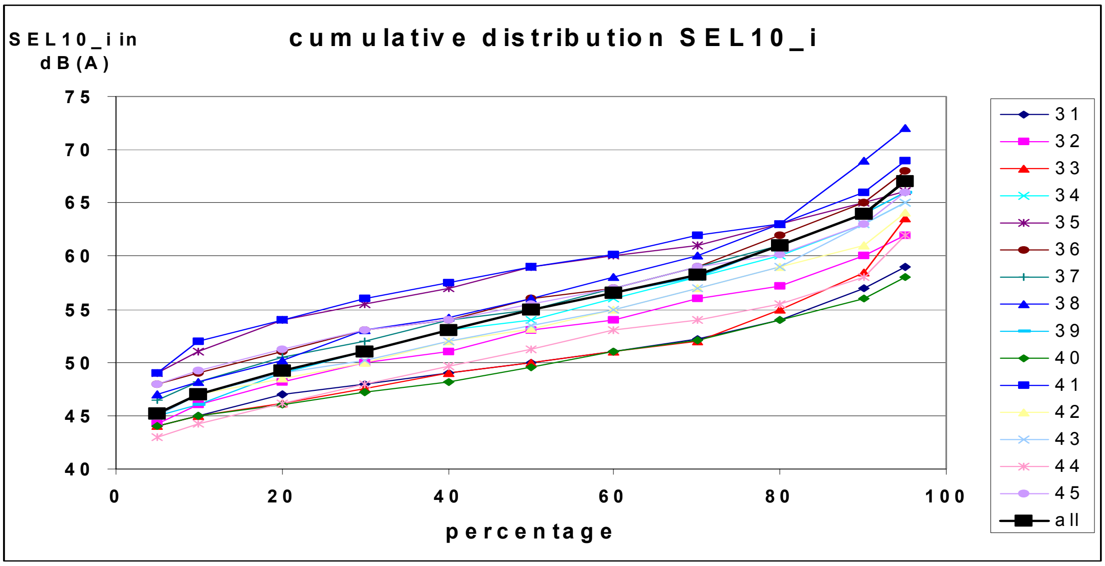


*Figure B1: Cumulative distribution of SEL10_i for 15 locations and for all locations together*

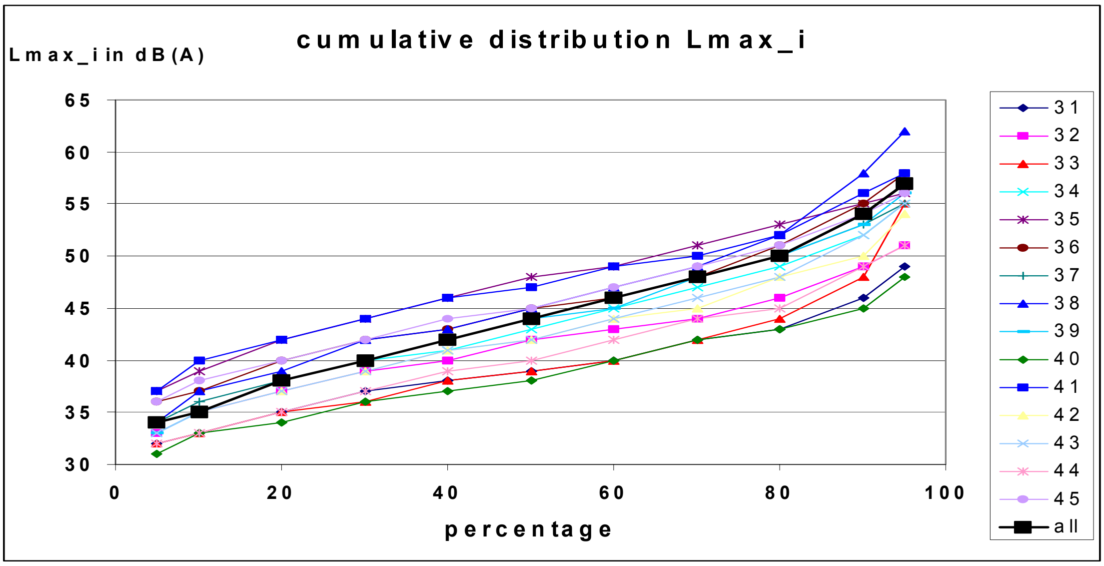


*Figure B2: Cumulative distribution of Lmax_i for 15 locations and for all locations together.*

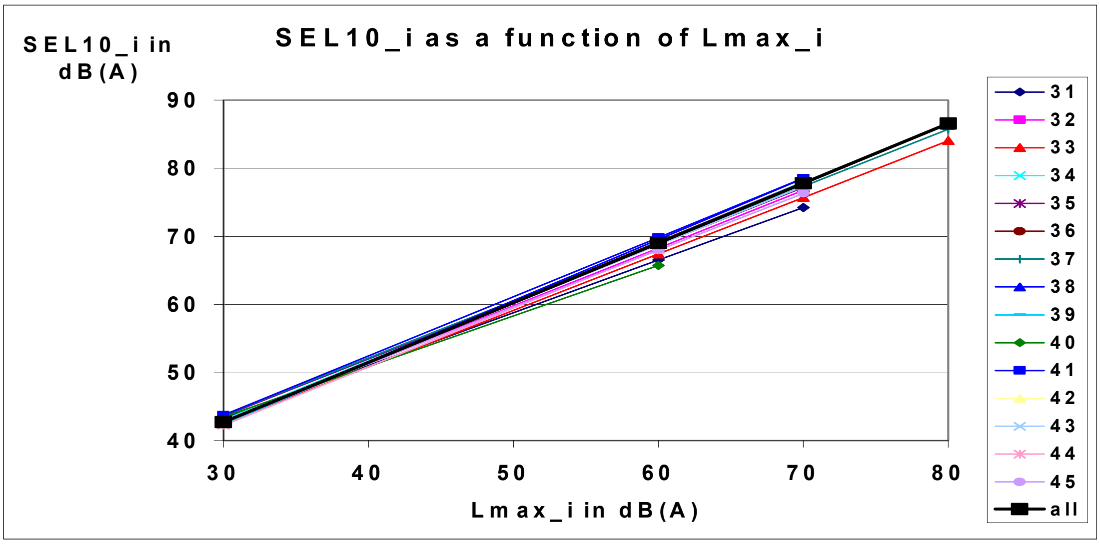


*Figure B3:* *Association between Lmax_i and SEL10_i for each location and for all locations.*

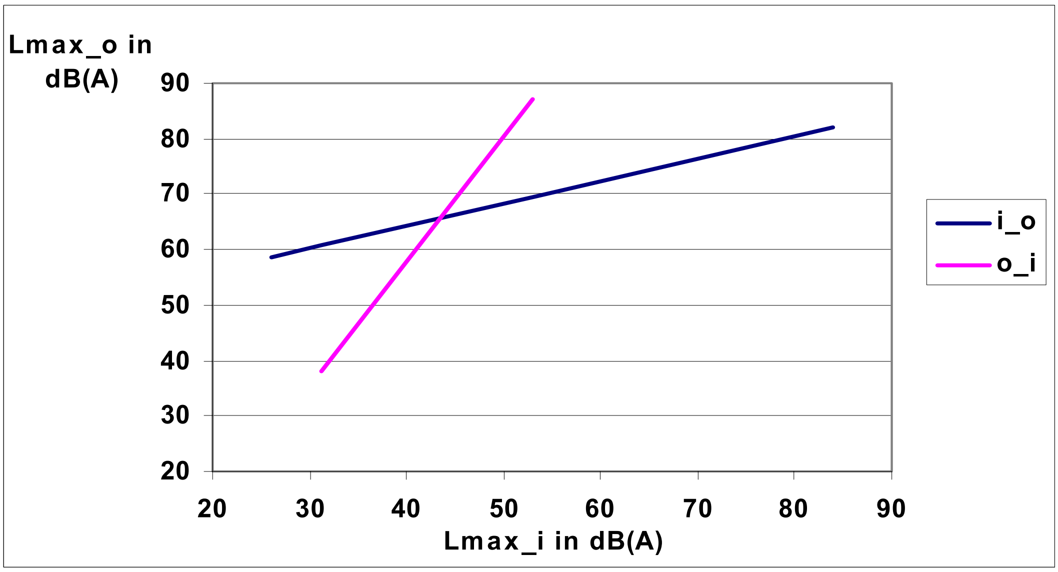


*Figure B4:* *Relationships between outdoor and indoor instantaneous aircraft noise metrics. The straight line i_o is the relationship with Lmax_i as independent variable (x-axis) and the straight line o_i is the relationship with Lmax_o as independent variable (y-axis serves as independent variable axis).*

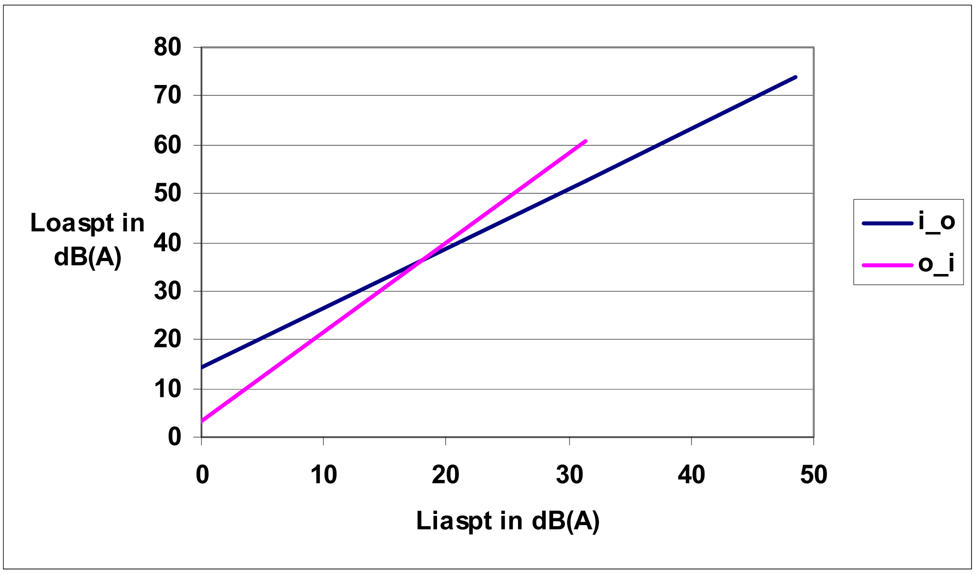


*Figure B5:* *Relationships between outdoor and indoor sleep period time aircraft noise metrics. The straight line i_o is the relationship with Liaspt as independent variable (x-axis) and the straight line o_i is the relationship with Loaspt as independent variable (y-axis serves as independent variable axis).*

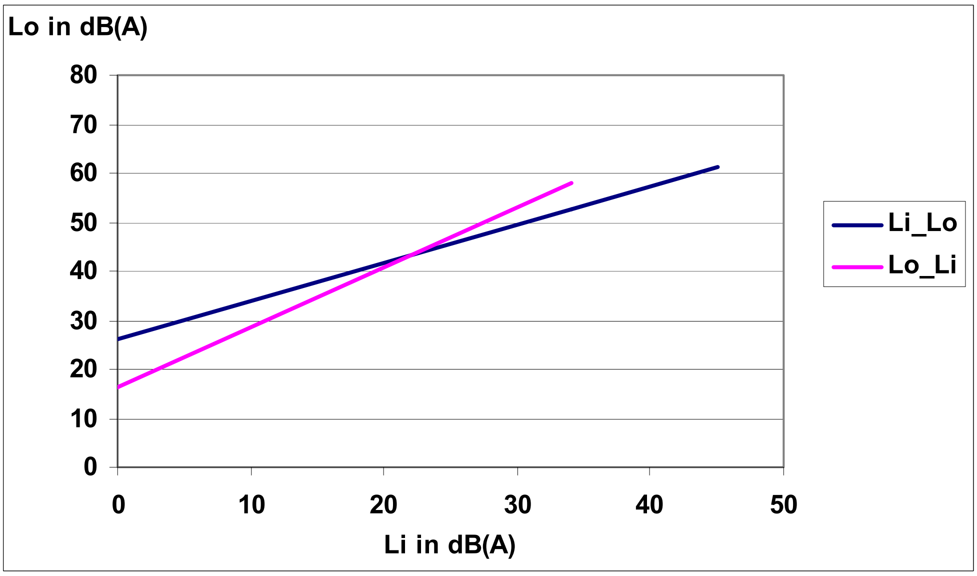


*Figure B6:* *Relationships between outdoor and indoor aircraft noise metrics over 11 sleep period times. The straight line Li_Lo is the relationship with Li as independent variable (x-axis) and the straight line Lo_Li is the relationship with Lo as independent variable (y-axis serves as independent variable axis).*

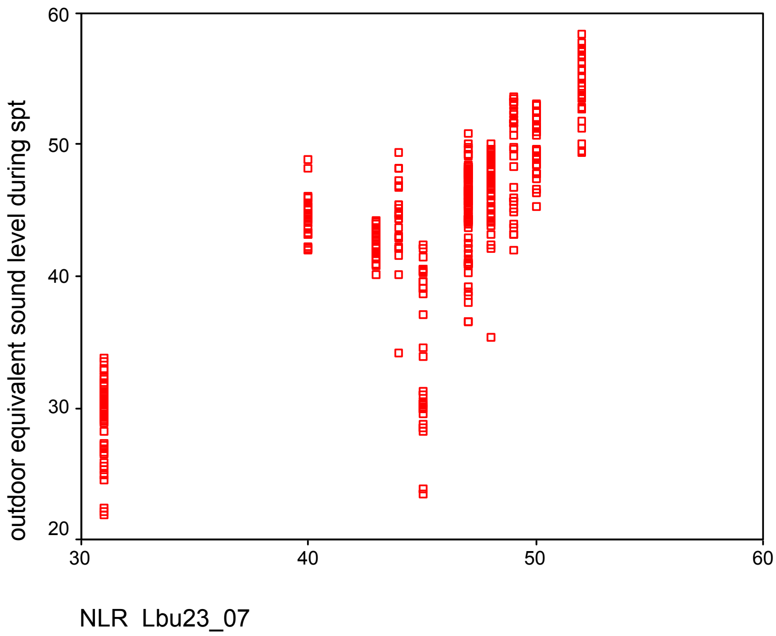


*Figure B7: Association between outdoor Lbu23-07h and Lo (outdoor aircraft noise equivalent sound level during 11 sleep period times).*

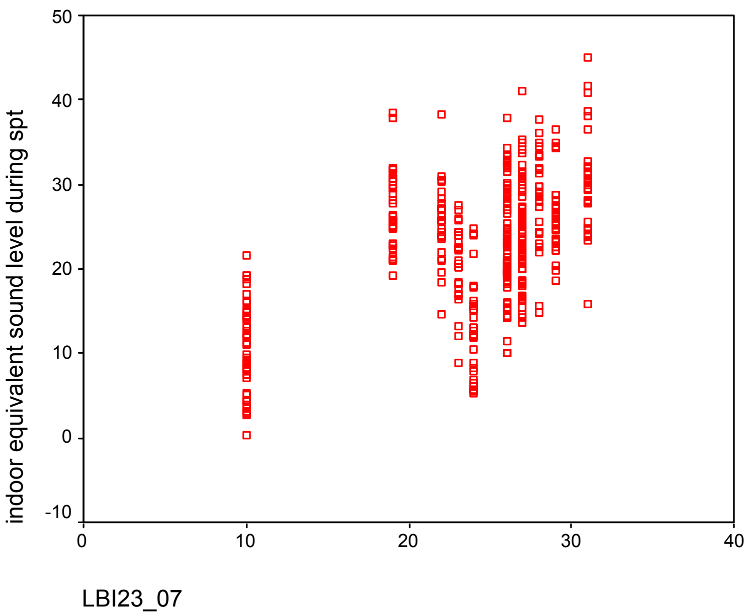


*Figure B8: Association between indoor Lbi23-07h and Li (indoor aircraft noise equivalent sound level during 11 sleep period times).*

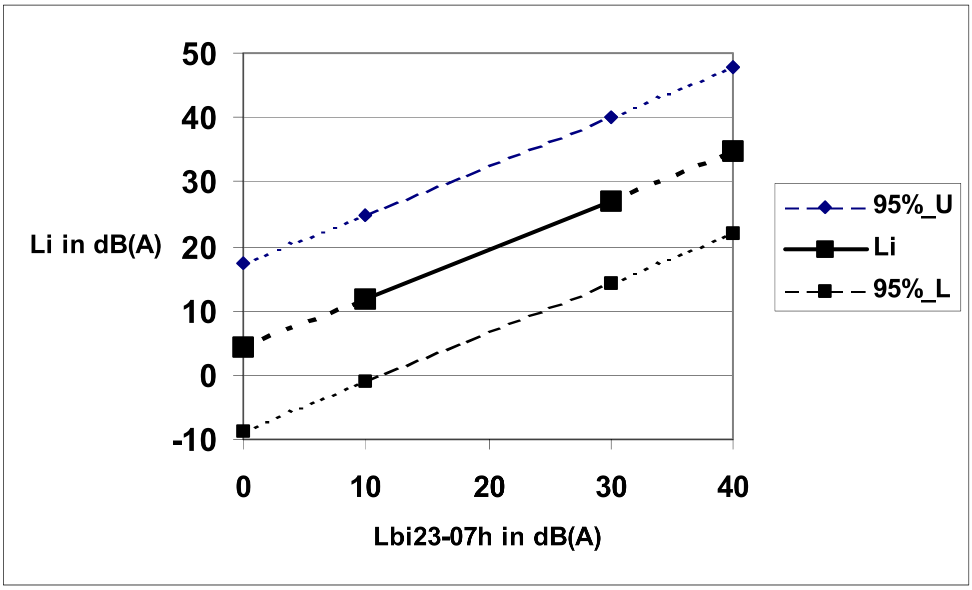


*Figure B9:* *Li as a function of Lbi23-07h. The 95% tolerance intervals (including 95% of the individual values of Li) are also presented.*

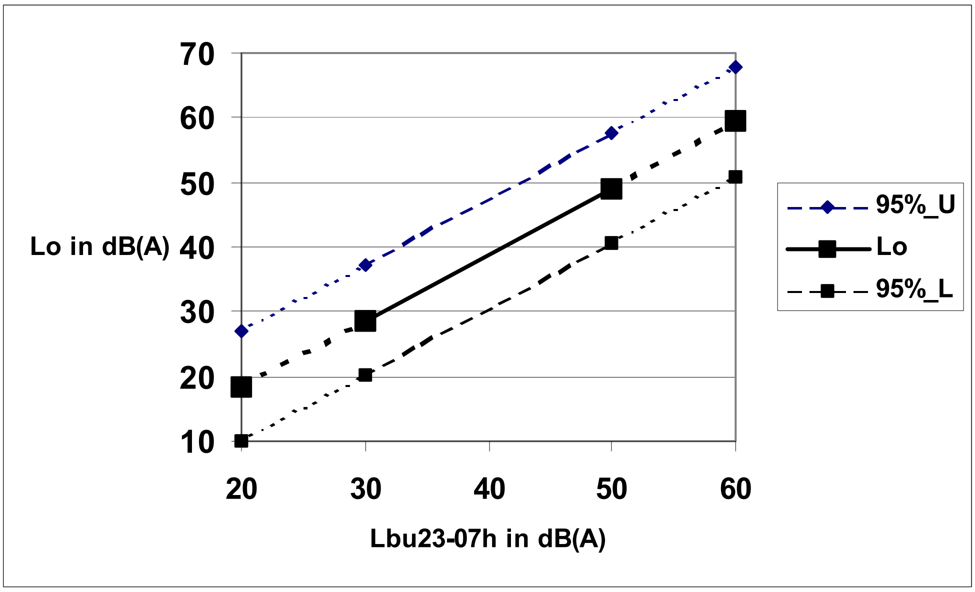


*Figure B10:* *Lo as a function of Lbu23-07h. The 95% tolerance intervals (including 95% of the individual values of Lo) are also presented.*

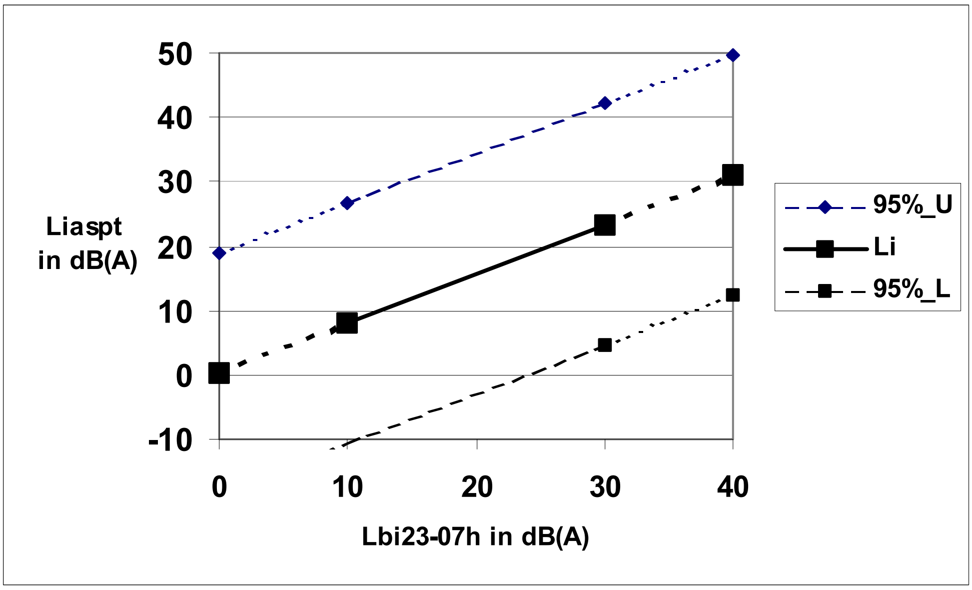


*Figure B11:* *Liaspt as a function of Lbi23-07h. The 95% tolerance intervals (including 95% of the individual values of Liaspt) are also presented.*

Exposure effect relationships

# Appendix C Analyses to assess relationships between instantaneous noise and effect variables

## C.1 Introduction

This Appendix presents detailed information about the analyses performed to specify relationships between instantaneous noise and effect variables. In section C.2 an outline is given of the procedures by which the exposure-effect relationships have been derived and in section C.3 noise situations in bedrooms and aircraft noise event measures are discussed. Sections C.4 and C.5 present models for the effect variables as a function of time after sleep onset. In section C.6 exposure-effect relationships for motility (m) and motility onset (k) are given, in section C.7 relationships for motility level (relscore) and section C.8 relates to pressing the marker by subjects as an indication that they are awake during sleep period time. Section C.9 discusses the total instantaneous increase in motility in the worst case situation. Section C.10 contains tables and section C.11 figures.

The analyses in this Appendix are limited to the sleep period times of subjects.

## C.2 General approach

*Effect variables*
Subjects wore an actimeter on the non-dominant wrist during each of the eleven 24 hours periods they participated in the study. This allows the assessment of the following effect variables as a function of time for each of the eleven sleep period times of a subject:

1. for each time interval of 15-s (at the end of the interval) the output of the actimeter (score). Score = 0 if the vibration level (motility) during a 15-s interval is below threshold. The measurement level of score is the ratio level: score can be 0 and the value of score increases with a factor x if the vibration level increases with a factor x (see Appendix A). The range of score (if unequal to 0) during sleep varies from subject to subject, since subjects have their own but different accelerations while moving their extremities and body. Therefore, analyses are carried out with relscore, the relative value of score equal to score divided by the median value of all values of score (for score unequal to 0) of a subject obtained during all sleep period times the subject participated in the study. Relscore is called motility level. By using relscore instead of score also the small differences observed in calibration factors between actimeters are taken into account;
2. for each time interval of 15-s (at the end of the interval) the indication whether motility occurred during that interval. The binary variable motility (m) is derived from the time series of score. The value of m is 0 or 1 (score > 0: m = 1 motility; score = 0: m = 0 no motility). m is called motility;
3. for each time interval of 15-s (at the end of the interval) the indication whether motility started during the interval. The binary variable motility onset (k) is derived from the time se-

ries of m. The value of k is 0 or 1 (k = 1 if m = 1 in a 15-s interval and m = 0 in the preceding 15-s interval; k = 0 in all other cases). k is called motility onset;

4. for each time interval of 15-s (at the end of the interval) the indication whether the event marker has been pressed or not (marker = 1 if event marker is pressed, marker = 0 if event marker is not pressed).

*Aircraft noise exposure variables*

Aircraft noise event metrics Lmax_i and SEL10_i are used to specify the aircraft noise events. In the initial analyses, also SEL10_o and Lmax_o have been considered. It turned out that no statistical significant relationships could be established between outdoor aircraft noise metrics and instantaneous effect variables. The number of indoor aircraft noise events assessed during sleep of subjects is equal to 63 242.

To match on a time basis the actimeter recordings of a subject asleep to the occurrences of aircraft noise events measured by the indoor noise monitor, first the time of an indoor aircraft noise event is specified by the clock time of Lmax_i. This clock time is compared with the clock times of the actimeter outputs (at the end of each 15-s period) and the 15-s interval at which Lmax_i occurs is called the central aircraft noise event interval. For each aircraft noise event a time window around the central aircraft noise event interval has been defined. This aircraft noise event window consists of 20 15-s intervals (et, numbered e1 to e20), 5 before the central interval (e1 to e5), the central interval (at e6) and 14 (e7 to e20) after the central interval. The analyses have shown that increase of probability of (onset of) motility due to aircraft noise is absent or minor at 15-s intervals other than e4 to e10.

*Relationships*

Relationships presented in the sections of C.6 have been obtained by applying random effects multi-level analyses with subjects as level 1.

To obtain exposure-effect relationships , for the *binary* variables m and k logistic regression models have been used. The probability that m=1, denoted by $p_m$, given the value Lmax_i or SEL10_i and 15-s interval et, is modelled as:

$$\ln [p_m(\text{Lmax\_i}, et)/(1-p_m(\text{Lmax\_i}, et)] = \alpha_{et} + \beta_{etm}*\text{Lmax\_i} + u_j \qquad [C1]$$

$$\ln [p_m(\text{SEL10\_i}, et)/(1-p_m(\text{SEL10\_i}, et)] = \alpha_{et} + \beta_{etm}*\text{SEL10\_i} + u_j \qquad [C2]$$

where: $\alpha_{et}$ is a constant dependent of et;

$\beta_{etm}$ is the regression coefficient of Lmax_i or SEL10_i at 15-s interval et;

$u_j$ is a random level 1 noise component with mean value equal to 0 and variance ‘s2d0’.

The probability that k=1 given the value Lmax_i or SEL10_i and 15-s time interval et, denoted by $p_k$, is modelled as:

$$\ln [p_k(\text{Lmax\_i, et})/(1-p_k(\text{Lmax\_i, et})] = \alpha_{et} + \beta_{etk}*\text{Lmax\_i} + u_j \quad [C3]$$

$$\ln [p_k(\text{SEL10\_i, et})/(1- p_k(\text{SEL10\_i, et})] = = \alpha_{et} + \beta_{etk}*\text{SEL10\_i} + u_j \quad [C4]$$

where: $\alpha_{et}$ is a constant dependent of et;

$\beta_{etk}$ is the regression coefficient of Lmax_i or SEL10_i at 15-s interval et;

$u_j$ is a random level 1 noise component with mean value equal to 0 and variance ‘s2d0’.

These formula’s will result in the *probability of (onset of) motility* during intervals et.

The models applied to motility level relscore are discussed in section C.7.

To obtain the *aircraft-noise induced increase in probability of motility* during interval et, the *probability of (onset of) motility that would have occurred if there would have been no aircraft noise event*, should be subtracted from $p_m$ (or $p_k$). The procedure to obtain the estimates of these probabilities of (onset of) motility is outlined in section C3. This procedure can be summarised as follows.
First, by only regarding the 15-s intervals outside the aircraft noise event windows, the probability of (onset of) motility has been assessed as a function of time after sleep onset (taken as the number of 15-s interval (x) after sleep onset) for each subject and each night separately. For relscore the linear relationship between relscore and x has been determined.
Then, these functions, one for each subject and each night, are interpolated for the 15-s intervals within the aircraft noise windows. In this way the predicted value of probability of m=1 (or k=1) if there would have been no aircraft noise event, denoted by $p_{exp\_m}$ (or $p_{exp\_k}$), for each 15-s interval et of each aircraft noise event has been determined.
The 63242 values of $p_{exp\_m}$ at a 15-s interval et vary from 0.01 to 0.10. For each of the 63242 15-s intervals et also the values of Lmax_i and SEL10_i of the aircraft noise event are known. To the 63242 combinations of $p_{exp\_m}$ (or $p_{exp\_k}$) and Lmax_i (or SEL10_i), a linear regression model has been applied with Lmax_i (or SEL10_i) as independent variable and $p_{exp\_m}$ (or $p_{exp\_k}$) as dependent variable. The functions thus obtained are denoted by exp_m (or exp_k).

The models for exp_m and exp_k are given by the following functions:

$$\text{exp\_m (Lmax\_i, et)} = \phi_{et} + \eta_{etm}*\text{Lmax\_i} + \varphi_j \quad [C5]$$

$$\text{exp\_m (SEL10\_i, et)} = \phi_{et} + \eta_{etm}*\text{SEL10\_i} + \varphi_j \quad [C6]$$

$$exp\_k\ (Lmax\_i, et) = \phi_{et} + \eta_{etk}*Lmax\_i + \varphi_j \qquad [C7]$$

$$exp\_k\ (SEL10\_i, et) = \phi_{et} + \eta_{etk}*SEL10\_i + \varphi_j \qquad [C8]$$

where: $\phi_{et}$ is a constant dependent of et;

$\eta_{etm}$ $\eta_{etk}$ is the regression coefficient of Lmax_i or SEL10_i at 15-s interval et;

$\varphi_j$ is a random level 1 noise component with

mean value equal to 0 and variance $^{2.}$

The models for aircraft noise-induced increase of probability of (onset of) motility, denoted by resp_m, and resp_k, are given by the following functions:

$$resp\_m(Lmax\_i, et) = p_m(Lmax\_i, et) - exp\_m(Lmax\_i, et) \qquad [C9]$$

$$resp\_m(SEL10\_i, et) = p_m(SEL10\_i, et) - exp\_m(SEL10\_i, et) \qquad [C10]$$

$$resp\_k(Lmax\_i, et) = p_k(Lmax\_i, et) - exp\_k(Lmax\_i, et) \qquad [C11]$$

$$resp\_k(SEL10\_i, et) = p_k(SEL10\_i, et) - exp\_k(SEL10\_i, et) \qquad [C12]$$

## C.3 Assessment of expected probability of m and k and expected value of rel-score

### C.3.1 Approach

Following the procedures summarised in section C.2, first for probability of (onset of) motility and for relscore models have been specified which give probability of (onset of) motility and relscore as a function of time after sleep onset, for 15-s intervals outside aircraft noise event windows. The models also take into account effects on probability of (onset of) motility and relscore of noises in the bedroom other than from aircraft. In the second step, from the models for probability of (onset of) motility and relscore as a function of time after sleep onset, probability of (onset of) motility and relscore are interpolated for each of the 15-s intervals of the aircraft noise windows.
A graphical example is given in figures C1 to C5. In figure C1 the probability of motility is given as a function of hours after sleep onset for a specific subject and a specific night. Not shown in the figure is the exclusion of the aircraft noise event windows: the plotted line is uninterrupted.

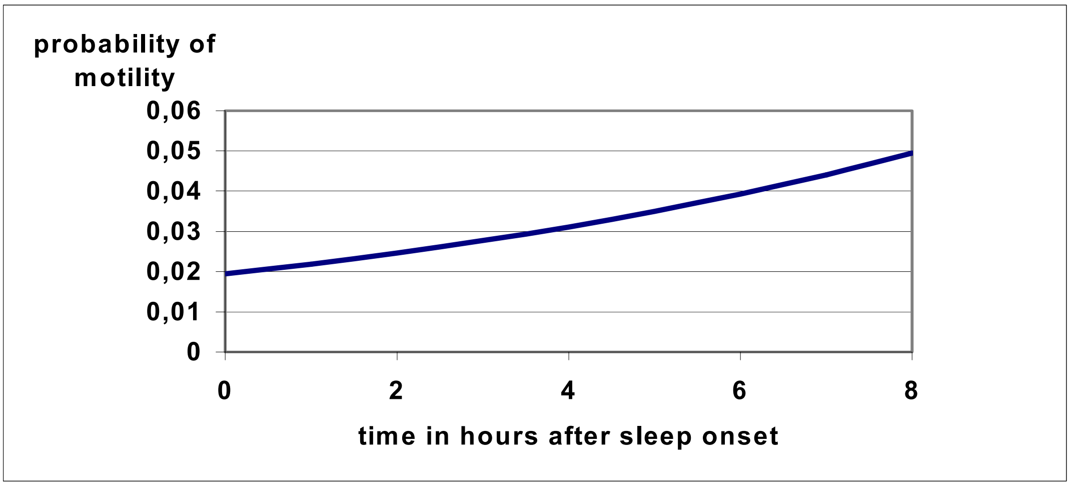


*Figure C1: Example of probability of motility as a function of time after sleep onset. The figure does not show the effect of other noises on probability of motility and the periods with possible effects of aircraft noise on probability of motility are not included in the figure.*

Figure C2 gives the example on another time scale than used in figure C1. The figure concerns the period from 4 to 4.5 hours after sleep onset. Probability of motility is plotted against the numbers of the 15-s intervals from 4 to 4.5 hours after sleep onset (4 hours = 4*60*4 = 960 intervals; 4.5 hours = 4.5*60*4 = 1080 intervals). The figure also shows an example of the impact of another noise in the bedroom on probability of motility: during a noisy window of 20 15-s intervals probability of motility is increased by about a factor 2.

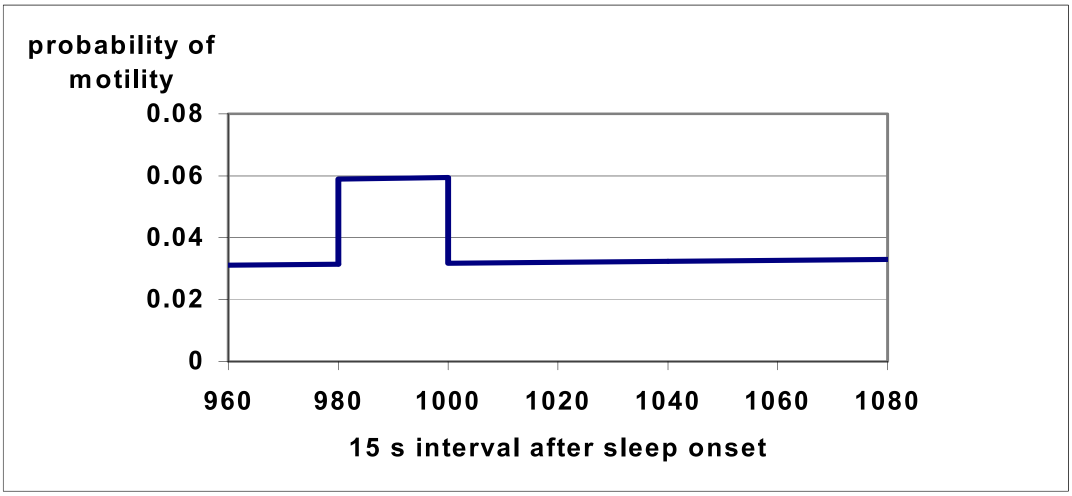


*Figure C2: An example of probability of motility as a function of time after sleep onset. The figure shows the effect of another noise in the bedroom on probability of motility in the 20 15-s intervals number 981 to 1000.*

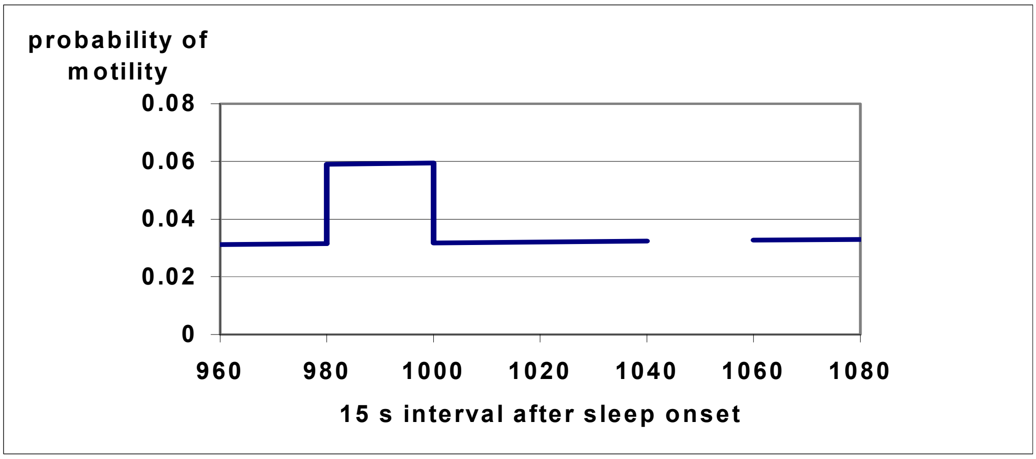


*Figure C3: An example of probability of motility as a function of time after sleep onset. The figure shows an aircraft noise window: 20 15-s intervals from interval 1041 to 1060 have been excluded when the model has been constructed.*

Figure C3 includes an aircraft noise window of 20 15-s intervals. Figures C4 and C5 show the interpolation of the expected values of probability of motility during the 15-s intervals of an aircraft noise event window: figure C4 if the aircraft noise window does not coincide with a noisy window and figure C5 if the aircraft noise window and a noisy window have an overlap of 10 15-s intervals.

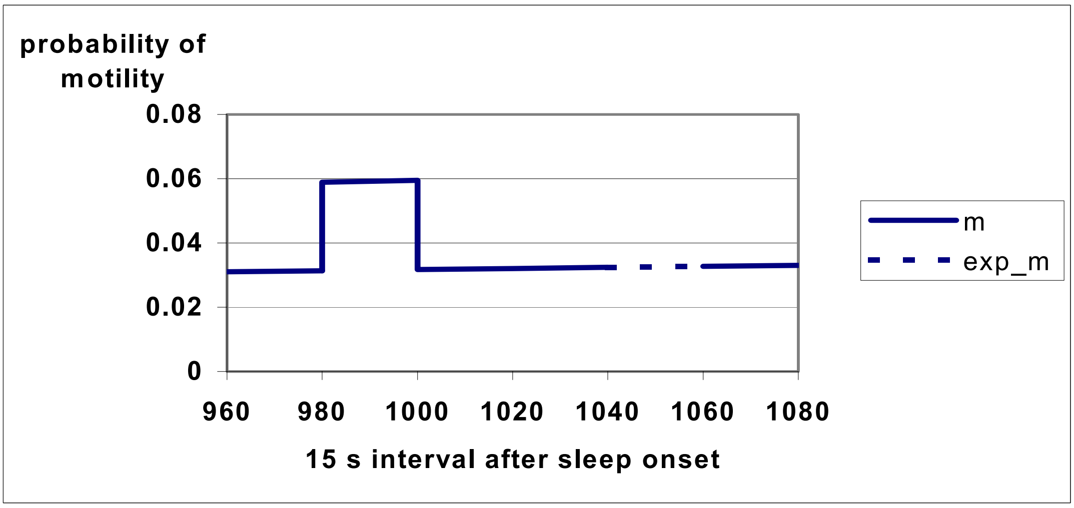


*Figure C4:* *An example of probability of motility as a function of time after sleep onset. The figure shows the interpolation of the expected values of probability of motility for the 20 15-s intervals from interval number 1041 to 1060. Note that the aircraft noise window and the other noise window do not coincide.*

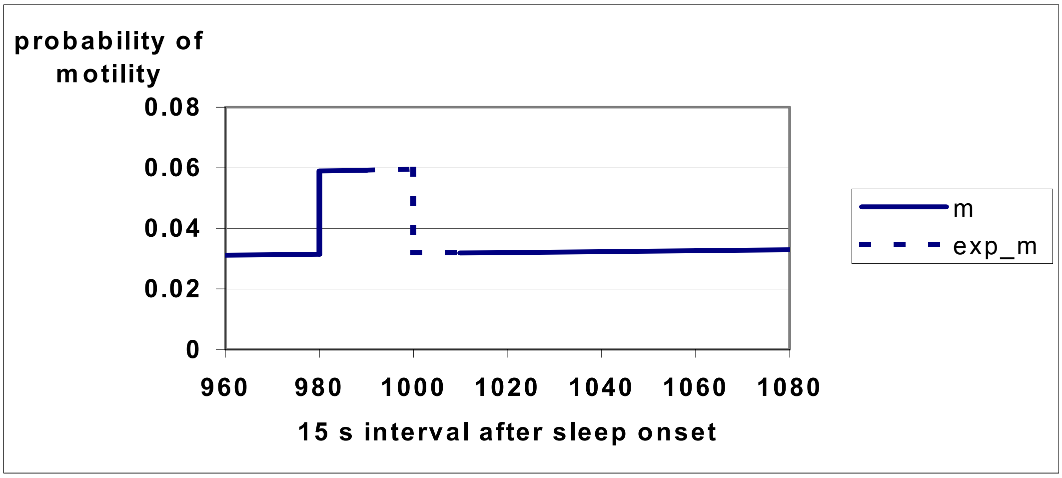


*Figure C5:* *An example of probability of motility as a function of time after sleep onset. The figure shows the interpolation during an aircraft noise window (from interval number 991 to 1010) of the expected value of probability of motility for these 20 15-s intervals, for the situation that the aircraft noise window and an other noise window coincide for the 10 intervals from number 991 to 1000.*

There are several requirements that have to be met for the models to be valid representations of the variables probability of (onset of) motility and relscore as a function of time. These requirements will be outlined in section C.3.2.

## C.3.2 Noise other than aircraft noise in bedrooms

### C.3.2.1 Description of the noise situation in bedrooms during sleep

During sleep the sound level in a bedroom fluctuates. Sounds in a bedroom come from various sources in and outside the bedroom. One of these sources is aircraft, examples of other sources are road traffic, indoor activities of inmates, children crying, and ventilating systems. Snoring of the subject or partner may also be a substantial noise source in a bedroom. Besides aircraft, also noise from other sources may have an instantaneous impact on probability of motility. In assessing the effects of aircraft noise, this impact should be taken into account. This has been realised in the following way. Sleep period time has been divided in:

- Periods with an aircraft noise event: aircraft noise windows;
- Periods with another noise event: noisy windows;
- Periods with a combination of aircraft noise and other noise events: overlap of aircraft and noisy windows;
- Quiet(er) periods.

In an iterative process these periods have been specified. This will be explained in the next sections. First the procedure to obtain aircraft noise windows is discussed and then the procedure to specify noisy windows.

The following aspects are of importance in the specification of whether or not it is, apart from aircraft noise, noisy in a bedroom:

- Some bedrooms are *on average* noisier than others. This may, for instance, be due to night-time road traffic noise, snoring of a subject or partner, equipment (ventilating system of computer);
- The *average* noise situation in a bedroom may *vary from night to night*. This variation may, for instance, occur as a consequence of the position of the bedroom window (opened or closed), weather conditions, absence of a snoring partner;
- The *average* noise situation in a bedroom may also *change during a sleep period time*. This change may, for instance, occur as a result of opening or closing the bedroom window, or of changes in the road traffic noise level in the course of the night;
- Apart from the *average* noise situation during a night, *noisy events* in the bedroom may occur during the sleep period time of a subject. These events may, for instance, occur as a result of children crying, activities of inmates, activities outdoors, such as slamming of car doors, people shouting, passing of (heavy) vehicles.

In the specification of models it is assumed that subjects may have a motility reaction due to events that are *relatively* noisy. Relatively is meant as relative to the average situation. For instance, if a subject is used to sleep in a bedroom with the average sound level of 20 dB(A), a subject may react to a noisy event with a (maximal) sound level of 30 dB(A); if the average sound level in a bedroom is usually 35 dB(A), a subject will not react to a noisy event with a maximal sound level of 30 dB(A), but only to noisy events with sound levels over 45 dB(A) or so.

### C.3.2.2 Windows for noisy events other than aircraft noise events

The indoor noise monitor measures and stores LAeq during one second (LAeq1s) as a function of time t. From the LAeq1s values after sleep onset time, for each 15-s interval two values have been obtained:

- the equivalent sound level over the interval (indicated by L);
- the maximal value of the 15 values of LAeq1s (indicated by Lmax,15s).

The variation of L outside the aircraft noise windows during sleep period times of subjects has been explored on the basis of the results obtained at the first six locations. The following observations have been made:

- for each subject and each sleep period time, the cumulative distribution of the L values for each sleeping hour (which implies 240 L values for a full hour without aircraft noise windows) has been assessed. By visual inspection of these cumulative distributions in the range of 5 to 95%, it is obvious that the distribution of L is not normal; dispersion from normal is at percentages above 75 to 95%[1]. On average, at the lower half of the distributions the difference between the median value of L over an hour (L_50_hour) and the value just not exceeded by 10% of the values L in an hour (L_10_hour) is 4 dB(A); at the higher half of the distributions the difference between the value just not exceeded by 90% of the values L (L_90_hour) and L_50_hour is on average 6 dB(A). This implies that the average value of L over an hour is to some extent affected by the higher L-values. Therefore preference is given to specify an average noise situation by a median value and not by a mean value;
- for a part of the subjects the median value of L (L50) over a sleep period time differs substantially from night to night. Incidentally differences in the median value of L of 9 to 11 dB(A) between the noisiest and quietest sleep period time have been observed. Therefore it is essential to differentiate between sleep period times in the description of the average noise situation in a bedroom;
- L_50_hour is about constant over the sleep period time. A multi-level linear regression analysis with hour after onset of sleep period time as independent variable and L_50_hour as dependent variable showed that the regression coefficient of L_50_hour is not statistically significant different from 0, tested two-sided ($P > 0.05$). Therefore the average noise situation during a sleep period time in a bedroom is specified by the median value of L over the sleep period time (L50) (aircraft noise windows excluded). To this result, two observations should be made:

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[1] Dispersion from a normal distribution occasionally occurs also at the lower end of the distribution if actual noise levels in the bedroom are below the lowest level used during the measurements (about 19 dB(A)).

- Although L50 is constant over the sleep period time, other parameters at the higher end of the distribution (such as L95) are not. (A multi-level analysis showed that the regression coefficient of L_95_hour is statistical significant larger than 0);
- For various acoustical applications 'background sound levels' are specified by L10 or L5 (assessed over a specific measuring time). In this report preference is given to the use of the median value, since it does give a better indication than L10 or L5 of the 'normal' noise situation in a bedroom. There is, obviously, a high correlation between L50 and L10 or L5.

Excluding the aircraft noise windows during sleep period time, two situations can be distinguished:
- Quiet periods;
- (Relative) noisy periods.

To specify (relative) noisy periods, a (relative) noisy 15-s interval is defined by:

$$L - L50 > 10 \text{ dB(A)} \qquad [C13]$$

For two reasons a difference of 10 dB(A) has been (somewhat arbitrarily) chosen. An increase of 10 dB(A) in sound level corresponds to an increase in loudness of a factor 2 and therefore the difference in loudness between the quiet and (relative) noisy intervals can be easily discriminated by people. For the concept of ' a relative noisy event', these events should not occur too frequently. Relative noisy 15-s intervals as specified above occur on average during 1.3% of the 15-s intervals of the sleep period times. This implies on average 22 relative noisy events during a sleep period time (aircraft noise excluded). Some sleep period times do not include any relative noisy events, others include in exceptional cases up to 50 relative noisy events.

A noisy period is, in analogy to the initial specification of an aircraft noise event window, defined by a window with 20 15-s intervals, with the central noisy interval the sixth interval, preceded by 5 and followed by 14 15-s intervals. If after a central noisy interval p another noisy interval q occurs within the noisy window of noisy interval p, noisy interval p is extended to cover the 14 intervals after noisy interval q. A noisy period can therefore be longer than 20 15-s intervals.

In the analysis of the data of the first locations, also a noisy peak interval was defined by:

$$Lmax,15s - L50 > 20 \text{ dB(A)} \qquad [C14]$$

The analysis showed that a noisy peak interval coincides with a noisy interval in more than 99% of the cases. Therefore Lmax,15s of noisy periods has not been considered in the final analyses.

By this procedure four categories of periods during sleep period time can be distinguished:
1. aircraft noise windows of 20 15-s intervals, with Lmax_i occurring during the sixth interval. The aircraft noise windows have been divided in isolated and overlapping aircraft noise win-

dows. Overlap of aircraft noise windows occurs if the difference in time between two successive Lmax_i values is less than 20*15 = 300 s;
2. noisy windows of at least 20 15-s intervals, with after the last noisy interval 14 not noisy 15-s intervals;
3. periods with a combination of an aircraft noise window and a noisy window;
4. quiet periods between aircraft noise windows and noisy windows without noisy intervals and without aircraft noise events.

## C.4 Models for m, k, and relscore outside aircraft noise windows

The constants in the models specified below have been assessed by excluding the values of probability of (onset of) motility and relscore during the aircraft noise windows. For the binary outcomes m and k logistic regression models have been used.
For the jth subject, probability that m=1 given the value of j, night and x, denoted by $p_m$, is modelled as

$$\ln [p_m(j,night,x)/(1-p_m(j,night,x)] = \alpha_j + \beta_{jn} + \beta_{jnoise} + \gamma_j*x \qquad [C15]$$

where: $\alpha_j$ is a subject-specific level effect;

$\beta_{jn}$ is a set of subject-night parameters (11 in total);

$\beta_{jnoise}$ is a subject specific noisy window parameter;

$\gamma_j$ is a subject specific parameter that models the time after sleep onset;

x is the number of the 15-s interval after sleep onset; x = t/15 where t is equal to the time after sleep onset in s.

The model for $p_k$, the probability of k=1 given the value for j, night and x is:

$$\ln [p_k(j,night,x)/(1-p_k(j,night,x)] = \alpha_j + \beta_{jn} + \beta_{jnoise} + \gamma_j*x \qquad [C16]$$

with definitions equivalent to those given for m.

The model for relscore has been specified as:

$$relscore\ (j,night,x) = \alpha_j + \beta_{jn} + \beta_{jnoise} + \gamma_j*x \qquad [C17]$$

with definitions equivalent to those given for m. The interpretation of the parameters for relscore is, however, quite different from the interpretation of the parameters in the equations with probability of (onset of) motility.

There are several requirements which have to be met for the models to be valid representations of the variables probability of (onset of) motility and relscore as a function of time. These requirements are:

- The model should hold for the complete sleep period time. This has been checked on the data of the first five locations (Hosmer-Lemeshow test). The hypotheses that the models for probability of (onset of) motility and relscore fit properly did not have to be rejected (P > 0.05, tested two-sided);
- In the 15-s intervals following an aircraft noise window there should be no instantaneous effect of aircraft noise on the instantaneous effect variables. This requirement should be met by 15-s intervals following the isolated aircraft noise windows and the 15-s intervals following the last of two or more overlapping aircraft noise windows. To check this we calculated a confidence interval for the difference between the mean value of a 15-s interval following the last interval of the appropriate aircraft noise windows and the observed mean value at that interval. It turned out that the 95% confidence interval of these differences equals –0.001 and +0.001. The upper confidence limit 0.001 is considered sufficiently small to conclude that there is no relevant difference between the calculated and observed mean value. This test has been undertaken for the two 15-s intervals succeeding the aircraft noise windows (for probability of (onset of) motility: Fleiss (1981), Statistical methods for rates and proportions; for relscore: equivalence test);
- In the 15-s interval after a noisy window there should be no instantaneous effect of the noise on the instantaneous effect variables. The same procedure as outlined above for aircraft noise windows has been applied on the two 15-s intervals succeeding the noisy windows. It turned out that the 95% confidence interval of the difference equals –0.002 and +0.002. The upper confidence limit 0.002 is considered sufficiently small that we conclude that there is no significant (and relevant) difference between the calculated and observed mean value.

From the results of the last two analyses it is obvious that the duration of the aircraft noise window and the duration of the noisy window both are sufficiently long to avoid aircraft noise and other noises to have an effect on the models that are appropriate for the quiet periods. If there is an effect of aircraft noise and other noises on the effect variables, the effects have vanished at the interval following the windows.

## C.5 Models for m, k, and relscore during aircraft noise windows

The earlier sections introduced the concept of aircraft noise windows and noisy windows. Models and functions, developed for the periods outside the aircraft noise windows, have been presented for the probablity of (onset of) motility and of relscore as a function of time after sleep onset taking into account presence or absence of noisy windows. The functions are interpolated for the 20 15-s intervals during the aircraft noise windows based on the following basic assumption: these interpolate dare the probabilities and relscore is the value that should be expected if there would not have been an aircraft noise event. The functions during aircraft noise windows are indicated by exp_m, exp_k, exp_rlsc.

In applying the models specified above there is one complication. During an aircraft noise window a noisy event (specified by a central noisy interval) during e1 to e20 may occur which has not been taken into account in the models. Visual inspection, carried out at the stage of initial data handling, of the acoustical signal during 60 s before and 60 s after Lmax_i occurs (comprising 50% of e2, e3 to e9 and 50% of e10) excludes to a large extent the presence of other predominant noises during that time: if so, the event would not have been considered an aircraft noise event (no aircraft noise metric values would have been assigned to it), and at a later stage of the analysis the event would be considered as a noisy event. It is possible, however, that during e1, e2(50%), e10 (50%), e11 to e20 a noisy event would have occurred. In accordance with the model presented earlier, these noisy events would need noisy windows with an increase in m, k and relscore of about a factor 2 compared to quiet intervals. On average about 1.3% of the 15-s intervals outside aircraft noise windows are central noisy event intervals. If it is assumed that this also applies to e1, e2, e10, e11 to e20, the average effect on the expected values of probability of (onset of) motility and relscore can be estimated as follows. There are 1.5 15-s intervals (e1 and 50% of e2) with a probability of being the central interval of a noisy event with an effect on the expected values at e4 to e10 which have not been considered as such. With respect to noisy events after the aircraft noise event, there is no interval with a probability of being the central interval of a noisy event with an effect on the expected values at e4. At e5 there is 0.5 of such an interval (50% of e10), at e6 1.5 of such intervals, up to at e10 5.5 of such intervals. Therefore, the total number of 15-s intervals with a probability of being the central interval of a noisy event with an effect on the expected values which have not been considered as such, is 1.5 at e4, 2 at e5, 3 at e6, 4 at e7, 5 at e8, 6 at e9, and 7 at e10. With a probability of 0.013 per 15-s interval, and an average increase in probability of motility during a noisy window of 0.025, the total adjustment in exp_m (0.025*number*0.013) is estimated at 0.0005 at e4 up to 0.0023 at e10. The total adjustment in exp_k is estimated at 0.0004 for e4 up to 0.0016 for e10 and the total adjustment in exp_rlsc is 0.0006 for e4 up to 0.0029 for e10. These adjustments are in the range of 2 to 9% of the expected values from the models without adjustments. The adjustments have been added to the expected values of probability of (onset of) motility and relscore in the assessment of exposure-effect relationships. It was not feasible to avoid these adjustments and to limit the aircraft noise windows to e3 to e10, because priority was given to exclude any possibility that in fitting the models for quiet periods, aircraft noise would have an impact on probability of (onset of) motility and relscore during these periods.

## C.6 Exposure-effect relationships for probability of motility m and of probability of motility onset k

### C.6.1 Introduction

This section has been structured as follows. In sections C.6.2 and C.6.3 exposure-effect relationships are presented. Section C.6.2 relates to all aircraft noise events, section C.6.3 to isolated aircraft noise events. An isolated aircraft noise event is an aircraft noise event for which e4 to e11 does not coincide with any e4 to e11 of another aircraft noise event. The rationale of this definition will be explained later. The isolated aircraft noise events constitute about 85% of all aircraft noise events. Confidence intervals for some relationships are also given. Section C.6.4 presents simplified equations for some exposure-effect relationships. In section C.6.5 possible effects of other variables on the effect variables and relationships are considered.

### C.6.2 Results for all aircraft noise events

In table C1 the coefficients of the logistic regression equations of the probability of m=1, and of k=1 on Lmax_i and SEL10_i for 15-s intervals e4 to e10 have been given, as well as the variance s2d0 and the deviance (-2loglikelihood). The presence of a random effect has been tested with a chi-squared test with one degree of freedom by using the decrease of the deviance of the model without and with a random effect. It turned out that the random effect is highly significant both for the model of probability of (onset of) motility. The second part of the table presents the coefficients of the linear regression equations of exp_m and exp_k as a function of Lmax_i and SEL10_i. These equations are the same for e4 to e10. To calculate resp_m and resp_k, the small adjustments discussed in section C.5 have been added to exp_m and exp_k.
The strongest relationship with m and k is obtained with Lmax_i. This has been tested by comparing Akaike's Information Criterion (AIC) of the two models, (Harrell, 2001; page 203). In the present cases, AIC is equal to the deviance. Therefore, the equation with the lowest deviance represents the ‘best’ aircraft noise metric. In each case the deviance for the relationship with Lmax_i as noise metric is lower than the deviance if SEL10_i is taken as noise metric.
In figure C6 to C9 (at the end of this Appendix) resp_m and resp_k have been plotted as a function of Lmax_i and SEL10_i for all aircraft noise events. Curves are presented for e4 to e10. The curves are limited to Lmax_i equal to 68 dB(A) and SEL10_i of 77 dB(A), the 95% values of these metrics in the database. Considering resp_m, this variable is larger at e7 and e6, the 15-s interval at which Lmax_i occurs, than at other intervals. At the higher aircraft noise values, resp_m increases with interval time from e4 to e6 and e7 and then decreases from e7 to e10. Resp_m is zero at SEL10_i equal to about 38 and Lmax_i equal to about 32 dB(A). With respect to resp_k, at the higher values of Lmax_i and SEL10_i resp_k is larger at e5 than at e6 and e7. Since k represents probability of motility onset, in the case of higher aircraft noise exposure events, motility starts more frequently in the 15-s interval before the maximal sound level occurs. Moreover, if motility starts in the 15-s interval e5, onset of motility is by definition zero at e6, and motility presumably 1. This explains the difference between resp_m and resp_k at higher values of aircraft noise exposure.

In figure C10 to C13 resp_m and resp_k have been plotted as a function of the time of the 15-s interval for various aircraft noise events (expressed in SEL10_i and Lmax_i). Interval times are labelled with respect to the interval Lmax_i occurs. Also given as vertical bars the 95% confidence intervals of some results (see later).

### C.6.3 Results for isolated aircraft noise events

In figure C14 to C17 resp_m and resp_k have been plotted as a function of Lmax_i and SEL10_i for isolated aircraft noise events. Comparing the results for all events and for isolated events, it is obvious that the largest differences occur at e10 and e4. As an example the difference between resp_m for isolated and all events is given in figure C18 as a function of Lmax_i (note that the scale of figure C18 is much smaller than that of the comparable figure C7). Especially resp_m at e10 for isolated events is smaller than the values for all events. The differences for e5 to e9 are about 0, and the differences for e4 are between those for e10 and e5. This can be explained as follows. Usually Lmax_i of aircraft noise events during sleep period times are separated by at least 5 15-s intervals (Lmax_i of isolated events, as defined, are separated by at least 8 15-s intervals). If two aircraft noise events are separated by 5 15-s intervals it implies that e10 of the first event coincides with e5 of a later event. In that case probability of motility at e10 of the first event may be affected by the increase in probability of motility (at e5) due to the later aircraft and probability of motility at e9 of the first event by the increase in probability of motility (at e4) due to the later aircraft. However, since the increase in probability of motility at e5 is on average larger than the increase in probability of motility at e4, the effect on probability of motility of the first event at e10 will be larger than on probability of motility at e9. Also, probability of motility at e4 of the later aircraft may be affected by the increase in probability of motility (at e9) due to the earlier aircraft and probability of motility at e5 to a lesser extent by the increase in probability of motility (at e10). If (not isolated) aircraft noise events are separated by 6, 7 or 8 15-s intervals it implies that e10 of the first event coincides with e4, e3, or e2 of the later event. Therefore probability of motility at e10 of the earlier aircraft may be affected by the increase in probability of motility at e4, e3, or e2 due to the later aircraft. Also probability of motility at e4 of the later aircraft may be affected by the increase in probability of motility at e10 (or later event times e11 etc.) due to the earlier aircraft. Obviously overlapping of aircraft noise events (separated by at least 5 15-s intervals) should have the largest effect on probability of motility at e10 and to a lesser extent on probability of motility at e4.

Figures C19 to C22 show resp_m and resp_k as a function of event intervals for various values of aircraft noise exposures (expressed in SEL10_i and Lmax_i) for isolated aircraft noise events. Added are the values 0 at e3 (3 intervals before Lmax_i) and at e11 (5 intervals after Lmax_i).

Confidence intervals have been calculated for the relationships at interval e6 between Lmax_i and SEL10_i as independent variables and resp_m and resp_k as dependent variables. The 95%-confidence intervals are given in figure C23 to C26.

The further analyses in section C.6 will be carried out with the data of *all* aircraft noise events and only with probability of (onset of) motility at *e6*.
To obtain the largest data base, preference is given to *all* data. In addition, the results at e6 for isolated events are nearly the same as for all events, since there is hardly any difference between the relationships of probability of (onset of) motility at e6 for all and isolated events.
There appears to be minor differences between the relationships at e6 and e7. Preference is given to a further analysis with the data at e6, because this interval includes the time of the occurrence of Lmax_i.

### C.6.4 Approximations of response functions

In principle the relationships at e6 between resp_m or resp_k and Lmax_i and SEL10_i are complicated because a number of coefficients specify the relations and calculation of values implies exponential manipulations. Therefore these functions have been approximated by simple quadratic functions with the following format:

$$resp\_m = b*(SEL10\_i - a) + c*(SEL10\_i - a)^2 \quad [C18]$$

$$resp\_m = b*(Lmax\_i - a) + c*(Lmax\_i - a)^2 \quad [C19]$$

$$resp\_k = b*(SEL10\_i - a) + c*(SEL10\_i - a)^2 \quad [C20]$$

$$resp\_k = b*(Lmax\_i - a) + c*(Lmax\_i - a)^2 \quad [C21]$$

The coefficients a, b and c are given in table C.1. The value of a is the value at which resp_m or resp_k is zero. The format of the functions has been chosen such that the equation is represented by a linear and quadratic term. Only the second term would not have resulted in a proper fit. The correspondence between the original and approximated function for m and Lmax_i is shown in figure C27.

### C.6.5 Variables other than aircraft noise exposure metrics with an effect on resp_m

These analyses have been carried out with the probability of motility at e6 and aircraft noise event variable Lmax_i.

In this section it is analysed whether variables in addition to Lmax_i have a statistical significant effect on resp_m. First, possible variables have been considered separately. Then, possible associations between variables have been taken into account, and, where relevant, two variables have been used in the analysis simultaneously.

#### *C.6.5.1 Step 1: variables entered separately*

To assess whether a variable has a statistical significant effect on resp_m, a variable is entered in addition to Lmax_i as independent variable in a multi-level logistic regression analysis based on $p_m$ and in a multi-level linear regression analysis with exp_m as dependent variable.

$p_m$ is modelled as:

$$\ln [p_m(Lmax\_i, e6, k)/(1-p_m(Lmax\_i, e6, k)] = \phi_{e6} + \eta_{e6m}*Lmax\_i + \delta_s*s + \varphi_j \quad [C22]$$

where: $\phi_{e6}$ is a constant;

$\eta_{e6m}$ is the regression coefficient of Lmax_i at 15-s interval e6;

$\delta_s$ is a constant dependent of determinant s;

$\varphi_j$ is a randomlevel 1 noise component with mean value equal to 0 and variance s2d0.

The following formula for exp_m applies:

$$exp\_m\ (Lmax\_i, e6, k) = \alpha_{e6} + \beta_{e6m}{*}Lmax\_i + \delta_s{*}s + \gamma_j \qquad [C23]$$

where: $\alpha_{e6}$ is a constant;

$\beta_{e6m}$ is the regression coefficient of Lmax_i at 15-s interval e6;

$\delta_s$ is a constant dependent of determinant s;

$\gamma_j$ is a random level 1 noise component with mean value equal to 0 and variance $^2$.

Resp_m(Lmax_i, e6, s) has been calculated as the difference between the function $p_m$(Lmax_i, e6, s) and the function exp_m(Lmax_i, e6, s). To assess whether a variable s has in addition to Lmax_i a statistical significant effect on resp_m, three cases have been considered:

- s is not a determinant of exp_m. This implies that the statistical significance of an effect of s on resp_m only depends on the statistical significance of an effect of s on $p_m$. For these variables it has been tested by using a Chi –squared test with one degree of freedom whether –2 loglikelihood decreases statistical significant ($P < 0.05$) if the variable is added as independent variable to the model of $p_m$. If so, the variable is a determinant of the logit of $p_m$ , and therefore an effect-mofifier of resp_m;
- s is a determinant of exp_m and the direction of the effect of s on exp_m is opposite to the direction of the effect of s on $p_m$. This implies that if s has a statistical significant effect on $p_m$, there is also a statistical significant effect of s on resp_m, and s is an effect-modifier of $p_m$ and resp_m;
- s is a determinant of exp_m and the direction of the effect of s on exp_m is the same as the direction of the effect of s on $p_m$. This applies to the two possible determinants x (15-s interval after sleep onset) and h (clock time, in hours starting at –2 at 22 o'clock in the evening to 8 at 8 o'clock in the morning). In these cases the increase in exp_m with s has to subtracted from the increase in $p_m$ with s, and then the statistical significance of an effect of s on $p_m$ – exp_m should be assessed. Since the impact of s on $p_m$ is assessed in a logistic regression analysis, such a procedure is not possible. Therefore it is decided in a qualitative way whether it is reasonable to assume a statistical significant effect of x and h om resp_m.

In the following, the variables considered, the results of the analyses, and a discussion of the results are given. It concerns

- *Type of aircraft noise events:* aircraft descending (approaching airport Schiphol) or ascending (leaving Schiphol): no statistical significant effect; This implies that ascending and descending aircraft with the same Lmax_i result in the same aircraft noise-induced increase in probabilty of motility. However, if at a given location, Lmax_i of e.g. ascending aircraft is higher than Lmax_i of descending aircraft, the impact of ascending aircraft will be higher;
- *Subject dependent aircraft noise exposure:* the variable Li (indoor equivalent sound level during all sleep period times of a subject) is an important determinant of resp_m, in addition to the effect of Lmax_i on resp_m. This is illustrated in figure C28. At the higher values of Lmax_i, subjects with relatively low night-time aircraft noise exposure show about 3 times as much aircraft noise-induced increase in probability of motility as subjects with high night-time aircraft noise exposure. In a situation with indoor Lnight equal to 0 dB(A), subjects are e.g. exposed each night to one aircraft with indoor Lmax equal to 35 dB(A) or each week to one aircraft with indoor Lmax equal to 44 dB(A;
- *Location dependent aircraft noise exposure:* the variable Lbi23-07h was used as potential determinant. There appeared to be no statistical significant effect. Lbi23-07h is a night-time aircraft noise exposure assessed for locations and this measure does not take into account subject related variations, such as sleeping with bedroom windows opened, and sleeping before 23 hours or after 7 hours. The correlation coefficient between Li and Lbi23-7h is equal to 0.57;
- *L50 (median sound level in the bedroom during a sleep period time in the absence of aircraft noise):* no statistical significant effect;
- *Double glazing of bedroom window(s):* Double glazing of the bedroom window has a small statistical significant effect on the relationship between resp_m at e6 and Lmax_i;
- *time after sleep onset:* time after sleep onset, expressed in the number x of the 15-s interval after sleep onset, has a strong effect on probability of motility. The coefficient of x in the logistic regression equation is 0.000121, which implies that probability of motility has to be multiplied by 1.000121 for an increase of x with 1, and with 1.27 for an increase with 1920 (8 hours) At Lmax_i equal to 68 dB(A) this increase is 0.019. The P-value of the coefficient is 0.0014. The coefficient of x in the regression equation of exp_m on Lmax_i is 0.00000126, which implies an increase in exp_m of 0.002, if x increases from 0 to 1920. This increase in exp_m is, at Lmax_i equal to 68 dB(A), 12% of the increase of probability of motility with x. Therefore we conclude that resp_m is an increasing function of time after onset of sleep. The result is given in figure C29. Resp_m has been plotted as a function of Lmax_i for values of x (number of 15-s interval) in the range of 0 (sleep onset) to 1920 (8 hours after sleep onset);
- *Clock time h in hours:* h has a strong effect on m. The coefficient of h in the logistic regression equation is 0.029, which implies that the function of probability of motility with Lmax_i has to be multiplied by 1.029 for an increase of h with 1, and with 1.33 for an increase of h with 10. The P-value of the coefficient is 0.0017. The coefficient of h in the regression equation of exp_m on Lmax_i implies an increase in exp_m of 0.002, if h increases from –2 to 8. This increase is at Lmax_i equal to 68 dB(A) 11% of the increase of m with h. Therefore we conclude that resp_m is an increasing function of clock time after sleep onset. The result is

given in figure C30. Resp_m has been plotted as a function of Lmax_i for 10 hours, from the hour starting at 22 o'clock in the evening to the hour starting at 8 o'clock in the morning;

- *demographic variables:* age, age*age, gender, citizenship, country of birth, education. The inclusion of age (and age*age) in the exposure-effect relationship of m on Lmax_i resulted in a decrease in –2 loglikelihood with 2 degrees of freedom which appeared to have a P value of 0.059, which is not statistical significant. The regression equation shows that probability of motility increases until an age of 45 years and then decreases. From the the relationship between exp_m and Lmax_i, with age and age*age added as determinants, the effect of age on exp_m has been assessed: the increase in exp_m due to age is smallest at an age of 46 years, and about 0.003 higher for ages 18 and 81 years. Therefore, taking into account the effect of age (and age*age) on exp_m (which is opposite to the effect of age (and age*age) on probability of motility), we conclude that age (and age*age) is a determinant of resp_m. None of the other demographic variables appeared to be determinants of resp_m. The small effect of age (and age*age) is shown in figure C31;
- *subject related variables:* at the start of their participation in the study subjects filled out a questionnaire The variables from the questionnaire subjects filled out at the start of their participation which have been considered are given in table C4. The only variable that showed a statistical significant effect on probability of motility at e6 turned out to be d2b, frequency of awakening by night-time aircraft noise.

#### *C.6.5.2 Step 2: variables entered simultaneously*

Section C.6.5.1 showed that six variables (Li, double glazing, x, h, age, d2b) are effect-modifiers of the relationship between resp_m and Lmax_i at e6. Li has by far the largest effect on resp_m. Since some of the other five variables are associated with Li, an effect of the other variables may have occurred through this association. Therefore each of the five variables have been added as possible determinants in the model with Li and Lmax_i. It turned out that adding the variable double glazing or d2b to the model did not statistical significant decrease the deviance. It is therefore apparent that double glazing and d2b are only effect-modifiers through their association with Li.

The final conclusion is therefore that four variables, are modifying the relationship between resp_m at e6 and Lmax_i. These four variables are Li, age, time since sleep onset, and time of night.

#### *C.6.5.3 Confounders*

Since there is no association between Lmax_i and any of the four effect-modifiers specified in section C.6.5.2, these four variables are no confounders.

## C.7 Motility level relscore

The fit of a model of relscore as a function of Lmax_i and SEL10_i failed because of the distribution of the values of relscore. Relscore is in about 95% of the cases equal to 0 and in the other 5% of the cases usually between 0.25 and 20. A number of random effects multi-level regression models have been tested. In one model average values of relscore have been taken (averaged over 25 or 50 values, sampled in descending order of values of Lmax_i) and a conditional multi-level regression analysis applied to the averaged results. In other models logarithmic, exponential, quadratic and root functions have been applied. Also a model with censored data was used. In all models the typical distribution of relscore remained a problem. The model that came closest to statistical significance (P = 0.079**)** is presented in this section and results are compared with results for probability of (onset of) motility. A so-called 'with zeros model' has been used, where at the one hand the probability that relscore is zero or not is modelled and next, conditional on the fact that relscore is not zero the logarithm of its value is modelled with a multi-level linear regression model. The random effects multi-level model for relscore with subjects as level has been specified as:

fit(relscore (Lmax_i, et)) = exp[f(relscore>0)]*P(relscore>0) [C24]

With:

f(relscore>0) = = $\alpha_{et} + \beta_{etrs}$*Lmax_i; [C25]

P(relscore>0) = exp ($\delta_{et} + \eta_{etm}$*Lmax_i)/(1 + exp ($\delta_{et} + \eta_{etm}$*Lmax_i)). [C26]

The model has been specified for relscore at e6 and Lmax_i only.

The model for exp_rlsc is:

fit(exp_rlsc (Lmax_i, et)) = $\alpha_{et} + \beta_{etrs}$*Lmax_i [C27]

Finally:

resp_rlsc(Lmax_i, et) = fit(relscore(Lmax_i, et)) – fit(exp_rlsc(Lmax_i, et)) [C28]

In figure C35 resp_rlsc at e6 is given as a function of Lmax_i, together with the functions for resp_m and resp_k. In comparing the three curves, it has to be taken into account that probability of motility is on average 0.04, probability of onset of motility 0.02 and relscore 0.05. Therefore, on a relative basis the increase in relscore is not larger than the increase in probability of motility. Although the relationship between relscore and Lmax_i, and consequently also the relationship between resp_rlsc and Lmax_i, is not statistical significant, the figure strongly suggests that including the level of motility in addition to the probability of motility in models, does not result in larger aircraft noise-induced effects.

## C.8 Number of marker pressings during sleep period time

Subjects have been requested to press the marker when they woke-up during sleep period time. The total number of marker pressings of all subjects during all sleep period times turned out to be 5951. More than 10% of the subjects never pressed the marker during sleep, others pressed the marker more than five times a night. The total number of marker pressings and the number of subject nights without marker pressings are too few to perform multi-level analyses. Table C5 shows the results of an analysis. There are over 7.87 million 15-s intervals within all sleep period times of all subjects. With a total number of marker pressings equal to 5951, this implies that during 0.0757% of the 15-s intervals a marker has been pressed. The 15-s intervals can be divided in intervals within aircraft noise windows and intervals outside these windows. The percentage of marker pressings during aircraft noise windows (with intervals e1 to e20) is larger than that at intervals outside aircraft noise windows (0.0807 against 0.0750). According to Fleiss (statistical methods for rates and proportions, 1981) the difference is statistical significant ($P < 0.05$, tested one-sided). The number of expected marker pressings during e1 to e20 of the aircraft noise event windows based on the probability outside these windows would be 709, and the observed number is 763, which is 7.6% higher than should be expected from the results outside the aircraft noise event windows.

It has also been analysed whether marker pressings are more frequently during the 15-s intervals e4 to e10 of the aircraft noise event windows. Also the percentage of marker pressings during e4 to e10 of the aircraft noise event intervals is statistically significant larger than outside these 15-s intervals. The number of expected marker pressings during e4 to e10 based on the probability outside these intervals would be 330, and the observed number is 357, which is 8.2% higher than should be expected from the results outside intervals e4 to e10.

To assess whether the probability of a marker pressing during an aircraft noise event increases with Lmax_i or SEL10_i of the event, four logistic regression analyses have been performed with Lmax_i or SEL10_i as independent variables, markpres as dependent variable (markpres = 1 if the marker has been pressed, markpres = 0 if the marker has not been pressed), and aircraft noise windows e1 to e20 and e4 to e10. None of the coefficients of markpres in the logistic regression equation turned out to be statistical significant different from 0; actually they appeared to be 0.000 in all four cases ($P > 0.96$).

## C.9 Worst case situations

In section C.5 of this Appendix relationships between aircraft noise metrics SEL10_i and Lmax_i and instantaneous aircraft noise-induced increase of probability of m=1 (resp_m) and of k=1 (resp_k) for each of the 7 15-s intervals e4 to e10 have been specified. The coefficients of the equations for resp_m and resp_k at e6 as a function of SEL10_i and Lmax_i have been given in

Table C2. The total increase in the 7 15-s intervals e4 to e10 of resp_m and of resp_k is about 4.6 times resp_m at e6 and about 4.2 times resp_k at e6.
The total instantaneous increase in probability of motility and of onset of motiltiy during n aircraft noise windows is given by:

increase_m (n aircraft noise events) = $4.6*(\sum [b*(SEL10\_i(p) - a) + c* (SEL10\_i(p) - a)^2])$ [C29]

increase_k (n aircraft noise events) = $4.2*(\sum [b*(SEL10\_i(p) - a) + c* (SEL10\_i(p) - a)^2])$ [C30]

with SEL10_i(p) SEL10_i of aircraft noise event p;

$\sum$ summation over n aircraft noise events during sleep period time, with for increase_m SEL10_i over 38 dB(A)) and for increase_k SEL10_i over 40 dB(A);

a, b, and c values given in table C1.

In Appendix B it has been shown that on average SEL - SEL10_i = 2 (dB(A)).By taking this difference into account resp_m can be written as:

f(SEL) = increase_m (n aircraft noise events) = $d*[b*(SEL(p) - e) + c* (SEL(p) - e)^2]$ [C31]

with $e = a + 2$, $d = 4.6$ and

a, b, and c as given for resp_m and SEL10_i in table C1.

For resp_k similar functions apply.

Mathematical it can be shown that at a given equivalent sound level during sleep there is a so-called worst case situation, in which the effect of the aircraft noise events is maximal (Passchier-Vermeer, 1995; Miedema et al, 1999). This worst case situation occurs if all SEL values are equal and the following equation applies:

$$f'(SEL) = 0.1 * \ln 10 * f(SEL) = 0.23 * f(SEL) \quad [C32]$$

where f' is the derivative of f.

In this procedure it is assumed that the effects of the aircraft noise events are independent.

If the value sel is the solution of equation C32, then:

$$d * [b + 2c * (sel - e)] = 0.23 * d * [b * (sel - e) + c * (sel - e)^2]$$

$$sel^2 + (b/c - 2/0.23 - 2*e) * sel + (e^2 - e*b/c - b/(0.23*c) + 2 * e/0.23) = 0$$

$sel = -0.5*(b/c-2/0.23-2*e)+0.5*[(b/c-2/0.23-2*e)^2-4*(e^2-e*b/c-b/(c*0.23)+2*e/0.23)]^{0.5}$

By substituting a (e = a + 2), b, and c of resp_m from table C2 in the formula, the solution for sel > a is:

sel = 45.3 dB(A) (which implies SEL10_i = 43.3 dB(A))

By substituting a (e = a + 2), b, and c of resp_k from table C2 in the formula, the solution for sel > a is:

sel = 46.6 dB(A) (which implies SEL10_i = 44.6 dB(A))

For a sleep period time of 8 hours and a given Lbi23-07h the following equation applies:

$$\text{Lbi23-07h} = sel + 10 * \lg n - 10 \lg 8*60*60 \qquad [C33]$$

With n the number of aircraft noise events with SEL equal to sel.

The solution for n is specified by:

$$n(\text{Lbi23-07h}) = 10^{(\text{Lbi23-07h}-sel+44.6)/10} \qquad [C34]$$

The maximal increase of m and k is a function of Lbi23-07h and specified by:

$$\text{max\_increase\_m}(\text{Lbi23-07h}) = 10^{(\text{Lbi23-07h}-sel+44.6)/10} * f(sel) \qquad [C35]$$

$$\text{max\_increase\_k}(\text{Lbi23-07h}) = 10^{(\text{Lbi23-07h}-sel+44.6)/10} * f(sel) \qquad [C36]$$

Thus, when f is a quadratic function of SEL that gives the probability of an effect, then the maximal effect in a night for an individual exposed to a given Lbi23-07h is found by inserting this Lbi23-07h and the above sel in the equation for the maximal increase. If Lbi23-07 is caused by events with SEL not equal to sel, then the increase is lower: max_ increase_m(Lbi23-07h) gives an upper bound for the effect of an average individual in a night. The maximal increase during a year with 365 sleep period times with equal aircraft noise exposure is equal to 365 times the values obtained by solving the equations C35 and C36.
The number of aircraft noise events during 8 hours in the worst case situation with a specific Lbi23-07h value can be found by substituting Lbi23-07h and sel in equation C34. Solutions with respect to motility and onset of motility are:

| | number of aircraft noise events | |
|---|---|---|
| Lbi23-07h in dB(A) | for max_increase_m | for max_increase_k |
| 10 | 8.5 | 6.3 |
| 20 | 85 | 63 |
| 30 | 851 | 631 |

Apparently, at the higher Lbi23-07h values, the number of aircraft noise events in the worst case situation is unrealistically high. Usually at these higher Lbi23-07h values, aircraft noise events have SEL values that are larger than 45.3 or 46.6 dB(A) (corresponding to SEL10_i values of 43.3 or 44.6).

## C.10 Tables

*Table C1 Upper point: information about the logistic regression equations of Pm and Pk as a function of Lmax_i and SEL10_i for 15-s inter-vals e4 to e10. aet is the intercept of the function, βetm and βetk the coeffi-cients of Lmax_i and SEL10_i, s2d0 and -2loglikelihood (deviance).Lower point: information about the linear regression equations of exp_m and exp_k as a function of Lmax_I and SEL10_i. ϕet are in intercept and ηet coefficients.*

| Variable | et | $\alpha_{et}$ | $\beta_{etm}$ and $\beta_{etk}$ of SEL10_i | $\beta_{etm}$ and $\beta_{etk}$ of Lmax_i | s2d0 | -2loglikelihood |
|---|---|---|---|---|---|---|
| m | 4 | -4.7126 | 0.02407 | | 0.1544 | 17432 |
| k | | -4.8692 | 0.0193 | | 0.08387 | 12474 |
| m | | -4.4266 | | 0.02357 | 0.1542 | 17428 |
| k | | -4.7195 | | 0.02069 | 0.08295 | 12468 |
| m | 5 | -5.3746 | 0.03624 | | 0.1624 | 17766 |
| k | | -5.3069 | 0.02744 | | 0.1538 | 12909 |
| m | | -5.109 | | 0.03912 | 0.1675 | 17737 |
| k | | -5.2447 | | 0.03271 | 0.1596 | 12887 |
| m | 6 | -4.7164 | 0.03677 | | 0.185 | 19246 |
| k | | -4.2947 | 0.01148 | | 0.1546 | 13946 |
| m | | -4.9467 | | 0.03842 | 0.2032 | 19181 |
| k | | -4.81 | | 0.02588 | 0.1661 | 13914 |
| m | 7 | -4.816 | 0.03856 | | 0.1617 | 18981 |
| k | | -4.4652 | 0.01383 | | 0.08792 | 13366 |
| m | | -4.9956 | | 0.03952 | 0.1812 | 18915 |
| k | | -4.7993 | | 0.02468 | 0.09917 | 13341 |
| m | 8 | -5.3178 | 0.0357 | | 0.1702 | 18039 |
| k | | -5.0251 | 0.02191 | | 0.1228 | 12570 |
| m | | -5.1427 | | 0.04046 | 0.1761 | 17998 |
| k | | -4.9796 | | 0.02626 | 0.1234 | 12555 |
| m | 9 | -4.8317 | 0.02669 | | 0.188 | 18022 |
| k | | -4.6347 | 0.01506 | | 0.1605 | 12829 |
| m | | -4.7374 | | 0.03112 | 0.1898 | 17995 |
| k | | -4.6557 | | 0.01927 | 0.1586 | 12819 |
| m | 10 | -4.4806 | 0.02084 | | 0.1319 | 18114 |
| k | | -4.4112 | 0.01171 | | 0.1032 | 12926 |
| m | | -4.3057 | | 0.02204 | 0.1319 | 18105 |
| k | | -4.2949 | | 0.012 | 0.1025 | 12924 |

| Variable | et | $\alpha_{et}$ | $\beta_{etm}$ and $\beta_{etk}$ of SEL10_i | $\beta_{etm}$ and $\beta_{etk}$ of lmax_i | s2d0 | -2loglikelihood |
|---|---|---|---|---|---|---|
| variable | e4 to e10 | $\phi_{et}$ | $\eta_{etm}$ and $\eta_{etk}$ of SEL10_i | $\eta_{etm}$ and $\eta_{etk}$ of Lmax_i | | |
| m | | 0.021233 | 5.84E-05 | | | |
| | | 0.022327 | | 4.8E-05 | | |
| k | | 0.01641 | 2.41E-05 | | | |
| | | 0.017037 | | 1.57E-05 | | |

*Table C2* *Coefficients of the quadratic equation of resp_m and resp_k as a function of SEL10_i and Lmax_i for interval e6 (the interval at which Lmax_i of an aircraft noise event occurs). The equations are applicable to the range of SEL10_1 or Lmax_i from at least a up to SEL10_i equal to 80 dB(A) or Lmax_i equal to 70 dB(A). At values below a, resp_m and resp_k are zero.*

| | resp_m | resp_k |
|---|---|---|
| aircraft noise event metric SEL10_i | | |
| a | 38 | 40 |
| b | 0.000532 | 0.000273 |
| c | $2.68*10^{-5}$ | $3.57*10^{-6}$ |
| aircraft noise event metric Lmax_i | | |
| a | 32 | 32 |
| b | 0.000633 | 0.000415 |
| c | $3.14*10^{-5}$ | $8.84*10^{-6}$ |

*Table C3* *Number and percentage of aircraft noise events on the indoor noise monitors during sleep period times of subjects with period of the night in five classes*

| time interval (clock-time) | number of aircraft noise events during sleep period times | percentage of aircraft noise events during sleep period times |
|---|---|---|
| 22 - 23 hours | 696 | 1.1 |
| 23 - 24 hours | 2529 | 4.0 |
| 24 - 6 hours | 23905 | 37.8 |
| 6 - 7 hours | 16823 | 26.6 |
| > 7 hours | 19289 | 30.5 |
| total | 63242 | 100 |

*Table C4 Variables considered as possible determinants in relationship of resp_m and Lmax_i at e6.*

| Variable | Description |
|---|---|
| c1b | Perception aircraft noise |
| c2b | Annoyance aircraft noise |
| d1b | Perception night-time aircraft noise |
| d2b | Awakening by night-time aircraft noise |
| d3b | Annoyance night-time aircraft noise |
| f3 | Attitude towards Schiphol |
| f7 | Dissatisfaction with aircraft noise around the house |
| f8 | Afraid of health impact by aircraft noise |
| gez1 | Subjective experienced health |
| slaapkwa | Sleep quality |
| slsom | Number of general sleep disturbances |
| vliegsom | Number of aircraft noise complaints per week |
| voegn | Health score during night-time |
| f6b_sum | Sum reasons frightened of aircraft noise |
| e1_3n | Safety: recognising own situation as living under a flight path |
| e_3 | Worried about living under a flight path |
| sensi | Noise sensitivity |
| sleepeff | Use of effective sleeping pills |

*Table C5 Information about marker pressings of subjects during sleep period times to indicate intermittent awakening.*

| intervals | number of 15-s intervals | number of marker pressings | percentage of 15-s intervals with a marker pressing |
|---|---|---|---|
| aircraft noise window e1 to e20 | | | |
| outside window | 6918960 | 5188 | 0.0750 |
| inside window | 945939 | 763 | 0.0807 |
| total | 7864899 | 5951 | 0.0757 |
| aircraft noise window e4 to e10 | | | |
| outside window | 7426275 | 5594 | 0.0753 |
| inside window | 438624 | 357 | 0.0814 |
| total | 7864899 | 5951 | 0.0757 |

## C.10 Figures

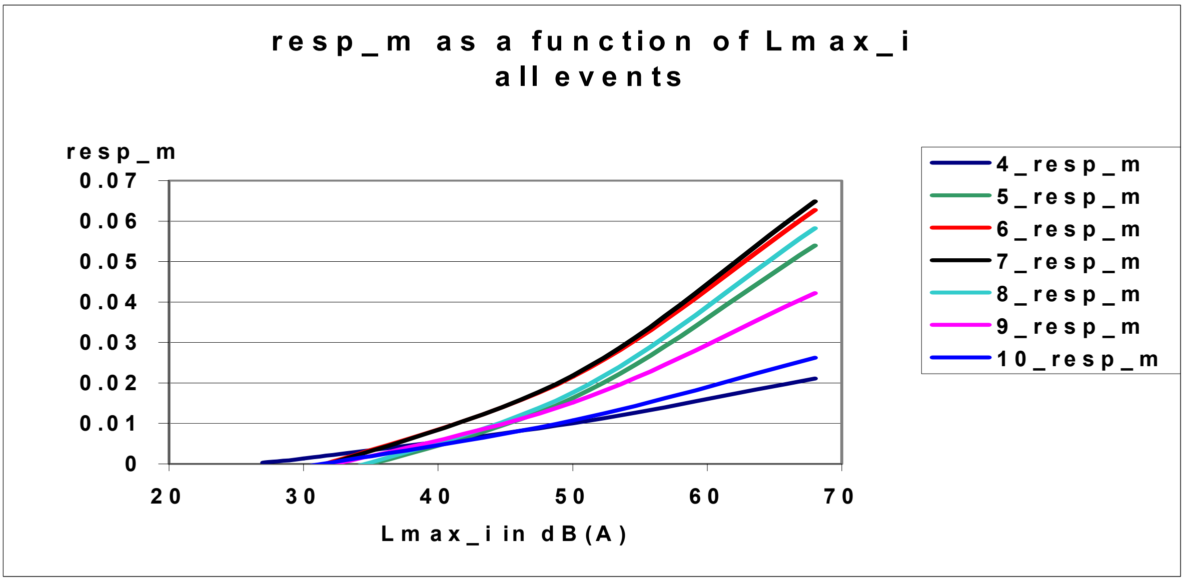


*Figure C6:* *Resp_m as a function of Lmax_i (indoor maximal sound level of an aircraft noise event) for 15-s intervals e4 to e10. The interval during which Lmax_i occurs is e6.*

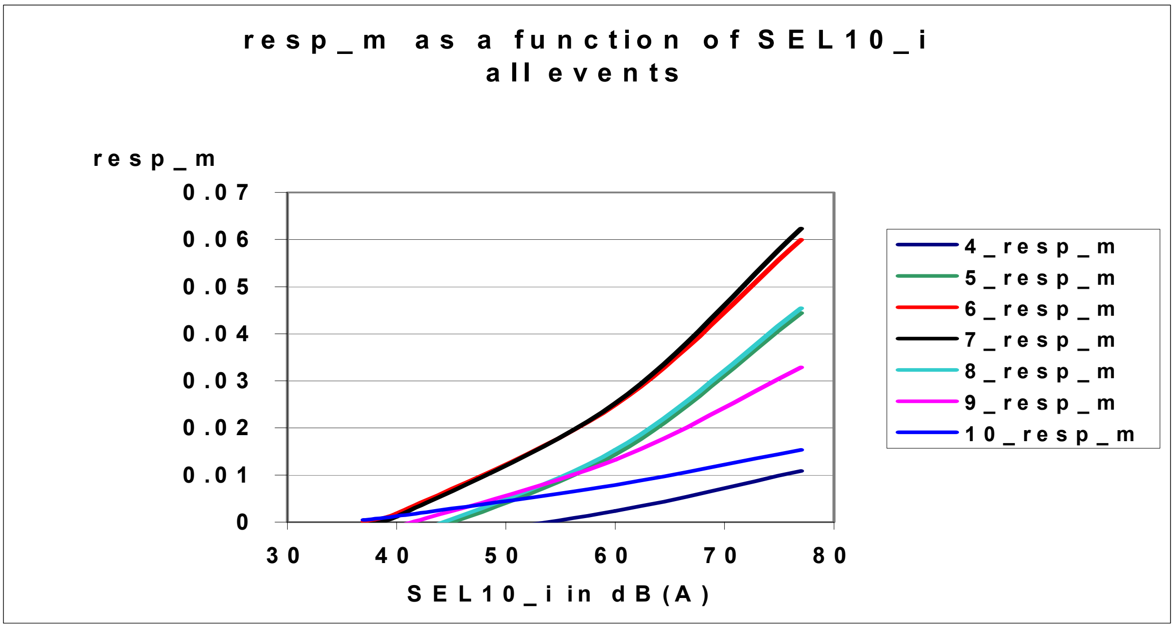


*Figure C7:* *Resp_m as a function of SEL10_i (indoor Sound Exposure Level) for 15-s intervals e4 to e10. The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is e6.*

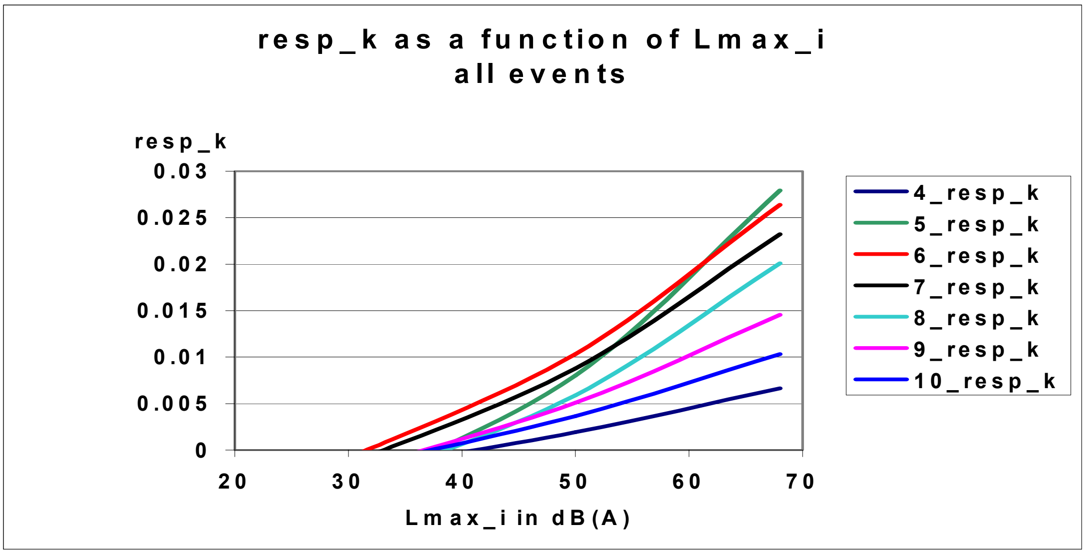


*Figure C8:* *Resp_k as a function of Lmax_i (indoor maximal sound level of an aircraft noise event) for 15-s intervals e4 to e10. The interval during which Lmax_i occurs is e6.*

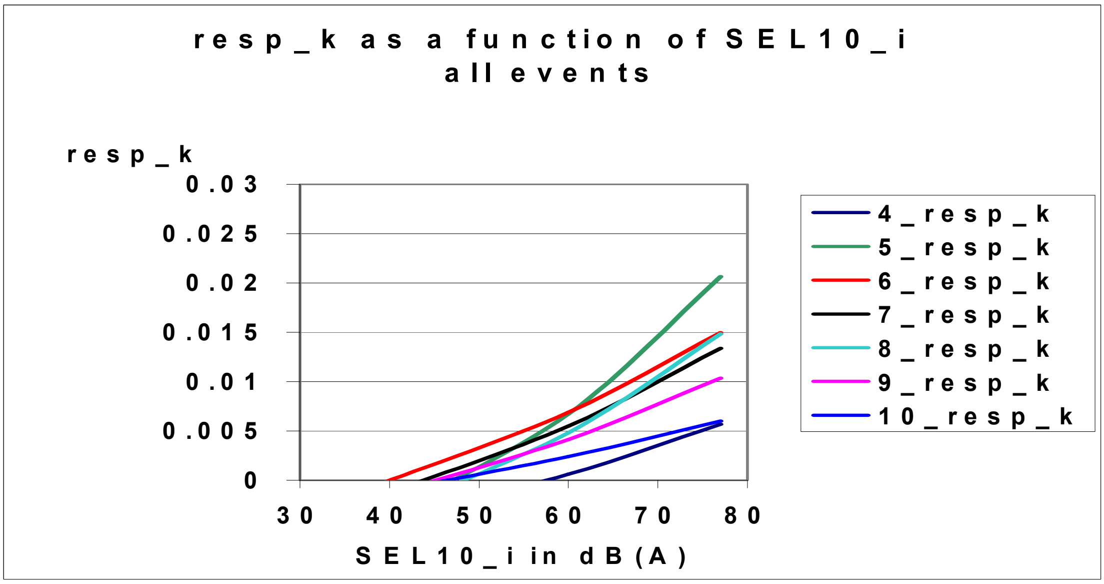


*Figure C9:* *Resp_k as a function of SEL10_i (indoor Sound Exposure Level) for 15-s intervals e4 to e10. The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is e6.*

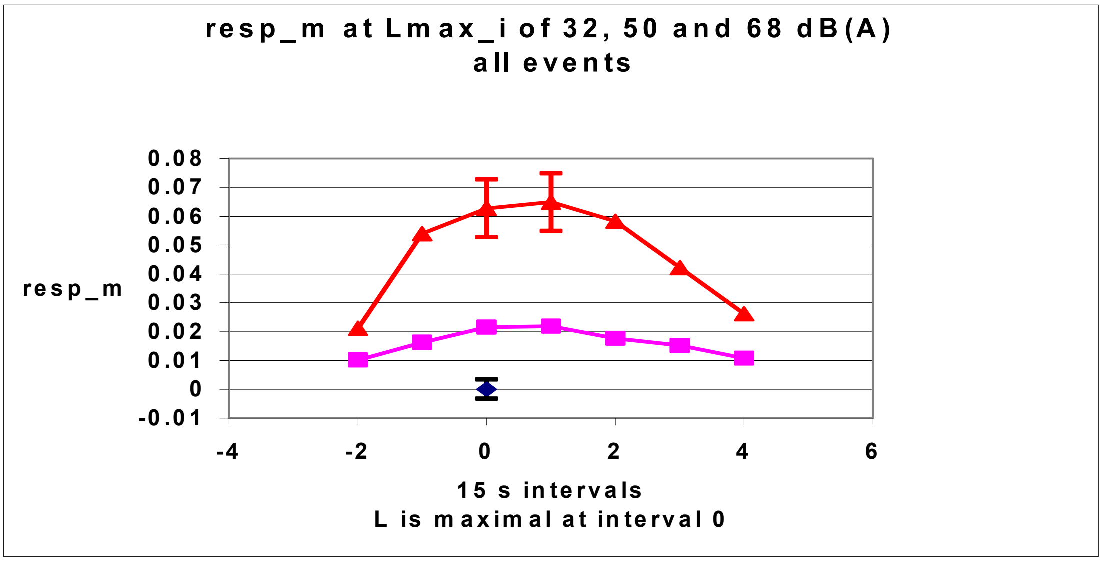


*Figure C10:* *Resp_m as a function of time in 15-s intervals for aircraft noise events with Lmax_i equal to 32, 50 and 68 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0. Vertical bars represent 95% confidence interval*

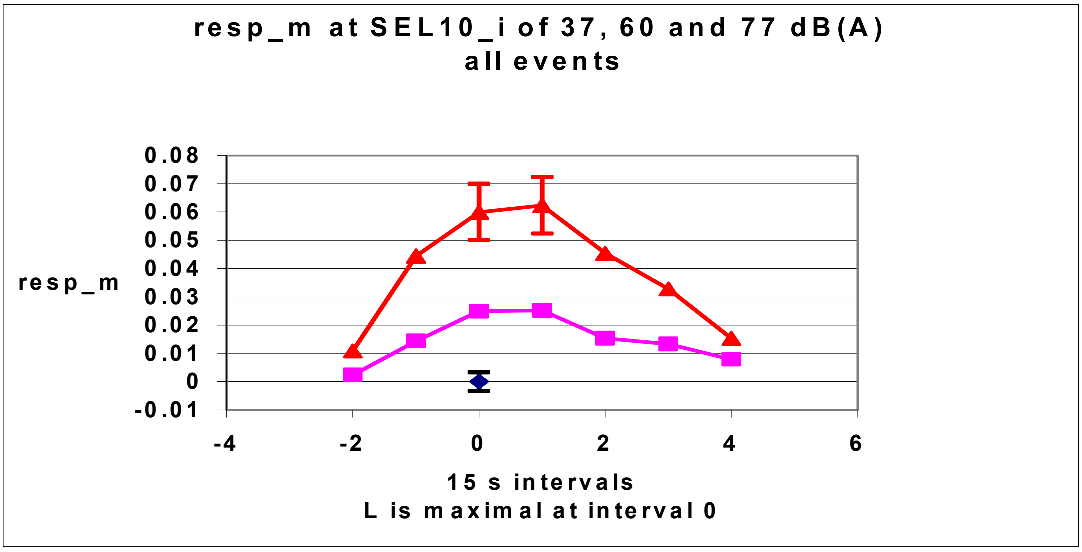


*Figure C11:* *Resp_m as a function of time in 15-s intervals for aircraft noise events with SEL10_i equal to 37, 60 and 77 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0. Vertical bars represent 95% confidence interval.*

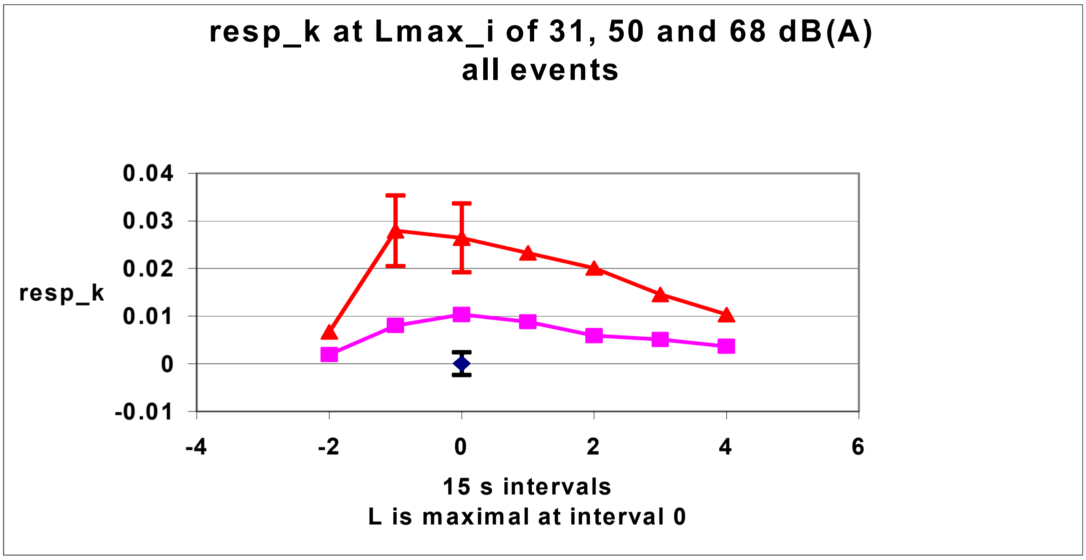


*Figure C12:* *Resp_k as a function of time in 15-s intervals for aircraft noise events with Lmax_i equal to 31, 50 and 68 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0. Vertical bars represent 95% confidence interval.*

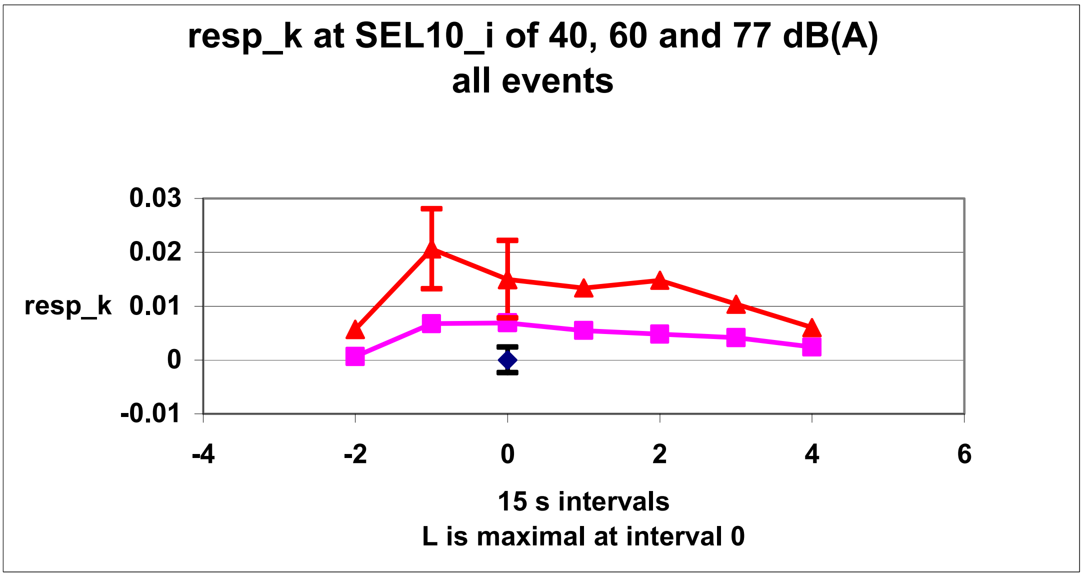


*Figure C13:* *Resp_k as a function of time in 15-s intervals for aircraft noise events with SEL10_i equal to 40, 60 and 77 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0. Vertical bars represent 95% confidence interval.*

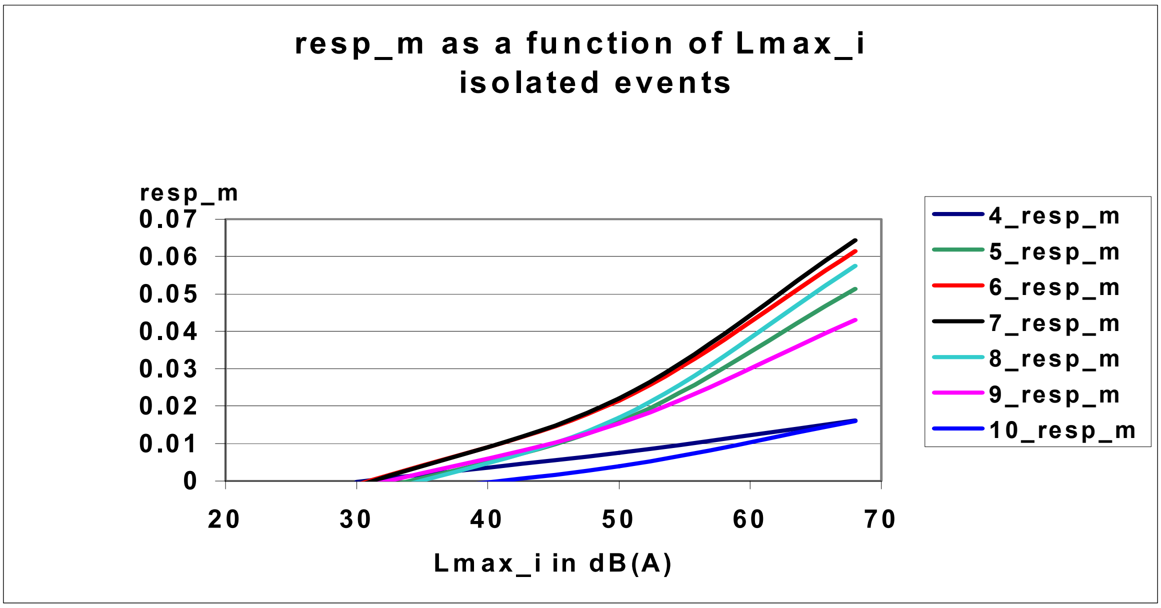


*Figure C14:* *Resp_m as a function of Lmax_i (indoor maximal sound level of an aircraft noise event) for 15-s intervals e4 to e10. The interval during which Lmax_i occurs is e6. Isolated aircraft noise events.*


*Figure C15:* *Resp_m as a function of SEL10_i (indoor Sound Exposure Level) for 15-s intervals e4 to e10. The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is e6. Isolated aircraft noise events.*

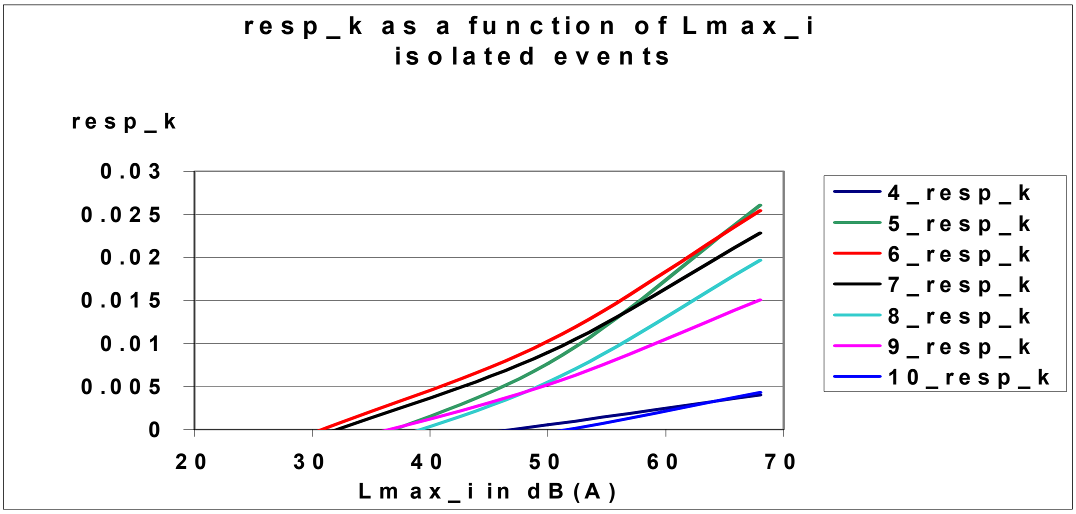


*Figure C16:* *Resp_k as a function of Lmax_i (indoor maximal sound level of an aircraft noise event) for 15-s intervals e4 to e10. The interval during which Lmax_i occurs is e6. Isolated aircraft noise events*

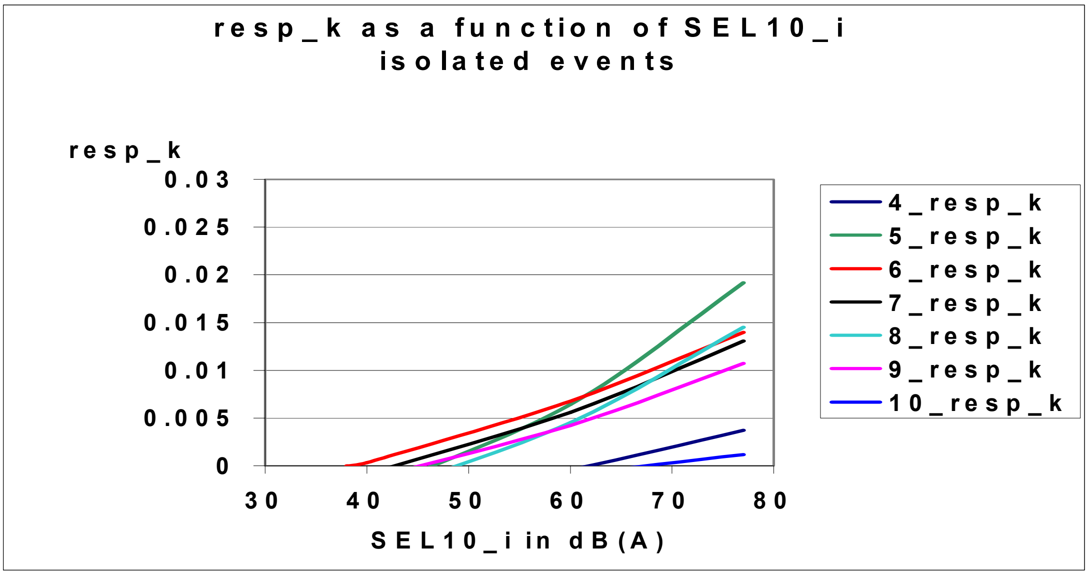


*Figure C17:* *Resp_k as a function of SEL10_i (indoor Sound Exposure Level) for 15-s intervals e4 to e10. The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is e6. Isolated aircraft noise events.*

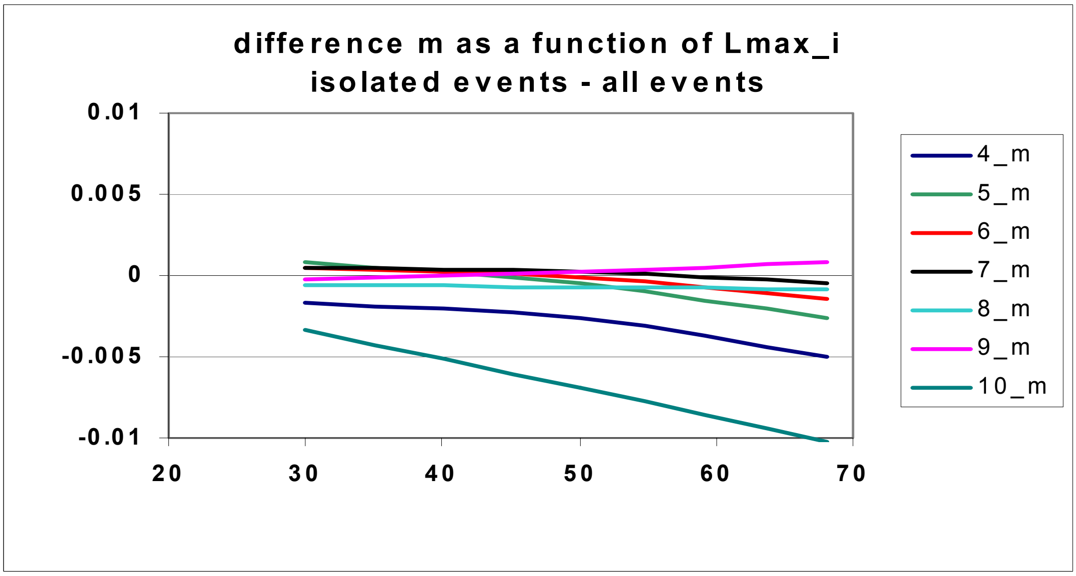


*Figure C18: Difference between resp_m for isolated aircraft noise events and all aircraft noise events as a function of Lmax_i in dB(A).*

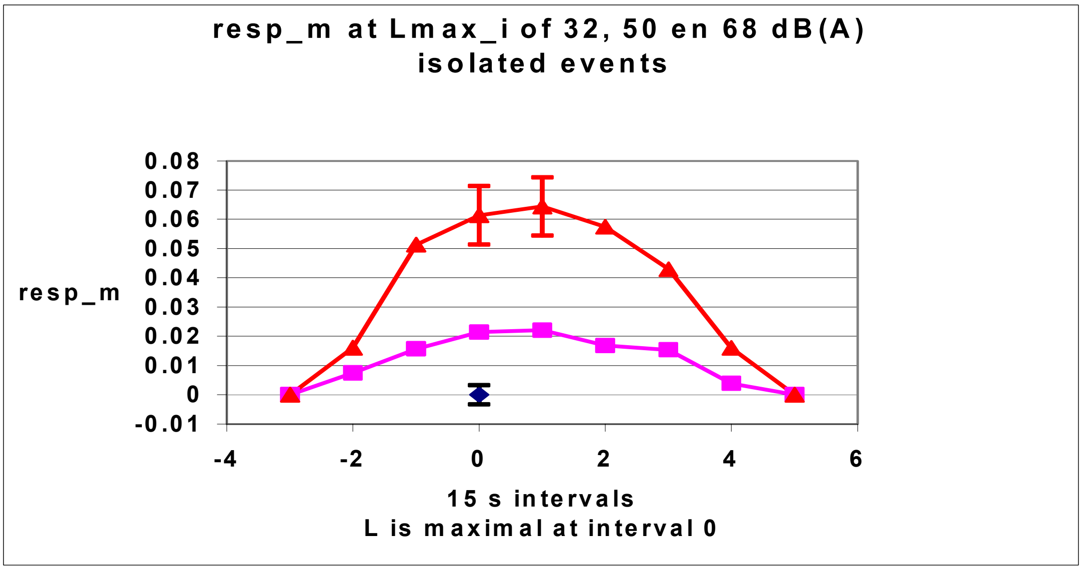


*Figure C19: Resp_m as a function of time in 15-s intervals for aircraft noise events with Lmax_i equal to 32, 50 and 68 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0. Vertical bars represent 95% confidence interval. Isolated aircraft noise events.*

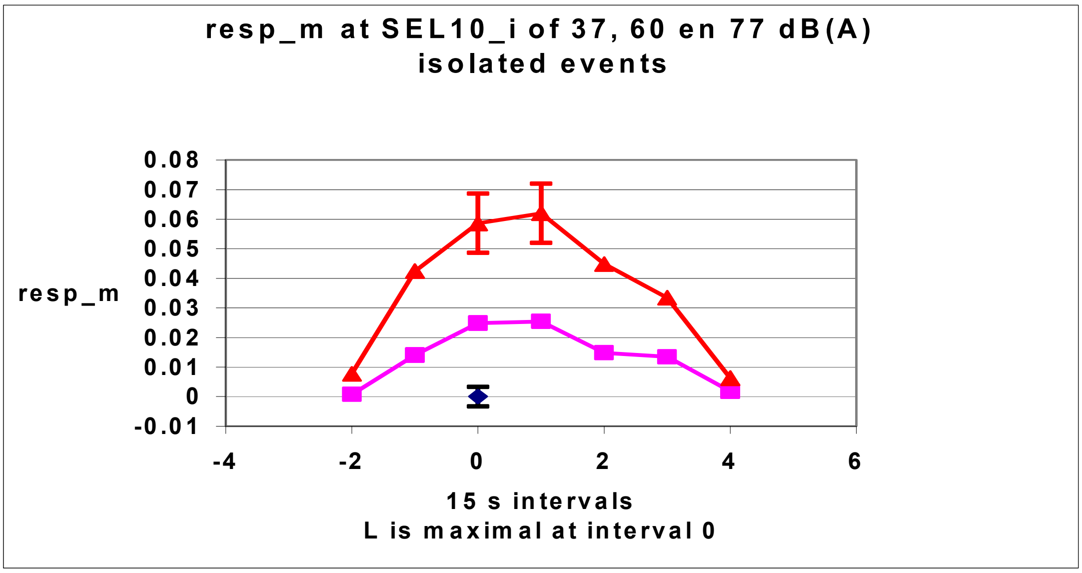


*Figure C20:* *Resp_m as a function of time in 15-s intervals for aircraft noise events with SEL10_i equal to 37, 60 and 77 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0. Vertical bars represent 95% confidence interval. Isolated aircraft noise events*

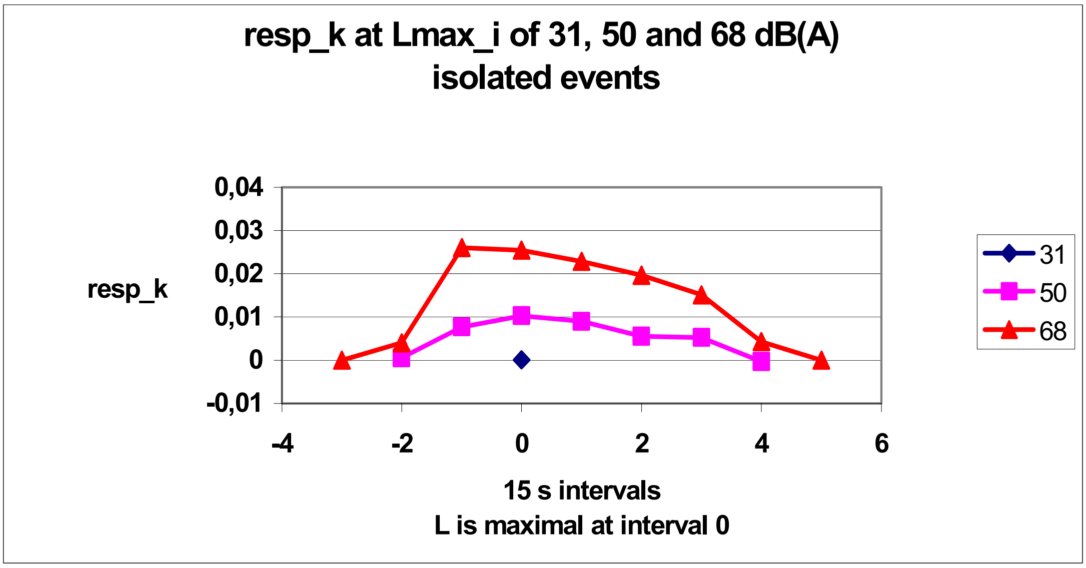


*Figure C21:* *Resp_k as a function of time in 15-s intervals for aircraft noise events with Lmax_i equal to 31, 50 and 68 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0. Isolated aircraft noise events.*

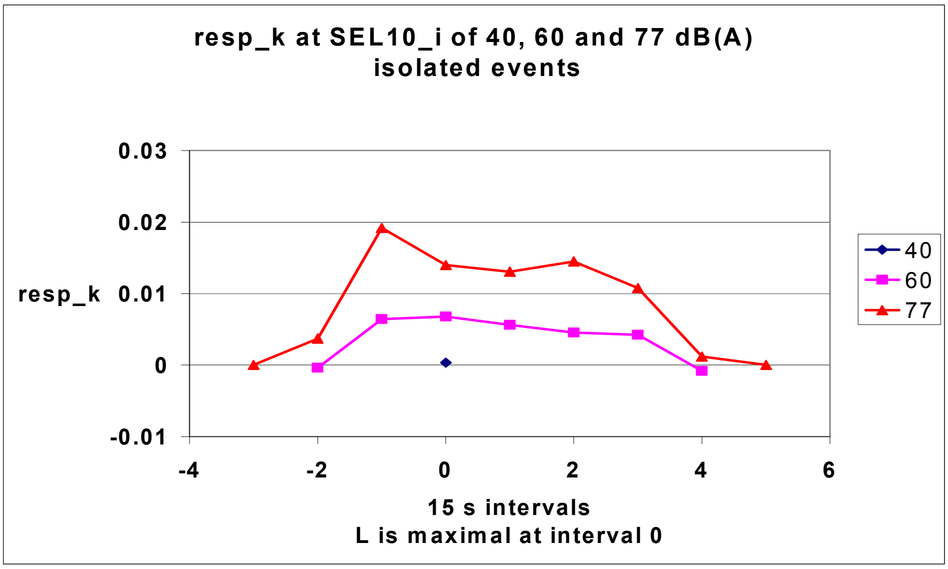


*Figure C22:* *Resp_k as a function of time in 15-s intervals for aircraft noise events with SEL10_i equal to 40, 60 and 77 dB(A). The interval during which Lmax_i (indoor maximal sound level of an aircraft noise event) occurs is interval 0. Isolated aircraft noise events.*


*Figure C23:* *Resp_m at e6 (interval during which Lmax_i occurs) as a function of SEL10_i for all events. Broken lines represent 95% confidence intervals.*

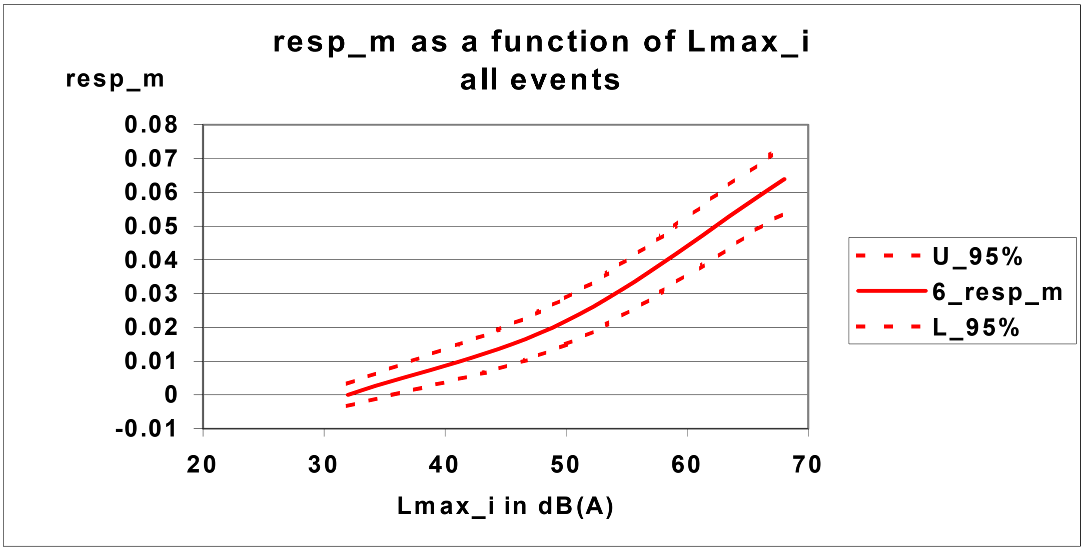


*Figure C24:* *Resp_m at e6 (interval during which Lmax_i occurs) as a function of Lmax_i for all events. Broken lines represent 95% confidence intervals*


*Figure C25:* *Resp_k at e6 (interval during which Lmax_i occurs) as a function of SEL10_i for all events. Broken lines represent 95% confidence intervals .*

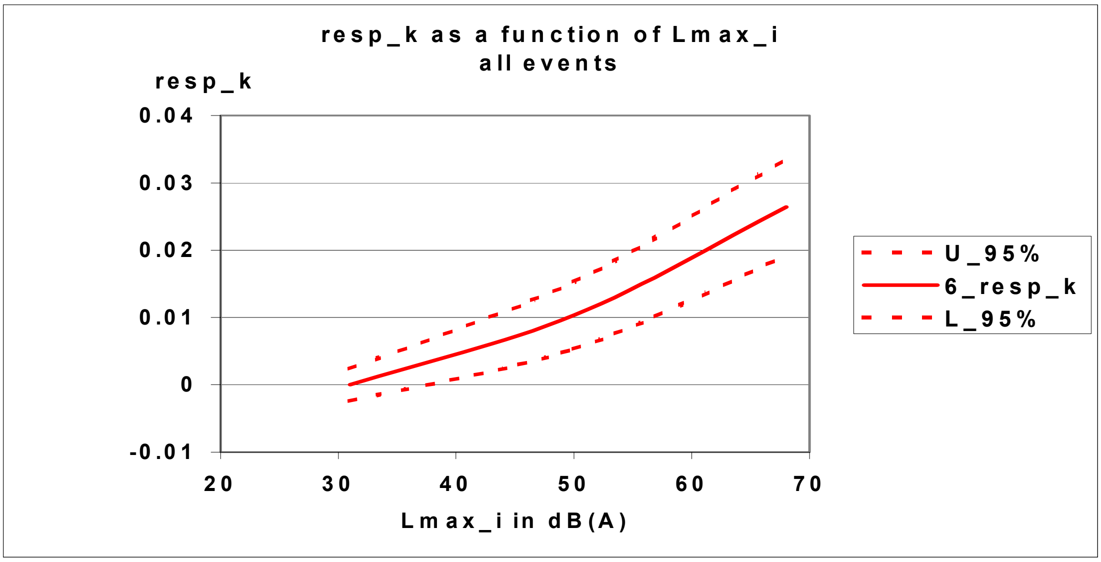


*Figure C26: Resp_k at e6 (interval during which Lmax_i occurs) as a function of Lmax_i for all events. Broken lines represent 95% confidence intervals .*

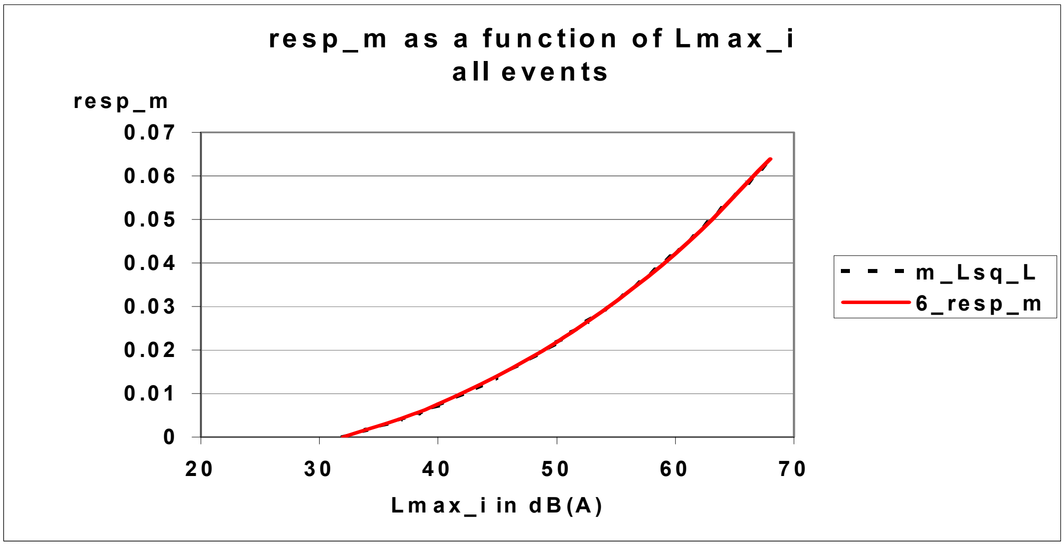


*Figure C27: Quadratic approximations of the function of resp_m over Lmax_i.*

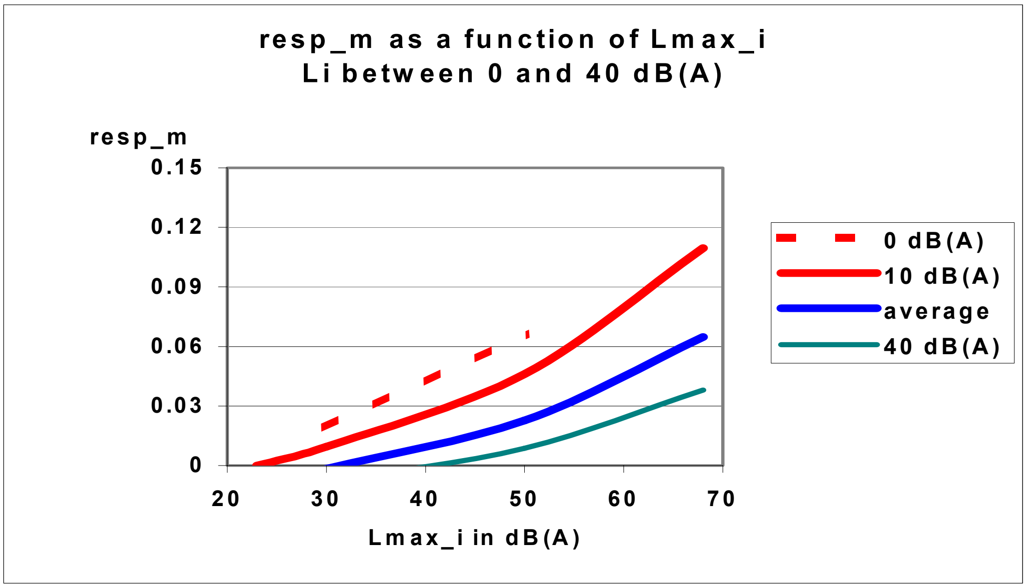


*Figure C28:* *Resp_m as a function of Lmax_i. Average function without Li as intervening variable, functions for Li equal to 0, 10, and 40 dB(A).*

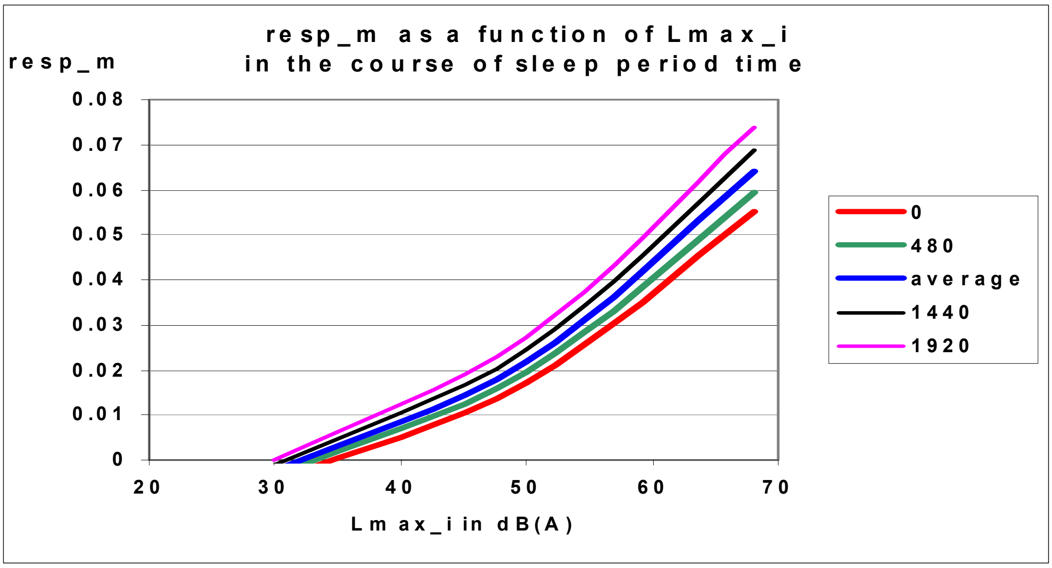


*Figure C29:* *Resp_m as a function of Lmax_i for various values of x (number of interval after sleep onset. Average function without x as intervening variable, functions for x equal to 0(sleep onset), 480 (2 hours after sleep onset), 1440 (6 hours after sleep onset) and 1960 (8 hours after sleep onset).*

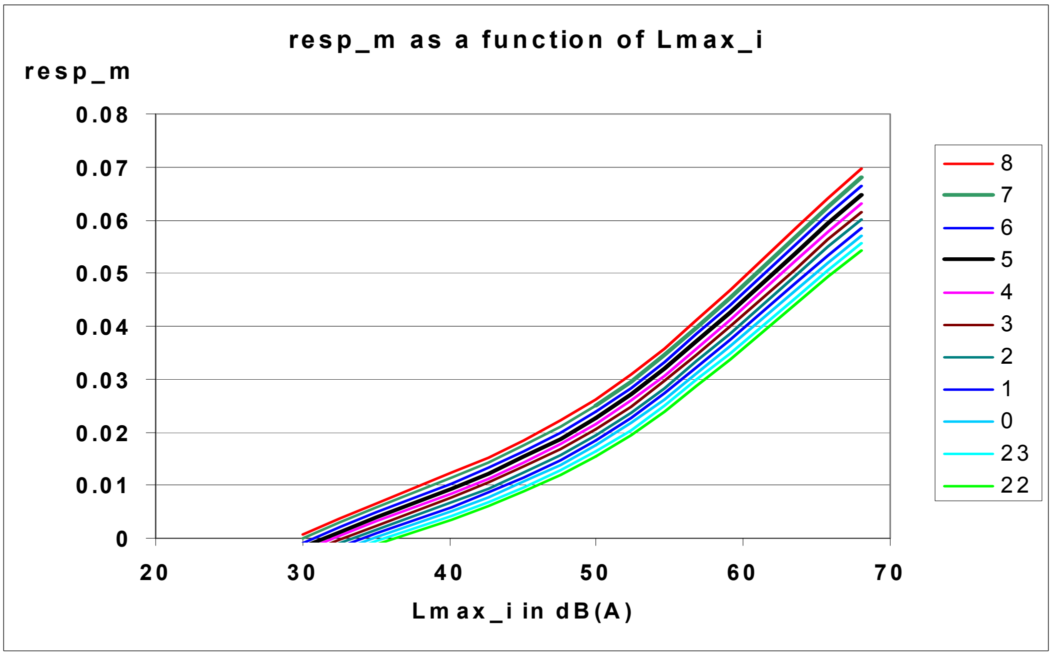


*Figure C30:* *Resp_m as a function of Lmax_i for hours of the night: 22 22-23 hours etc..*

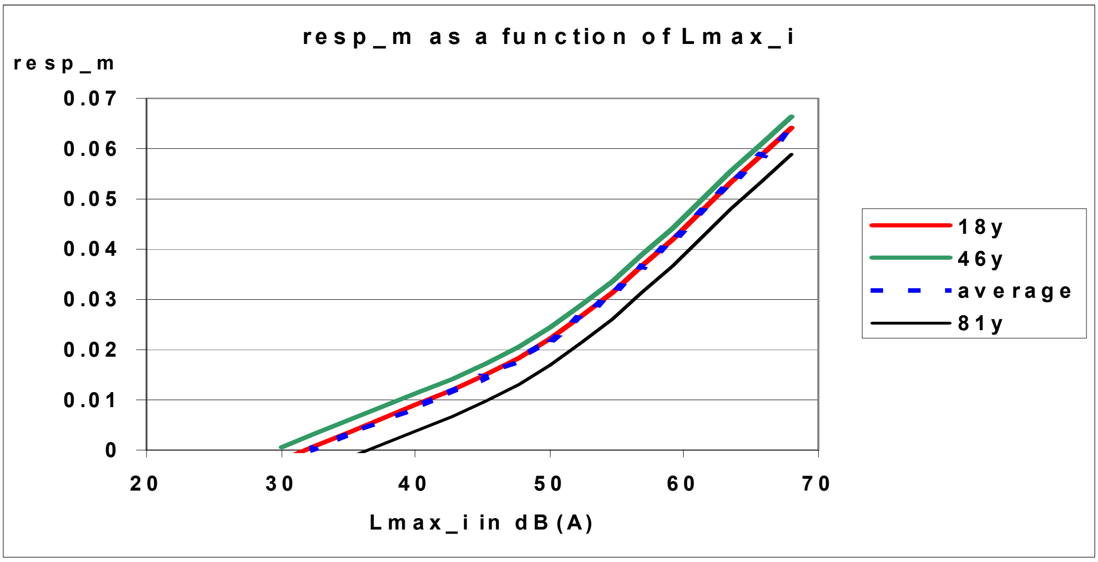


*Figure C31:* *Resp_m as a function of Lmax_i for various ages of subjects. Average function without age as intervening variable, functions for ages 18, 46 and 81 years.*

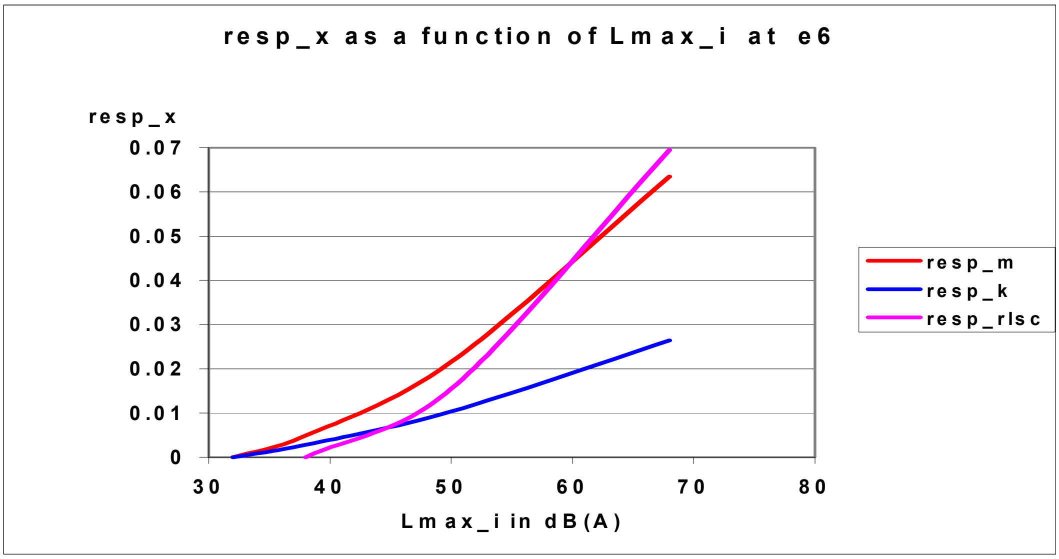


*Figure C32: Relationships between Lmax_i and resp_m, resp_k, and resp_rlsc.*

# Appendix D Analyses for relationships of 24-hours variables

## D.1 Introduction

This Appendix is related to data obtained on a 24 hours basis. The subjects participated in the study during one interval from a Monday evening starting at 22 hours until a Friday morning 11 days later. Participation in the study included the following tasks of subjects during each of the 11 participation days:

- Filling out a morning- and evening diary on a laptop made available to the subjects by TNO (the English translation of the diaries is given in report 2001.205);
- Performing a reaction time test on the laptop just before going to bed;
- Filling out a sleepiness strip five times during day and evening and wearing a watch which produced a noise signal at the times the sleepiness strip had to be filled out;
- Wearing an actimeter during 24 hours. The actimeter is equipped with an event marker.

At 15 locations 418 subjects participated in the study for eleven 24 hours periods, including eleven sleep period times. This implies a data base consisting of 4598 subject nights. Due to various reasons some data is missing. Some of these reasons are: subjects spent the night not at home, e.g. due to personal circumstances, subjects did go to bed after termination of the noise measurements at 9 hours in the morning (particular young subjects on Saturday and Sunday morning), subjects did not perform their tasks, such as filling out the evening and morning diary, or performing the reaction time test, or filling out the sleepiness strip during day and evening-time, failure of equipment, lay-out of the study, which required subjects to fill out the sleepiness strip for only ten days and evenings. On average, the number of available responses in the evening diary is about 4480, in the morning diary about 4500, number of sleepiness strips filled out about 4000, number of reaction time tests about 4380, information about (aircraft) noise exposure about 4570 nights, information obtained by actimetry about 4500 nights.

In TNO report 2001.205 (chapter 4) detailed information is given about the results obtained with the evening and morning diary.

Analyses have been carried out for the following periods before and during sleep period time:

. sleep period time;
. edges of the night (23 - 24 hours, and 6 - 7 hours);
. sleep latency time.

In chapter 3 the model is given which is the basis for the analyses in this Appendix.

This Appendix has been structured as follows. In section D.2 exposure-effect relationships are presented: section D.2.1 concerns sleep period time, section D.2.2 the edges of the night, and section D.2.3 sleep latency time. Section D.3 considers the association between effect variables and in section D.4 the results about the use of sleeping pills are given. Tables with the results of the analyses are presented in section D.5 and figures in section D.6.

## D.2 Exposure-effect relationships

### D.2.1 Sleep period time

#### D.2.1.1 Introduction

Random effects multi-level regression analyses, with subjects as first level have been carried out. The presence of the random effect is tested, using the deviance of the models with and without a random effect, with a chi-squared test. It turned out that the random effects are highly significant.

The following aircraft noise exposure variables have been considered:
- Liaspt: equivalent sound level during sleep period time of a subject;
- niaspt: number of aircraft noise events detected on the indoor noise monitor during sleep period time of a subject.

The following effect variables have been used in the analyses:
- mspt, kspt, rlscspt;
- sleep quality assessed in the morning diary on a 5 and 11 points scale;
- fragmentation index;
- number of marker pressings per night;
- number of remembered awakenings per night;
- results of the reaction time test performed during the evening, in relation to aircraft noise exposure during the preceding sleep period time;
- sleepiness during day- and evening-time, in relation to aircraft noise exposure during the preceding sleep period time.

Possible determinants considered are:
- Demographic variables: age (and age*age), gender, citizenship, composition of household, education, country of birth;
- Lo – Li (difference between outdoor and indoor aircraft noise equivalent sound level over sleep period times);
- L50 (median value of L (equivalent sound level during a 15-s interval) during a sleep period time outside aircraft noise windows;
- Variables obtained from the evening and morning diary, such as:
  - number of cups of coffee and alcoholic drinks in the evening;
  - number of times smoked during the evening;
  - duration of naps during day and evening-time;
  - personal hearing protection used;
  - sleepiness before going to bed;
  - use of sleeping pills or drugs able to increase sleepiness and/or sleep depth;
  - reason or not of difficulty to fall asleep (reason_cl: specific reason for difficulty to fall asleep: 1 reason mentioned in the morning diary, 0 no specific reason mentioned);

- aircraft noise reason for difficulty to fall asleep (reason_ac: reason for difficulty to fall asleep is aircraft noise: 1 aircraft noise mentioned in the morning diary, 0 aircraft noise not mentioned);
- sleepiness during day- and evening-time, in relation to aircraft noise exposure during the preceding sleep period time;

• Variables obtained from the questionnaire:

| Label variable | Description |
|---|---|
| c1b | Perception of aircraft noise |
| c2b | Annoyance due to aircraft noise |
| d1b | Perception of night-time aircraft noise |
| d2b | Awakening by night-time aircraft noise (5 points scale, 1 nearly each night, 5 never) |
| d3b | Annoyance due to night-time aircraft noise |
| f6a | Sometimes afraid of aircraft noise |
| f6b | Frequency of being afraid of aircraft noise |
| f7 | Dissatisfaction with aircraft noise around the house |
| f8 | Afraid of health impact by aircraft noise |
| gez1 | Experienced health |
| slaapkwa | Sleep quality |
| slsom | Number of general sleep disturbances |
| vliegsom | Number of effects on sleep by aircraft noise per week |
| voegd | Health score evaluated for 24 hours |
| voegn | Health score evaluated for night-time |
| sensi | Noise sensitivity assessed by the Weinstein list |
| f6b_sum | Sum reasons frightened of aircraft noise |
| e1_3n | Safety: recognising own situation as living under a flight path |
| e1_7n | Safety: recognising own situation living in the vicinity of a large airport |
| e_3 | Worried about living under a flight path |
| e_7 | Worried about living in the vicinity of a large airport |

The equation of the relationship between an effect variable y, an aircraft noise exposure metric A and possible associated variables and determinants V2 to Vx is given by:

$$y(A,V2, \ldots,Vx) = constant + b1*A + b2*V2 + b3*V3 + + bx*Vx + \varepsilon_{ij} \qquad [D1]$$

in which:

b1, ,bx are regression coefficients of A , V2, …,Vx;
$\varepsilon_{ij}$ is a random level 1 noise component with mean value equal to 0 and variance $\sigma^2$.

If for V2 and V3 age and age*age are substituted, formula D1 becomes:

$$y = constant + b1*A + b2*age + b3*age*age + \ldots \qquad [D2]$$

If b3 is negative, the function b2*age + b3*age*age has a maximum, if b3 is positive, this function has a minimum.

For some variables it has been considered whether they are effect-modifiers, i.e. whether an interaction term of the format A*V in addition to the variables A and V has a statistical significant regression coefficient. This turned out to be the case only once, see section D.2.1.2, step 2.

### D.2.1.2 Analyses and results for mspt, kspt, and rlscspt

In this section the analyses are described, and the results given and discussed.
The analyses consisted of the following steps:

1. Each of the effect variables mspt, kspt, and rlscspt has been entered in a multi-level linear regression analysis with Liaspt and niaspt as independent variables. For each relationship the coefficient of the effect variable turned out to be statistical significant ($P < 0.05$) and in accordance with the model in which adverse effects due to aircraft noise exposure increase with increasing aircraft noise exposure;
2. Demographic variables have been added as possible determinants. It turned out that only age, age*age and country of birth have a statistical significant coefficient. The results are given in table D.1 for the relationships with age and age*age as determinants (upper and lowest part of the table), and for the relationship between Liaspt and effect variables, and age, age*age, and country of birth as determinants. In figures D1 to D6 the results are presented graphically with age and age*age as determinants. As an example, in figure D7 mspt is given as a function of age for two values of Liaspt. The interaction term Liaspt*age has a statistical significant regression coefficient. At age 46 years the increase in mspt as a function of Liaspt is larger than at age 18 and 81 years. Therefore, although mspt at the age of 46 years is smaller than at lower and higher ages, the effect of aircraft noise exposure at the age of 46 years is larger;
3. L50 added as possible determinant with age and age*age already included as determinants in the relationship. The coefficient of L50 is statistically significant. The results are given in table D2 (upper part). An example for mspt and Liaspt is given in figure D8. Obviously the effect of aircraft noise exposure during the night, although statistical significant, is less than effects of age and L50. It is clear that mspt increases with increase in L50;
4. Lo – Li added as possible determinant with age and age*age already included as determinants in the relationship. The coefficient of Lo – Li is statistically significant. The results are given in table D2 (lower part). An example is given in figure D9. Obviously, since mspt, kspt and rlscspt decrease with increasing values of Lo – Li, ‘sound insulation of the bedroom’ has an effect on mean motility;
5. The following variables from the morning diary turned out to be determinants, in addition to age and age*age: reason_cl (reason for difficulty to fall asleep), reason_ac (difficulty to fall asleep due to aircraft noise), number of cups of coffee and number of times smoked in the evening, duration of naps during day and evening-time, and the use of sleeping pills, effec-

tive to induce sleepiness and deeper sleep. The coefficients are given in table D3, lower part. Figures for mspt and Liaspt with determinants are given in figures D10 and D11. It is obvious that having reasons for difficulty to fall asleep have an effect on mean mspt. This is especially appropriate if aircraft noise is the reason for difficulty to fall asleep;

6. To specify determinants obtained from the questionnaire, backward step linear regression analyses have been performed with Liaspt, age, age*age , and the variables from the questionnaire as independent variables. The only determinant turned out to be awakening by night-time aircraft noise. The coefficients of the relationships are given in table D3. An example is given in figure D12. Subjects indicating that they awake (nearly) each night by aircraft noise (awake = 1) show higher values of mspt, kspt and rlscspt than subjects that indicate to be never awakened by aircraft noise (awake = 5);
7. To specify confounders, the asscociation between determinants of mspt, kspt, and rlscspt and Liaspt has been considered. Only L50 is statistically significant associated with Liaspt. The association is weak. If Liaspt increases by 35 dB(A), L50 increases with 0.5 dB(A). The effect of an increase in L50 on mspt is an increase in mspt of 0.00028. This increase is 7% of the increase in mspt if Liaspt increases by 35 dB(A) according to the regression equation in table D2.

#### D.2.1.3 Analyses of sleep quality and fragmentation index

There turned out to be no statistical significant relationship between sleep quality and Liaspt or niaspt, for both ratings (on a 11- and 5-points scale). The coefficients of the relationships between fragmentation index and Liaspt and niaspt are given in table D4. Figures are given in figures D13and D14.

#### D.2.1.4 Analyses for remembered awakenings and marker pressings

Both, number of marker pressings and number of remembered awakenings are statistical significant related to Liaspt and niaspt. Results are given in table D4, second and third row and figures D15 to D18. From the equations it turned out that number of marker pressings and number of remembered awakenings are maximal at ages between 78 to 86. Therefore no results are given for the age at which these functions are maximal, since they nearly coincide with curves for age 81 years.
Subjects had the opportunity to indicate whether they have been awakened during sleep period time by outdoor noise and if so, what type of noise did wake them up. In total, after 151 subject nights a subject noted down at least once to have been awakened during sleep by aircraft noise (with for eight nights more than once). In a logistic regression analysis the probabilty of remembering to having been awakened (at least one) by aircraft noise during a night has been assessed as a function of Liaspt. The result is given in figure D19. Coefficients have been included in table D4.

In table D5 the association between number of remembered awakenings and number of marker pressings is given. The correlation coefficient is 0.58.

### D.2.1.5 Analyses of awakening in the morning and sleepiness during day and evening-time

Table 24 of report 2001.205 shows that in 21 subjects nights (0.5%) subjects claim to have been awakened by aircraft noise at the end of sleep period time. This number is considered too low to use this variable in an analysis.

Sleepiness has been assessed on a 9 point scale seven times during day and evening: after getting out of bed (in the morning diary), five times during day and evening-time from at 10 hours to20 hours, once in the evening diary before going to sleep. All seven sleepiness variables showed a statistical significant increase with Liaspt during the night before the strip has been filled out (sleepiness increases with increasing night-time aircraft noise exposure). However, after adding age and age*age as determinants, only the coefficient of 'sleepiness at 10 hours in the morning' remained statistical significant. The result is given in table D4 (last column). For each of the seven times sleepiness has been assessed, sleepiness is given as a function of age in figure D20.

### D.2.1.6 Analyses and results for reaction time tests

The results of the reaction time test are specified by five variables: number of mistakes (pressing the computer bar too early), median value and value exceeded in 10% of the 90 trials and median value and value exceeded in 10% of the last 45 trials. The coefficients of each of these five variables in the possible relationship with Liaspt or niaspt turned out to be not statistical significant. The relationships between reaction time variables and age are given in figures D21 and D22.

Mspt has a statistical relationship (P = 0.046) only with number of mistakes, and not with reaction time variables. The number of mistakes increases with on average 0.25 if mspt increases from 0.014 (5% value of mspt) to 0.071 (95% value of mspt). Kspt and rlscspt have no statistical significant relationships with any reaction time test variable.

### D.2.2 Edges of the night

*23 to 24 hours*
At about one third of the nights, subjects are asleep before 23 hours. Based on the data obtained during these nights it has been analysed whether the aircraft equivalent sound level from 23 to 24 hours has an effect on the relationships between Liaspt and the effect variables mean motility, number of marker pressings, number of remembered awakenings due to aircraft noise. None of these three relationships appeared to be influenced by the aircraft equivalent sound level between 23 and 24 hours. Therefore aircraft between 23 and 24 hours does not have a special effect on the relationships. Aircraft between 23 and 24 hours contributes about 3.5 to 4% to a total effect (such as increase in motility, increase in number of marker pressings, increase in number of remembered awakenings due to aircraft noise) of night-time aircraft noise during a sleep period time. For an hour between 24 and 6 hours the percentage of 6 to 6.3% applies.

*6 to 7 hours*
About half the sleep period times (2233: 49%) end after 7 hours. It is therefore possible to use 49% of the subject nights to assess whether the effect of aircraft noise exposure from 6 to 7 hours differs from the effect earlier in the night. The available data have been analysed in various ways. Statistical significant differences have not been assessed.

One of the methods consisted of dividing the subject nights, for the subject nights with the subject asleep until after 7 hours, in two groups:

- group 1: relatively high aircraft noise exposure between 6 and 7 hours - aircraft noise exposure from 6 to 7 hours (Lia06) at least 7 dB(A) larger than aircraft noise exposure from sleep onset up to 6 hours: Lia06 – Lia_06 >= 7 dB(A);
- group 2: relatively low aircraft noise exposure between 6 and 7 hours - aircraft noise exposure from 6 to 7 hours (Lia06) 7 dB(A) or more less than aircraft noise exposure (Lia_06) from sleep onset up to 6 hours: Lia06 – Lia_06 < 7 dB(A).

By applying multi-level models with subjects as first level, three measures of motility have been compared: mean motility before 6 hours (m_06), mean motility between 6 and 7 hours (m06), and mean motility during sleep period time (mspt). Since age and Li have an effect on mean motility, the data have been splitted up according to age in four age-classes, and accoring to Li also in four classes. For each of the 16 sub-class the difference in each of these three variables in the two groups has been calculated. The results are presented in table D6. A positive value implies a higher mean motility in the subjects exposed to relatively higher aircraft noise levels between 6 and 7 hours than in the other sub-group. The table does not show any systematical differences. The highest difference observed (m06 = 0.027 for the sub-group in the lowest age- and Li-class) is based on a comparison of two small groups of 13 nights in group 1 and 59 nights in group 2. None of the differences between group 2 and group 1 are statistical significant (tested one-sided).

Other strategies led to similar results. Therefore the effect of aircraft noise exposure from 6 to 7 hours on motility is not different from the effect earlier in the night. Since there is much less data for other effect variables, it is assumed that also for the other effects there is no difference between relationships applicable for 6 to 7 hours and relationships applicable for earlier hours of the night.

The contribution of aircraft between 6 and 7 hours to a total effect of night-time aircraft noise is considerable, because from 6 to 7 hours there occurs much more aircraft than in the earlier hours of the night, and about half the nights subjects sleep till after 7 hours. Aircraft between 6 and 7 hours contributes 26.6% to a total effect of night-time aircraft noise during a sleep period time (see chapter 2, edges of the night). This estimate depends on the distribution of aircraft over the night, sleep period times of subjects, and presumably also on the way aircraft approaches and leaves the airport. The estimate therefore may not be applicable to other situations.
If the aircraft noise exposure between 6 and 7 hours of subjects would have been the same as during an hour in the period from 24 to 6 hours, the contribution of aircraft noise between 6 and 7 hours to a total effect would be reduced from 26.6% to 6.3%, i.e. a reduction in the total effect of 20.3%, provided that the aircraft noise events would be postponed until all subjects are awake.

This reduction in effect would be reached by a reduction in number of aircraft noise events between 6 and 7 hours from 26.6% to 6.0%, i.e. by a reduction with a factor 4. If the aircraft noise events between 6 and 7 hours would be postponed for one hour, then number of subjects exposed to these events would be reduced by a factor 1.9, and the contribution to the total effect would be 16.8% [6.0+(26.6 – 6.0)/1.9], instead of the original 26.6%, i.e a reuction of about 10% of the total effect.

### D.2.3 Sleep latency time

The following aircraft noise exposure variables have been considered as independent variables in multi-level regression analyses with subjects as first level:

- Llaten: equivalent sound level during sleep latency time;
- nlaten: number of aircraft noise events detected on the indoor noise monitor during sleep latency time. Llaten and nlaten are zero in 85.5% of sleep latency times.

In the first step, the following effect variables have been considered:

- sleep latency time (in minutes);
- difficulty to fall asleep (11 points scale: 0 no difficulty at all, 10 extremely difficult).

Sleep latency time has not been considered as a function of number of aircraft events during sleep latency time. That would be incorrect, since even without any effect of numer of aircraft events on sleept latency time, the longer sleep latency time, the more aircraft noise events will occur. Therefore, an association between sleep latency time and number of aircraft noise events does not imply a causal relationship. Age and age*age are determinants. The upper part of table D8 also shows that age alone or age and age*age are no determinants in the relationships between Llaten or nlaten and difficulty to fall asleep. In figure D23 sleep latency time has been given as a function of Llaten.

In the second step backward regression analyses have been performed with dependent variables given in step one, where appropriate with age and age*age as determinants, and the variables obtained from the evening and morning diary, given in section 3.1.1, such as reason or not of difficulty to fall asleep (reason_cl), and aircraft noise reason for difficulty to fall asleep (reason_ac). Results are presented in table D8 (lower part). In figure D24 the effect of ‘difficulty to fall asleep due to aircraft noise’ on sleep latency time is shown. This reason has been given in 12 morning diaries. Table D8 shows that this effect is much larger than if all reasons (including difficulty to fall asleep because of aircraft noise, worries, illness, etc.) are taken together: the effect of sleep_ac is about 9 minutes larger than sleep_cl. In total a reason for difficulty to fall asleep was given in 311 morning diaries. It could be shown that duration of naps during day and evening, number of cups of coffee in the evening and number of alcoholic beverages have a (slight) effect on sleep latency time period and/or score of difficulty to fall asleep. Coffee increases sleep latency time and difficulty to fall asleep score, alcoholic beverages decreases these functions. In figure D25 the score of difficulty to fall asleep is given as a function of Llaten, with difficulty to fall asleep due to aircraft noise as determinant.

There is a slight association between difficulty to fall asleep and sleep latency time. The linear relationship between both variables shows that sleep latency time is on average 8.6 minutes, if score of difficulty to fall asleep is equal to 0 and 17.7 minutes if score is equal to 10.

## D.3 Association between effect variables

In addition to exposure-effect relationships, relations between effect variables have been considered. In the analyses, the sequence of the variables is taken into account: the earlier of the two effect variables serves as independent variable and the effect variable assessed at a later stage of the 24 hours cycle as dependent variable (e.g. sleep latency period time as independent variable and sleep quality as dependent variable). The following variables have been considered:

| | |
|---|---|
| Type 1 variables | Score of difficulty to fall asleep, sleep latency time (2 variables); |
| Type 2 variables | Mspt, kspt, and rlscspt (3 variables); |
| Type 3 variables | Number of marker pressings, and number of remembered awakenings (2 variables); |
| Type 4 variables | Sleep quality on a 5 and 11 points scale (2 variables); |
| Type 5 variables | Sleepiness during time awake (5 variables); |
| Type 6 variables | Reaction times and number of mistakes during reaction time test (5 variables). |

Each of the 5 type 6 variables have been related to the 14 type 1 to type 5 variables. For only one of the 70 possible combinations a result of the reaction time test has a statistical significant relationship with any of the other variables. This concerns mspt and the number of mistakes in the reaction time test.
Between most of the type 1 to type 5 variables statistical significant relationships exist. The results are given in the left hand columns of table D9. The upper (first) section presents the coefficients of statistical significant relationships between type 1 and type 2 to 5 variables. The second section gives the coefficients of the relationships between type 2 and type 3 to 5 variables, the third section coefficients of the relationships between type 3 and type 4 to 5 variables, and the lowest section the coefficients of the relationships between type 4 and type 5 variables.
From the relationships the maximal change of a dependent variable, if the independent variable changes maximal in case of a discrete variable and from the 5% to 95% value if the variable is continuous, has been determined. The results are given in the right hand side of table D9. Figure D26 gives the result for the nine relationships of type 1 to 4 variables with the five sleepiness scores (type 5 variables) (slpkw_10 has been changed from 0 to 10 into 10 to 0). The maximal changes in sleepiness score have been averaged over the five values obtained between 10 and 20 hours.

In the morning diary, sleep quality is rated by subjects on an 11 points scale (slpkw_10: 0 very bad, 10 very good) and on an 5 points scale (slpkw_05: 5 very bad, 1 very good). In figure D27 two regression lines are shown: one with slpkw_10 as independent variable and one with slpkw_05 as independent variable. The correlation between slpkw_10 and slpkw_05 has a correlation coefficient equal to 0.79.

## D.4 Use of sleeping pills

A logistic regression model has been applied to assess the effect of Liaspt on the use of sleeping pills or other medication with a sleep-inducing and/or sleep deepening effect. Age is an effect-modifier. The coefficients are included in table D10 and a figure is given in Figure D28.

## D.5 Tables

*Table D1 Coefficients of multi-level linear regression equations with Liaspt and niaspt as independent variables and mspt, kspt, and rlscspt as dependent variables, age, and age*age as determinants (upper and lower part of the table) and age, and age*age and country of birth as determinants (middle part of the table).*

| | mspt | kspt | rlscspt |
|---|---|---|---|
| Constant | 0.06039 | 0.03361 | 0.08439 |
| Liaspt | 0.000123 | 0.000043 | 0.000206 |
| Age | -0.00130 | -0.00052 | -0.00194 |
| Age*age | 0.000014 | 0.0000055 | 0.000022 |
| | | | |
| Constant | 0.06802 | 0.03760 | 0.09789 |
| Liaspt | 0.000124 | 0.000044 | 0.000209 |
| Age | -0.00131 | -0.00053 | -0.00196 |
| Age*age | 0.000015 | 0.0000055 | 0.000022 |
| Country of birth | -0.00756 | -0.00511 | -0.01352 |
| | | | |
| Constant | 0.06104 | 0.03218 | 0.08557 |
| niaspt | 0.000075 | 0.000032 | 0.000112 |
| Age | -0.00128 | -0.00052 | -0.00191 |
| Age*age | 0.000014 | 0.0000053 | 0.000022 |

*Table D2 Coefficients of multi-level linear regression equations with Liaspt as independent variable and mspt, kspt, and rlscspt as dependent variable, age, age*age and Lo – Li as determinants (upper part of table) and age, age*age and L50 as determinants (lower part of table).*

| | mspt | kspt | rlscspt |
|---|---|---|---|
| Constant | 0.04748 | 0.027137 | 0.061313 |
| Liaspt | 0.000117 | 0.000041 | 0.000192 |
| Age | -0.00135 | -0.00055 | -0.00188 |
| Age*age | 0.000015 | 0.0000057 | 0.000021 |
| L50 | 0.000568 | 0.000288 | 0.00088 |
| | | | |
| Constant | 0.066743 | 0.036878 | 0.088813 |
| Liaspt | 0.000110 | 0.00004 | 0.000226 |
| Age | -0.00136 | -0.00055 | -0.00189 |
| Age*age | 0.000015 | 0.00000545 | 0.000022 |
| Lo - Li | -0.00023 | -0.00012 | -0.00027 |

*Table D3* *Coefficients of multi-level linear regression equations with Liaspt as independent variable and mspt, kspt, and rlscspt as dependent variable, age, age*age and reason_cl and reason_ac and other variables from the evening diary as determinants (upper parts of table) and age, age*age and d2b (awakening by night-time aircraft noise) as determinant (lowest part of table).*

| | mspt | kspt | rlscspt |
|---|---|---|---|
| constant | 0.059228 | 0.033297 | 0.079601 |
| Liaspt | 0.000127 | 0.00005 | 0.000246 |
| Age | -0.00129 | -0.00052 | -0.00179 |
| Age*age | 0.000014 | 0.000006 | 0.000021 |
| reason_cl | 0.008646 | 0.003069 | 0.012796 |
| | | | |
| constant | 0.060624 | 0.033768 | 0.08175 |
| Liaspt | 0.000126 | 0.00005 | 0.000243 |
| age | -0.00132 | -0.00053 | -0.00184 |
| age*age | 0.000015 | 0.000006 | 0.000021 |
| reason_ac | 0.012252 | 0.001356 | 0.025066 |
| | | | |
| constant | 0.06176 | 0.035009 | 0.083424 |
| Liaspt | 0.000125 | 0.00005 | 0.000241 |
| age | -0.00141 | -0.00061 | -0.00198 |
| age*age | 0.000015 | 0.000007 | 0.000022 |
| coffee_ev | 0.000515 | | 0.000973 |
| sleepeff | | -0.00103 | |
| duration naps | 0.000071 | 0.000029 | 0.000097 |
| times smoked_ev | | 0.0002 | |
| | | | |
| constant | 0.067731 | 0.038384 | 0.092101 |
| Liaspt | 0.000116 | 0.000040 | 0.000197 |
| age | -0.00141 | -0.00059 | -0.00197 |
| age*age | 0.000015 | 0.000006 | 0.000022 |
| d2b aircraft noise awakening | -0.00116 | -0.00075 | -0.0017 |

*Table D4* *Coefficients of multi-level linear regression equations with Liaspt and niaspt as independent variable and fragmentation index, number remembered awakenings, and number of marker pressings as dependent variable, age, age*age as determinants. Coefficients of a multi-level logistic regression equation of probability of having remembered to have been awakened by aircraft noise , age, age*age as determinants.*

| | Fragmentation index | Number remembered awakenings | Number of marker pressings | Probability of remembering to have been awaked by aircraft noise | Sleepiness score at 10 hours |
|---|---|---|---|---|---|
| | | | | Logistic regression | |
| constant | 13.86 | 0.083 | -0.38 | -11.5013 | 4.897111 |
| Liaspt | 0.016 | 0.0043 | 0.0051 | 0.095653 | 0.006603 |
| age | -0.429 | 0.044 | 0.050 | 0.217 | -0.06743 |
| age*age | 0.0052 | -0.00025 | -0.00032 | -0.00182 | 0.000542 |
| | | | | | |
| constant | 13.85 | 0.088 | -0.41 | | |
| niaspt | 0.015 | 0.0036 | 0.0057 | | |
| age | -0.424 | 0.045 | 0.053 | | |
| age*age | 0.0052 | -0.00026 | -0.00034 | | |

*Table D5* *Association between number of marker pressings during sleep period time and number of remembered awakenings assessed by morning diary.*

| Number of remembered awakenings | Number of marker pressings during sleep period time | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6+ | total |
| 0 | 23.1 | 3.0 | 1.3 | 0.2 | 0.1 | 0.1 | 0.0 | 27.8 |
| 1 | 7.2 | 15.5 | 3.4 | 0.9 | 0.2 | 0.1 | 0.2 | 27.5 |
| 2 | 3.9 | 5.7 | 7.2 | 2.0 | 0.9 | 0.4 | 0.2 | 20.4 |
| 3 | 2.0 | 2.2 | 2.9 | 3.1 | 1.4 | 0.6 | 0.5 | 12.6 |
| 4 | 1.1 | 0.7 | 1.0 | 1.0 | 0.9 | 0.4 | 0.5 | 5.6 |
| 5 | 0.3 | 0.2 | 0.5 | 0.7 | 0.4 | 0.3 | 0.4 | 2.9 |
| 6+ | 0.2 | 0.1 | 0.3 | 0.2 | 0.2 | 0.3 | 1.9 | 3.2 |
| total | 37.9 | 27.4 | 16.4 | 8.1 | 4.3 | 2.1 | 3.7 | 100 |

*Table D6* *Differences in mean motility of subjects exposed from 6 to 7 hours to relatively high aircraft noise levels and those exposed to lower levels of aircraft noise during that hour. Subjects in four classes of Li (li = 1, lowest values of Li, Li = 4, highest values of Li) and four age classes (class 1 age < 25 years, class 4 age > 65 years) .m_06: mean motility before 6 hours, m06: mean motility between 6 and 7 hours, mspt: mean motility during sleep period time.*

| class of Li | age class | m_06 | m06 | mspt |
|---|---|---|---|---|
| 1 | 1 | 0,005 | 0.027 | 0.008 |
| | 2 | 0.000 | 0.001 | 0.001 |
| | 3 | 0.000 | -0.003 | -0.001 |
| | 4 | -0.015 | 0.004 | -0.015 |
| | all | -0.001 | 0.001 | 0.000 |
| 2 | 1 | -0.005 | -0.004 | -0.006 |
| | 2 | -0.001 | -0.003 | -0.001 |
| | 3 | -0.003 | 0.003 | -0.002 |
| | 4 | -0.002 | -0.006 | -0.002 |
| | all | -0.002 | -0.001 | -0.002 |
| 3 | 1 | -0.007 | -0.004 | -0.007 |
| | 2 | 0.000 | -0.002 | 0.000 |
| | 3 | -0.001 | -0.017 | -0.003 |
| | 4 | 0.003 | -0.008 | 0.002 |
| | all | -0.001 | -0.006 | -0.002 |
| 4 | 1 | 0.014 | -0.019 | 0.012 |
| | 2 | 0.004 | -0.011 | 0.003 |
| | 3 | 0.001 | -0.005 | 0.000 |
| | 4 | -0.007 | 0.002 | -0.007 |
| | all | 0.000 | -0.006 | -0.001 |
| all | 1 | -0.001 | 0.003 | 0.000 |

| | | | |
|---|---|---|---|
| 2 | 0.002 | -0.003 | 0.001 |
| 3 | -0.001 | -0.004 | -0.002 |
| 4 | -0.004 | -0.005 | -0.005 |
| all | -0.001 | -0.003 | -0.001 |

Table D7 *Median values of aircraft noise equivalent sound levels per location and for all locations together (last row). Lia06: aircraft equivalent sound level from 6 to 7; Lspt_06: aircraft equivalent sound level during sleep with the exception of the period between 6 and 7; L06_Ln06: Lia06 – Lspt_06. All values in dB(A).*

| Loc | Lia06 | Lspt_06 | L06_Ln06 | Li | Lbi23_07 |
|---|---|---|---|---|---|
| 31 | 13,94 | 18,76 | -3,60 | 19,59 | 26 |
| 32 | 20,44 | 20,62 | 0,94 | 22,22 | 23 |
| 33 | 23,79 | 17,84 | 5,62 | 20,06 | 27 |
| 34 | 17,44 | 20,92 | 0,00 | 22,91 | 27 |
| 35 | 28,60 | 29,47 | 2,37 | 29,17 | 28 |
| 36 | 22,85 | 24,33 | 0,00 | 26,36 | 27 |
| 37 | 25,57 | 23,28 | 3,53 | 25,70 | 22 |
| 38 | 27,17 | 28,59 | 2,53 | 29,93 | 31 |
| 39 | 31,20 | 24,11 | 6,51 | 26,96 | 26 |
| 40 | 0,00 | 8,07 | -4,35 | 11,42 | 10 |
| 41 | 28,48 | 28,07 | 0,94 | 25,97 | 19 |
| 42 | 0,00 | 6,88 | 0,00 | 12,44 | 24 |
| 43 | 29,51 | 21,17 | 8,62 | 23,48 | 26 |
| 44 | 0,00 | 4,85 | 0,00 | 9,41 | 10 |
| 45 | 27,09 | 24,44 | 3,15 | 25,44 | 29 |
| all locations | 22,63 | 21,07 | 2,26 | 23,14 | 26 |

Table D8 *Duration of sleep latency time as a function of equivalent sound level during sleep latency time (Llaten), with age, age*age and other determinants as independent variables (left hand column). Difficulty to fall asleep as a function of Llaten and nlaten (number of aircraft noise events during sleep latency time, with various determinants as independent variables (right hand columns).*

| Slt (sleep latency time in minutes) | | Score of difficulty to fall asleep | | Score of difficulty to fall asleep | |
|---|---|---|---|---|---|
| constant | 17.41 | constant | 2.51 | constant | 2.51 |
| Llaten | 0.198 | Llaten | 0.0184 | nlaten | 0.377 |
| age | -0.378 | | | | |
| age*age | 0.0041 | | | | |
| constant | 17.40 | constant | 2.50 | constant | 2.50 |
| Llaten | 0.196 | Llaten | 0.0178 | nlaten | 0.351 |
| age | -0.378 | reason_ac | 4.83 | reason_ac | 4.59 |
| age*age | 0.0043 | | | | |
| reason_ac | 13.46 | | | | |
| constant | 16.72 | constant | 2.21 | constant | 2.21 |
| Llaten | 0.194 | Llaten | 0.0140 | nlaten | 0.278 |

| | | | | | |
|---|---|---|---|---|---|
| age | -0.361 | reason_cl | 4.72 | reason_cl | 4.70 |
| age*age | 0.0042 | | | | |
| reason_cl | 4.55 | | | | |
| | | | | | |
| constant | 16.78 | Constant | 2.45 | constant | 2.46 |
| Llaten | 0.197 | Llaten | 0.0129 | nlaten | 0.256 |
| age | -0.363 | reason_ac | 3.15 | reason_ac | 2.97 |
| age*age | 0.00401 | alcohol_ev | -0.15 | alcohol_ev | -0.15 |
| coffee_ev | 0.261 | coffee_ev | 0.12 | coffee_ev | 0.12 |
| duration naps | 0.016847 | sleepeff | 0.4581 | sleepeff | 0.4568 |
| reason_ac | 13.66 | duration naps | 0.0066 | duration naps | 0.0063 |

*Table D9 Left hand side of table: relationships and associations between effect variables. Statistical significant coefficients of linear regression equations with dependent variables in rows and independent variables in columns.Right hand side of table: change in a dependent variable if the independent variable changes from minimum to maximum (for variables in classes) and from the 5% to 95% value for continuous variables .*

| | Regression coefficient | | | Change in effect variable in first column | | |
|---|---|---|---|---|---|---|
| | Score for difficulty to fall asleep | Sleep latency time | | Score for difficulty to fall asleep | Sleep latency time | |
| mspt | 0.00104 | 0.000041 | | 0.010 | 0.007 | |
| kspt | 0.00045 | | | 0.005 | | |
| rlscspt | 0.00147 | 0.000097 | | 0.015 | 0.016 | |
| nmark | 0.041 | | | 0.4 | | |
| nremembered | 0.128 | | | 1.3 | | |
| slpkw_10 | -0.363 | -0.011 | | -3.6 | -1.8 | |
| slpkw_05 | 0.189 | 0.0041 | | 1.9 | 0.7 | |
| strip1_an | 0.122 | 0.00693 | | 1.2 | 1.1 | |
| strip2_an | 0.096 | 0.00456 | | 1.0 | 0.7 | |
| strip3_an | 0.050 | | | 0.5 | | |
| strip4_an | 0.045 | | | 0.5 | | |
| | | | | | | |
| | mspt | kspt | rlscspt | mspt | kspt | rlscspt |
| nmark | 16.55 | 12.27 | 8.56 | 0.9 | 0.4 | 0.8 |
| nremembered | 16.67 | 13.67 | 8.43 | 1.0 | 0.4 | 0.7 |
| fragmentation index | 176 | 251 | 8.20 | 10 | 8 | 7 |
| slpkw_10 | -19.33 | -19.37 | -9.47 | -1.1 | -0.6 | -0.8 |
| slpkw_05 | 10.00 | 11.56 | 5.11 | 0.6 | 0.4 | 0.5 |
| strip1_an | 6.05 | 7.12 | 2.56 | 0.4 | 0.2 | 0.2 |
| strip2_an | 8.21 | 9.44 | 3.44 | 0.5 | 0.3 | 0.3 |
| strip3_an | 4.25 | | 1.60 | 0.2 | | 0.1 |
| strip4_an | 4.46 | | 1.58 | 0.3 | | 0.1 |
| strip5_an | 4.04 | | 1.50 | 0.2 | | 0.1 |
| mistakes in reaction time test | 4.36 | | | 0.3 | | |

| | nmark | nremem-bered | nmark | nremem-bered |
|---|---|---|---|---|
| slpkw_10 | -0.302 | -0.524 | -2.1 | -3.1 |
| slpkw_05 | 0.145 | 0.261 | 1.0 | 1.6 |
| strip1_an | 0.099 | 0.133 | 0.7 | 0.8 |
| strip2_an | 0.103 | 0.136 | 0.7 | 0.8 |
| strip3_an | 0.089 | 0.099 | 0.6 | 0.6 |
| strip4_an | 0.070 | 0.083 | 0.5 | 0.5 |
| strip5_an | | 0.057 | | 0.3 |
| | Slpkw_10 | Slpkw_05 | Slpkw_10 | Slpkw_05 |
| strip1_an | -0.144 | 0.369 | -1.4 | 1.5 |
| strip2_an | -0.108 | 0.279 | -1.1 | 1.1 |
| strip3_an | -0.083 | 0.215 | -0.8 | 0.9 |
| strip4_an | -0.052 | 0.127 | -0.5 | 0.5 |
| strip5_an | -0.024 | 0.064 | -0.2 | 0.3 |

*Table D10* *Coefficients of a logistic regression analysis with Liaspt as independent variable, probability of using sleeping pills as dependent variable, and age as effect-modifie.*

| | Probability of using sleeping pills |
|---|---|
| constant | -9.241 |
| Liaspt | 0.079 |
| age | 0.035 |

## D.6 Figures

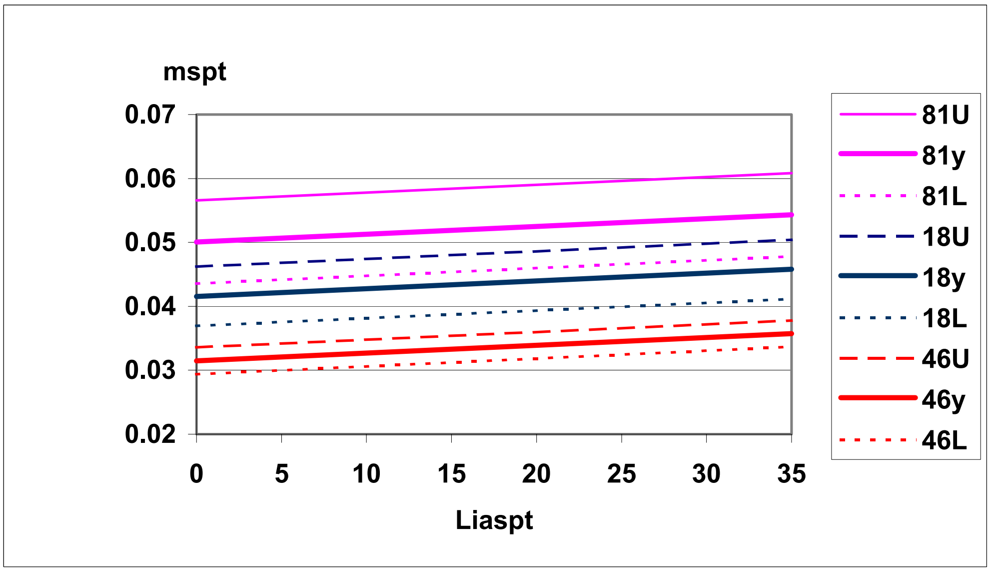


*Figure D1: Mspt as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years and for the age at which mspt is minimal. Broken lines represent 95% confidence intervals.*

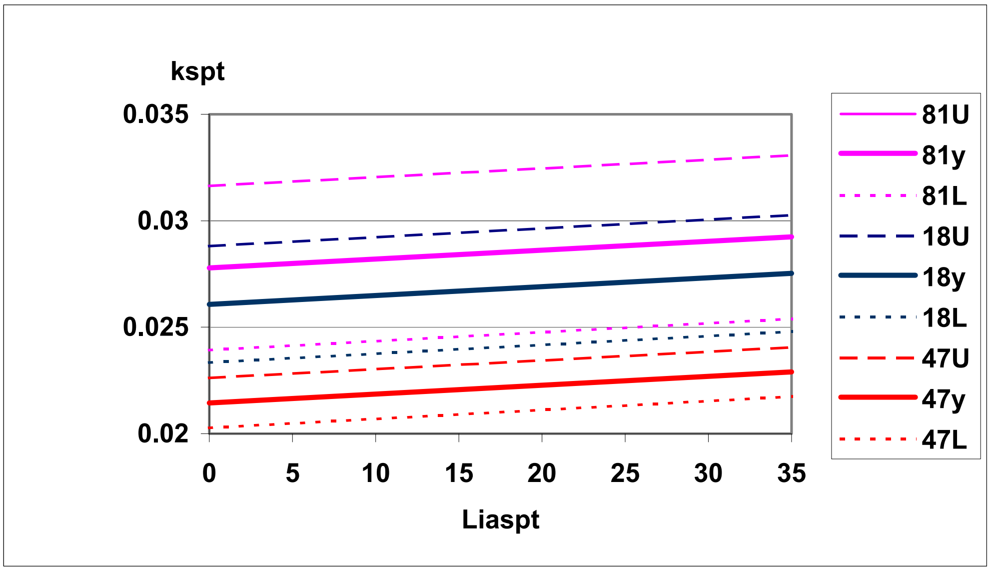


*Figure D2: Kspt as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years and for the age at which kspt is minimal. Broken lines represent 95% confidence intervals.*

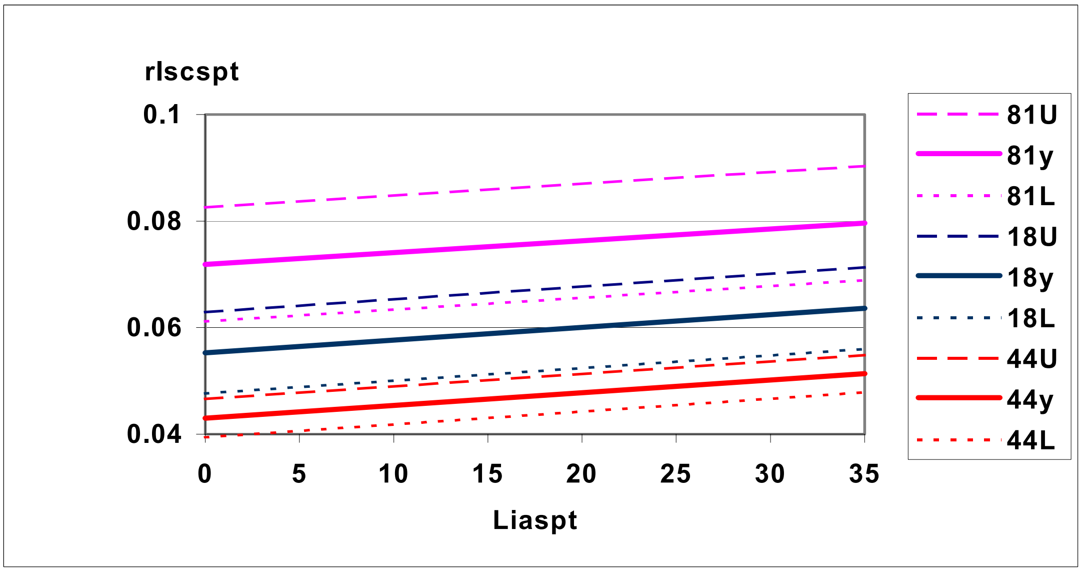


*Figure D3:* *Rlscspt as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years and for the age at which rlscspt is minimal.*

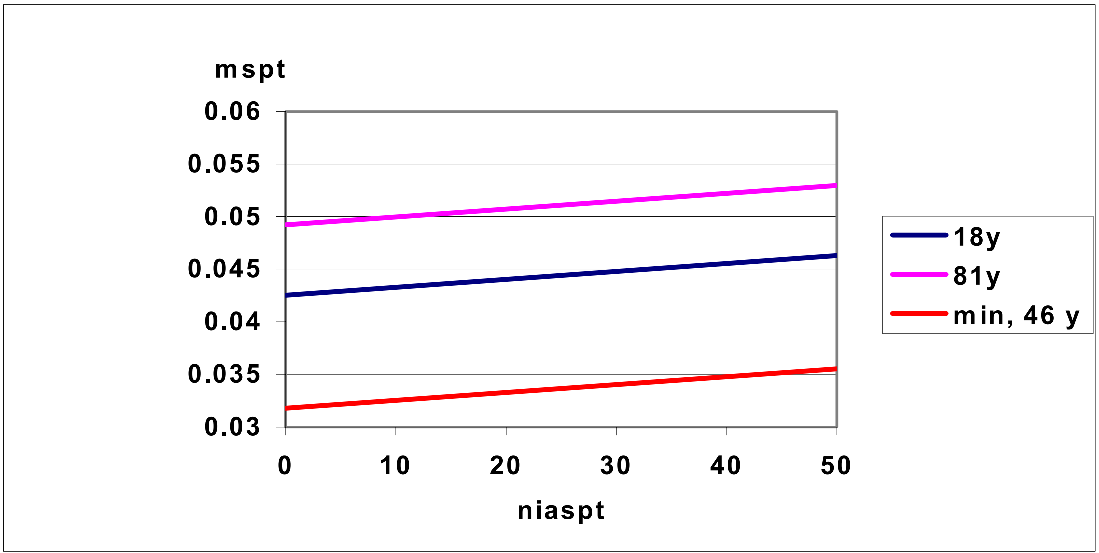


*Figure D4:* *Mspt as a function of niaspt (number of aircraft noise events during sleep period time) in dB(A) for age 18 and 81 years and for the age at which mspt is minimal.*

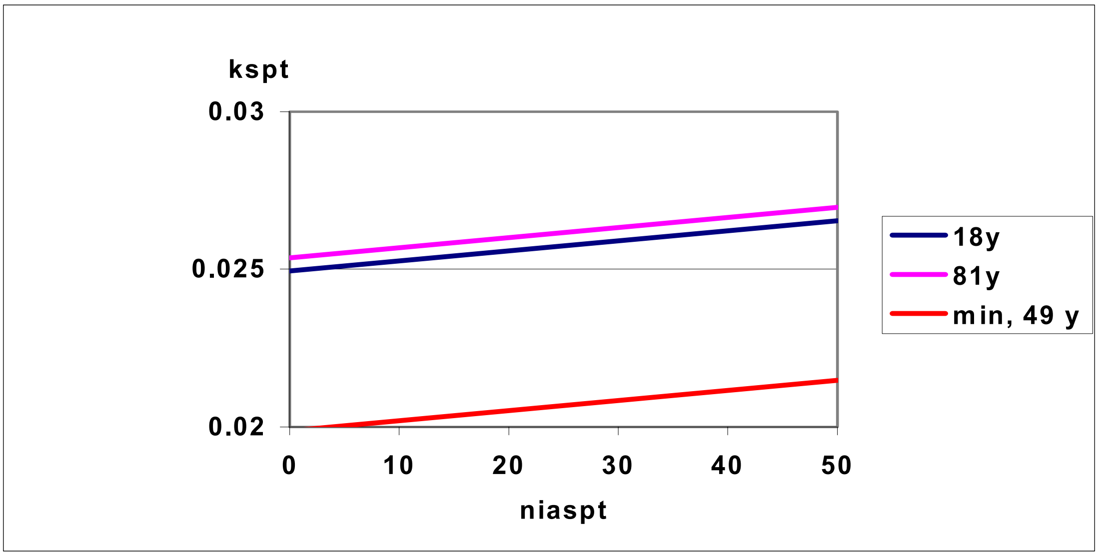


*Figure D5: Kspt as a function of niaspt (number of aircraft noise events during sleep period time) in dB(A) for age 18 and 81 years and for the age at which kspt is minimal.*

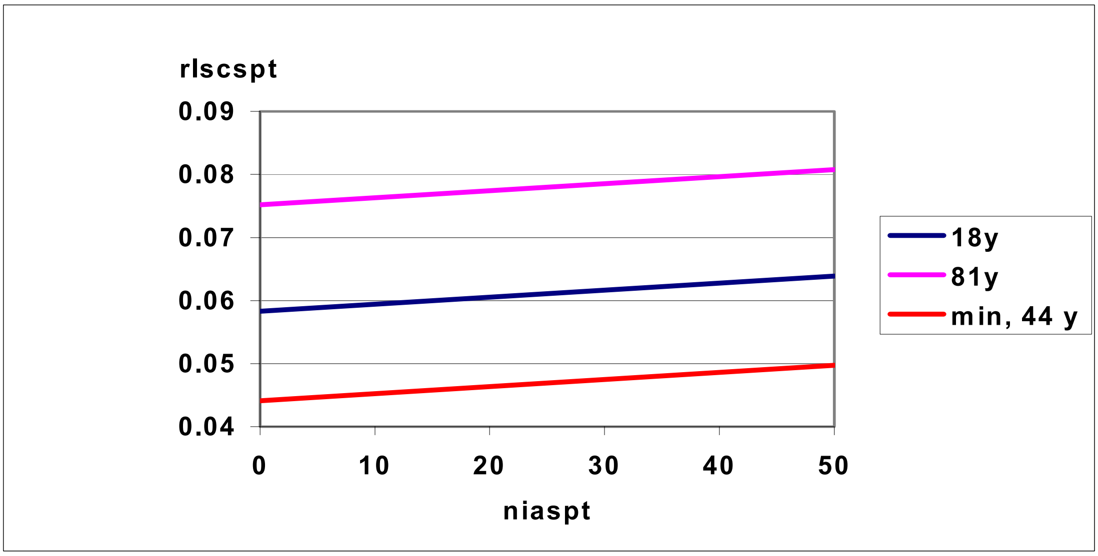


*Figure D6: Rlscspt as a function of niaspt (number of aircraft noise events during sleep period time) in dB(A) for age 18 and 81 years and for the age at which rlscspt is minimal.*

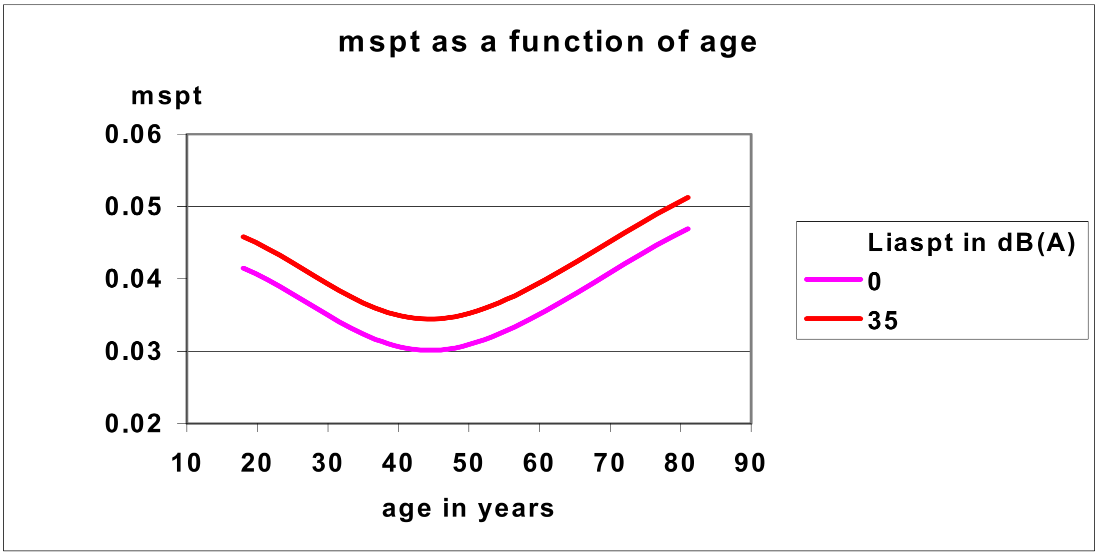


*Figure D7: Mspt as a function of age for the situations with Liaspt (equivalent sound level of aircraft noise during sleep period time) equal to 0 and 35 dB(A).*

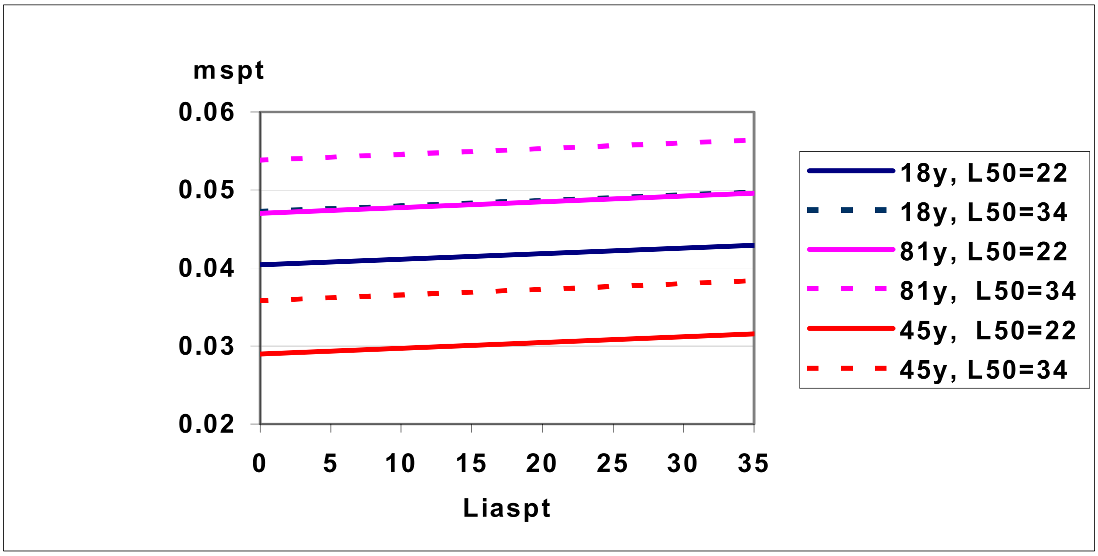


*Figure D8: Mspt as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years and for the age at which mspt is minimal and for situations in which L50 (median value of L during sleep period time outside aircraft windows) is 22 or 34 dB(A).*

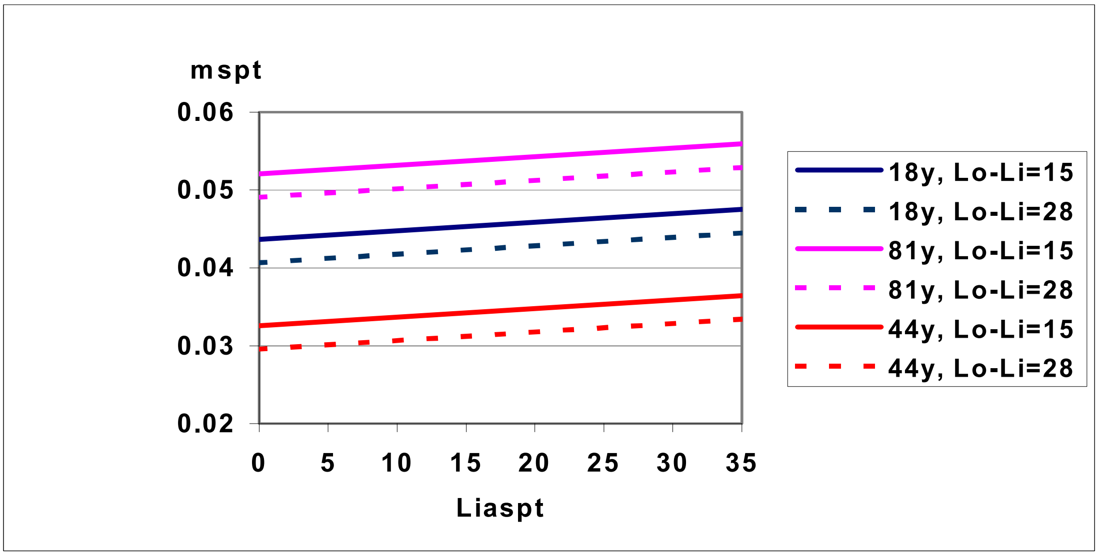


*Figure D9:* *Mspt as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years and for the age at which mspt is minimal and for situations in which Lo - Li (difference between outdoor and indoor equivalent sound level of aircraft noise during sleep period time) is 15 or 28 dB(A).*

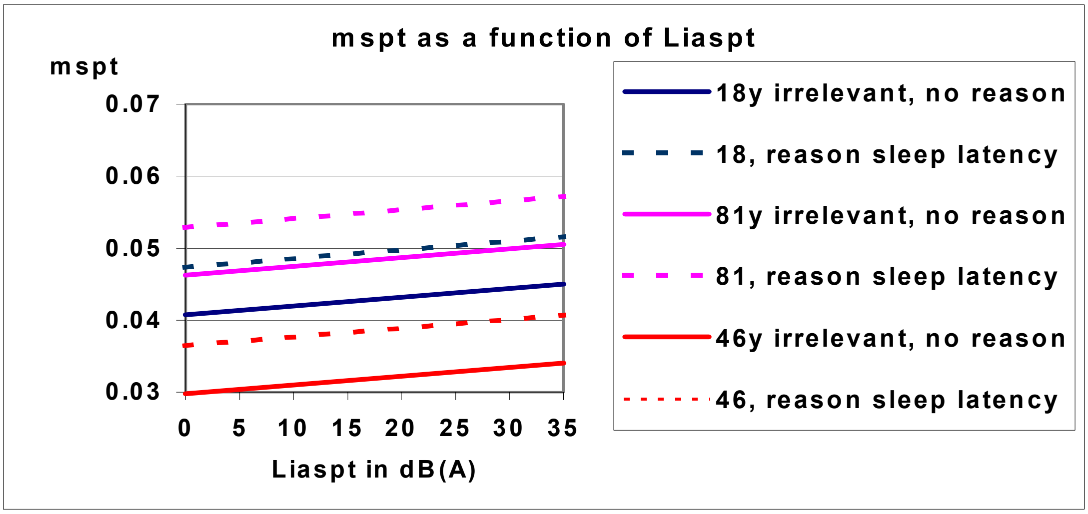


*Figure D10:* *Mspt as a function of Liaspt for ages 18, 46 and 81 years with parameter ‘having a reason for difficulty to fall asleep’ or irrelevant, no special reason’.*

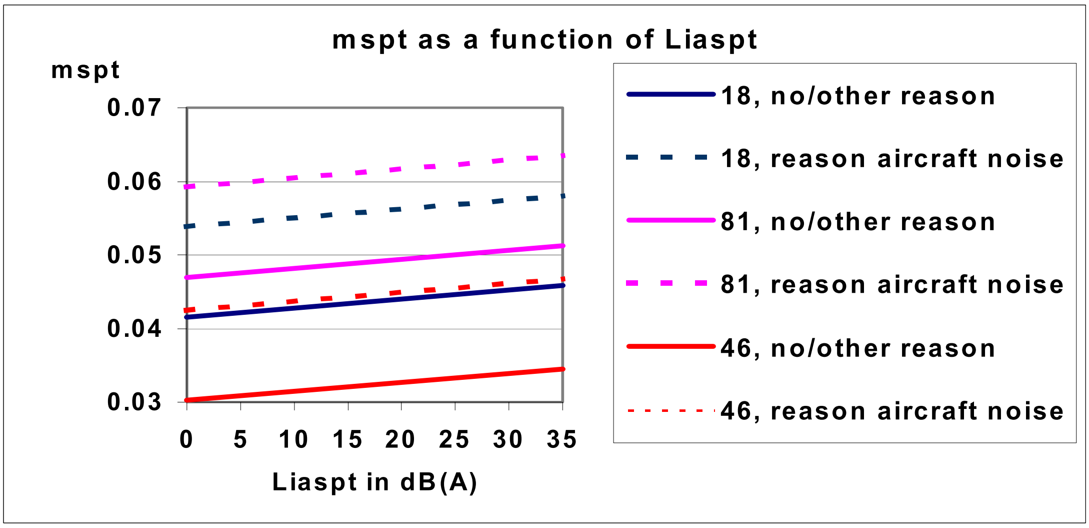


*Figure D11:* *mspt as a function of Liaspt for ages 18, 46 and 81 years with parameter 'aircraft noise the reason for difficulty to fall asleep' and 'no reason, irrelevant, or other reason than aircraft noise'.*

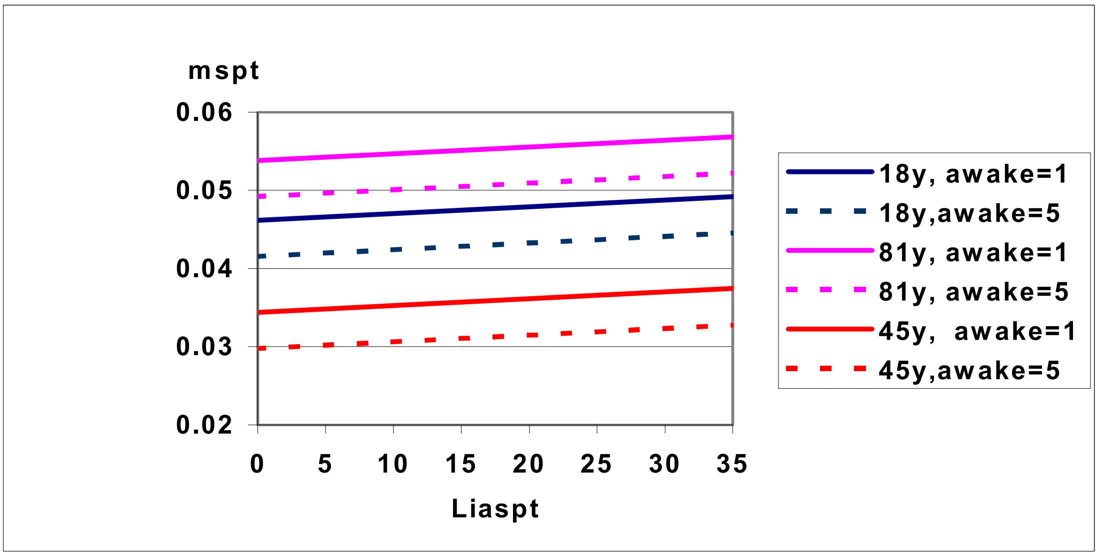


*Figure D12:* *Mspt as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years and for the age at which mspt is minimal, for subjects indicating in the questionnaire to wake up (nearly) each night by aircraft noise (awake = 1) or never to wake up by aircraft noise (awake = 5).*

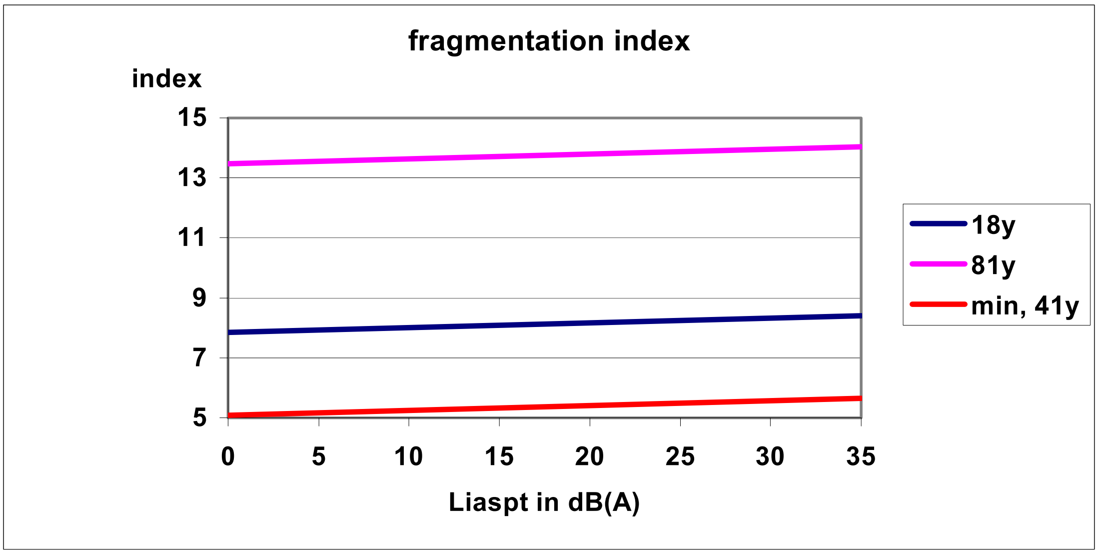


*Figure D13: Fragmentation index as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years and for the age at which the fragmentation index is minimal.*

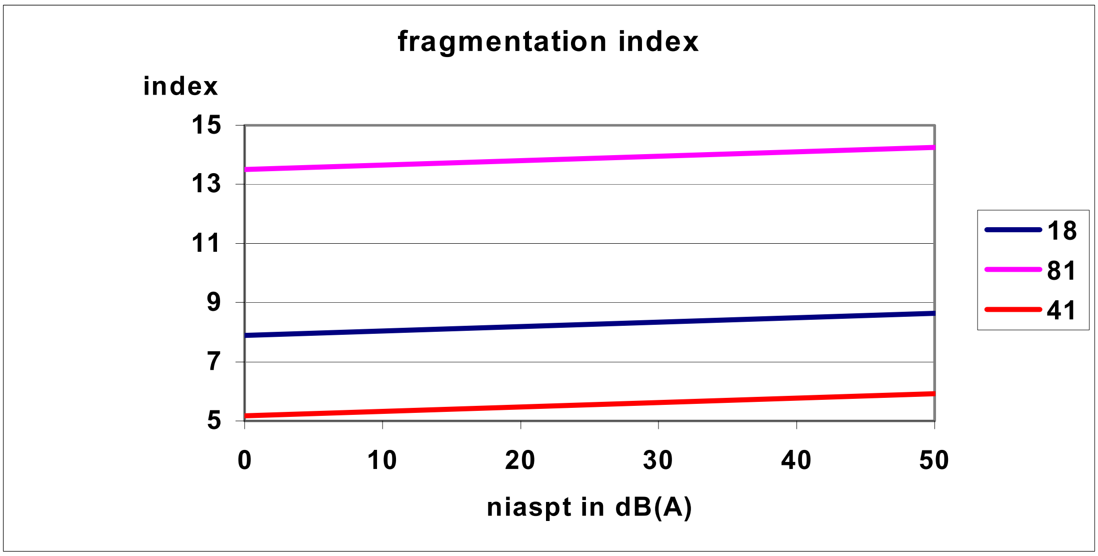


*Figure D14: Fragmentation index as a function of niaspt (number of aircraft noise events during sleep period time) for age 18 and 81 years and for the age at which the fragmentation index is minimal.*

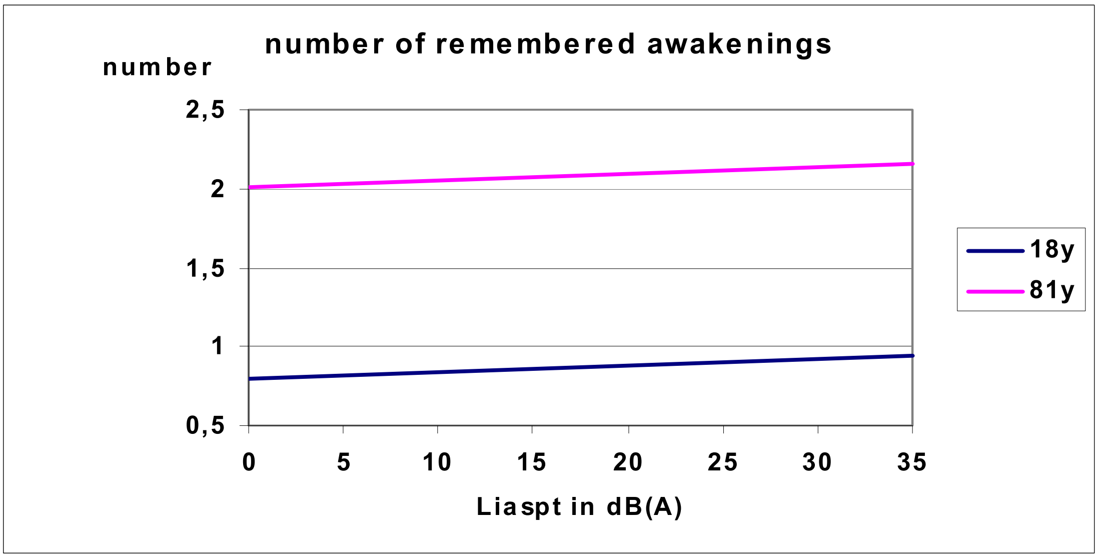


*Figure D15:* *Number of remembered awakenings as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years.*

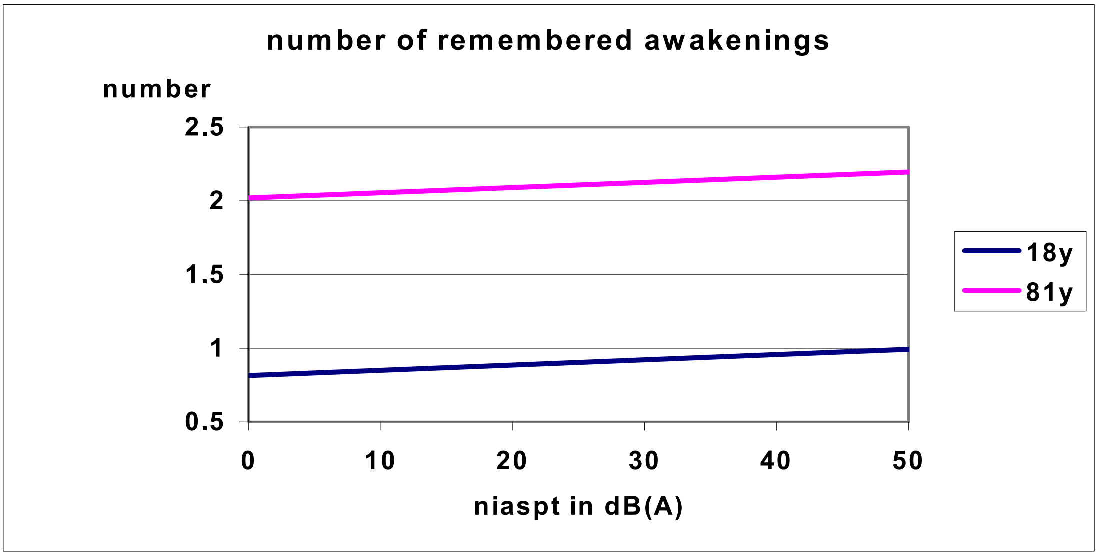


*Figure D16:* *Number of remembered awakenings as a function of niaspt (number of aircraft noise events during sleep period time) for age 18 and 81 years.*

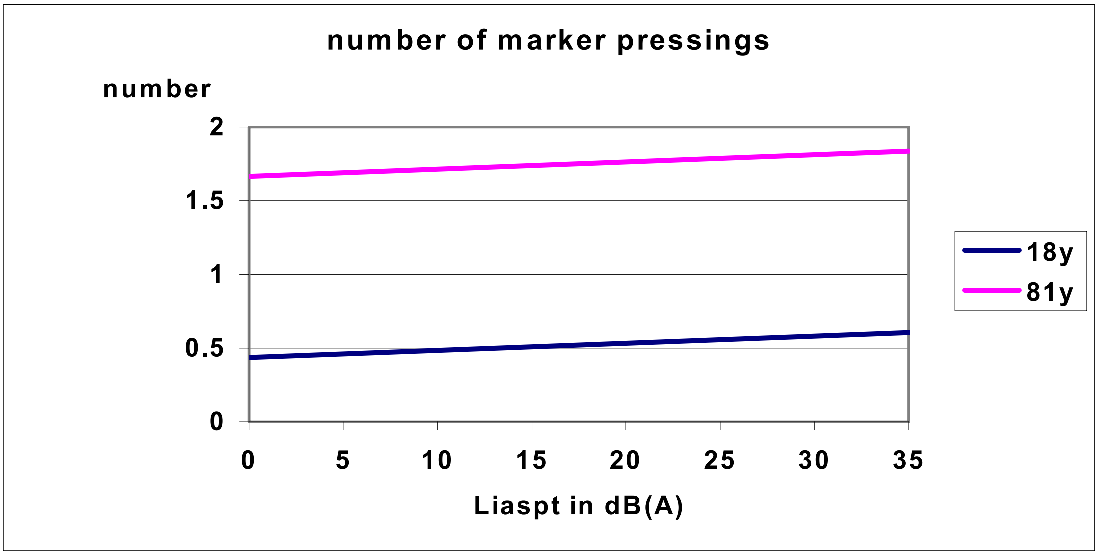


*Figure D17:* *Number of marker pressings during sleep period time as a function of Liaspt (equivalent sound level of aircraft noise during sleep period time) in dB(A) for age 18 and 81 years.*

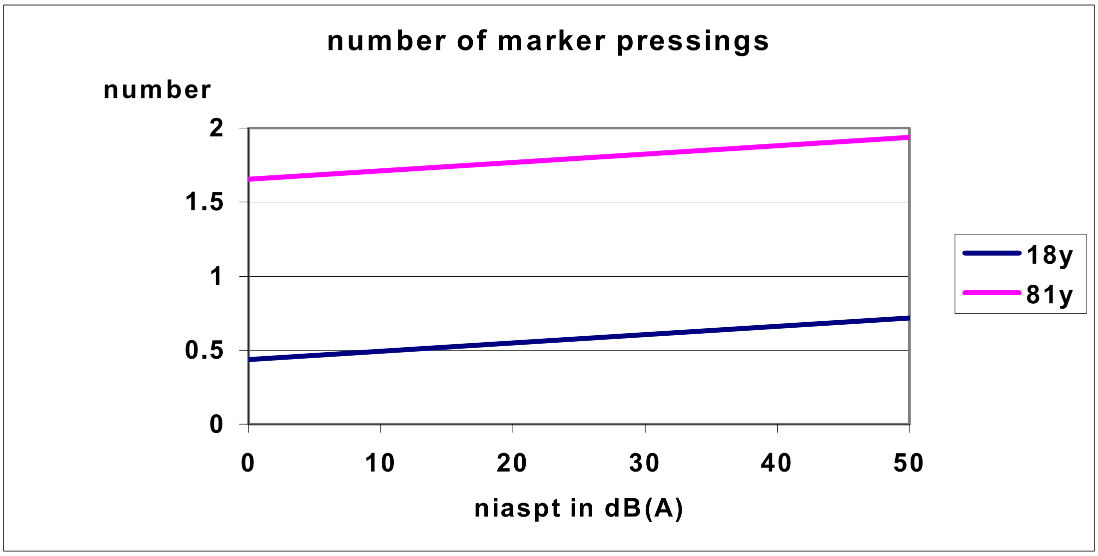


*Figure D18:* *Number of marker pressings during sleep period time as a function of niaspt (number of aircraft noise events during sleep period time) for age 18 and 81 years.*

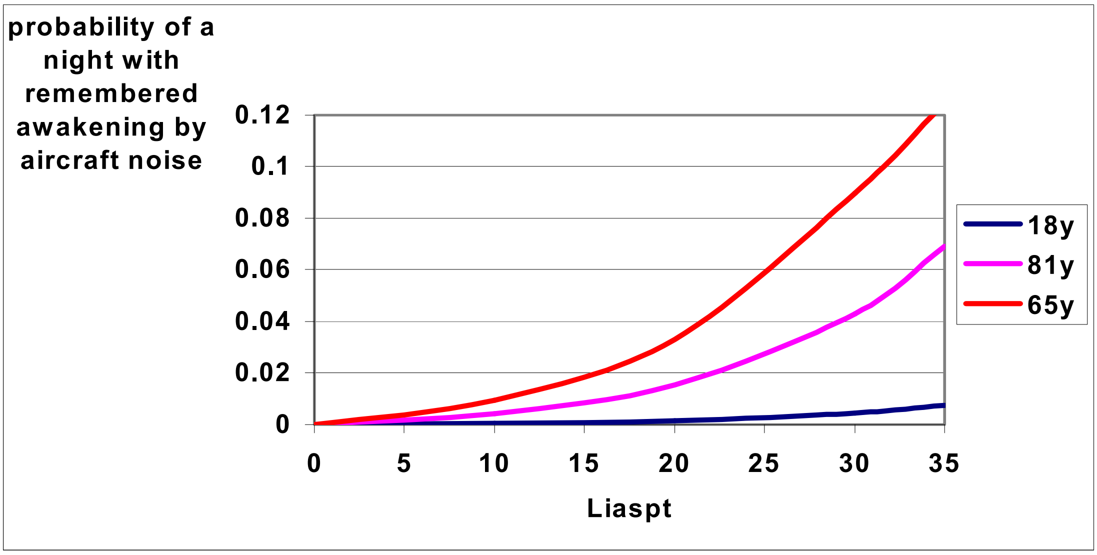


*Figure D19: Probability of a night to have remembered to have been awakened by aircraft noise as a function of Liaspt.*

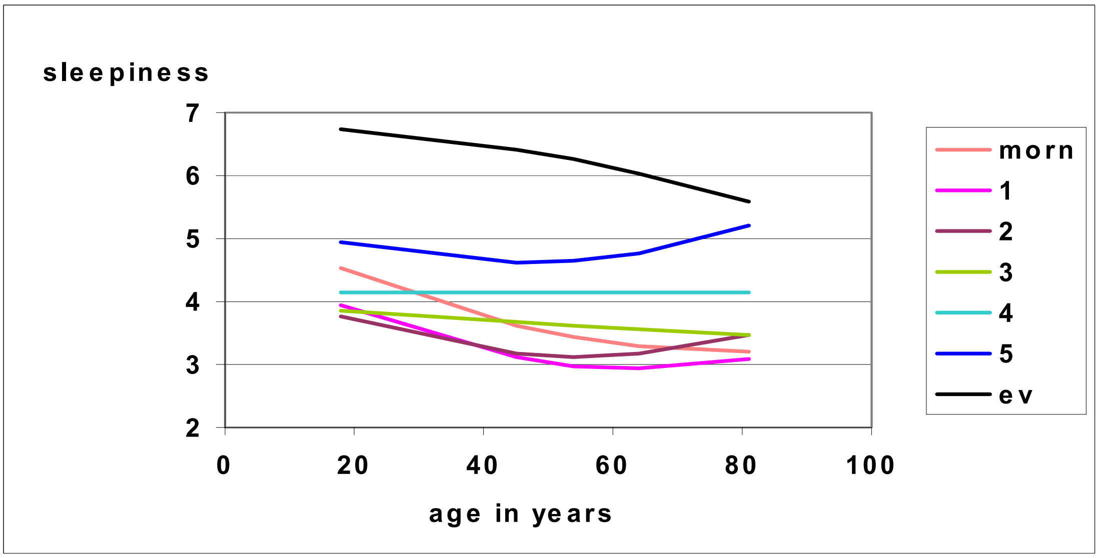


*Figure D20: Sleepiness as a function of age for various times of day and evening. Sleepiness score 0 not sleepy at all, 9 extremely sleepy.*

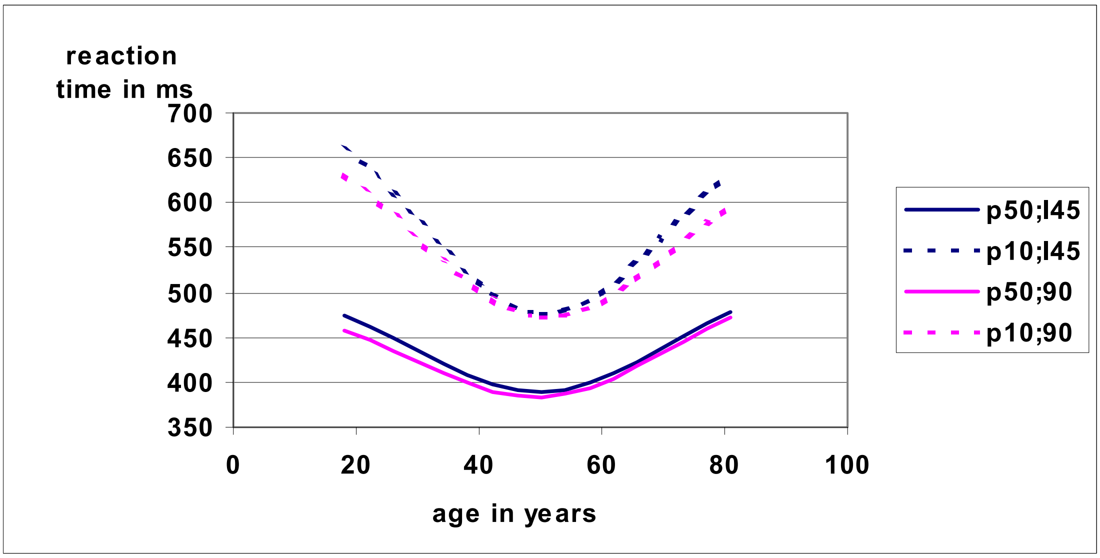


*Figure D21:* *Reaction times as a function of age of subjects.p50;l45: median score of last 45 trials, p10;l45 score exceeded in 10% of the last 45 trials, p50;90 median score of all 90 trials, p10;90 sore exceeded in 105 of all trials.*


*Figure D22:* *Number of mistakes during the reaction time tests as a function of age of subjects.*

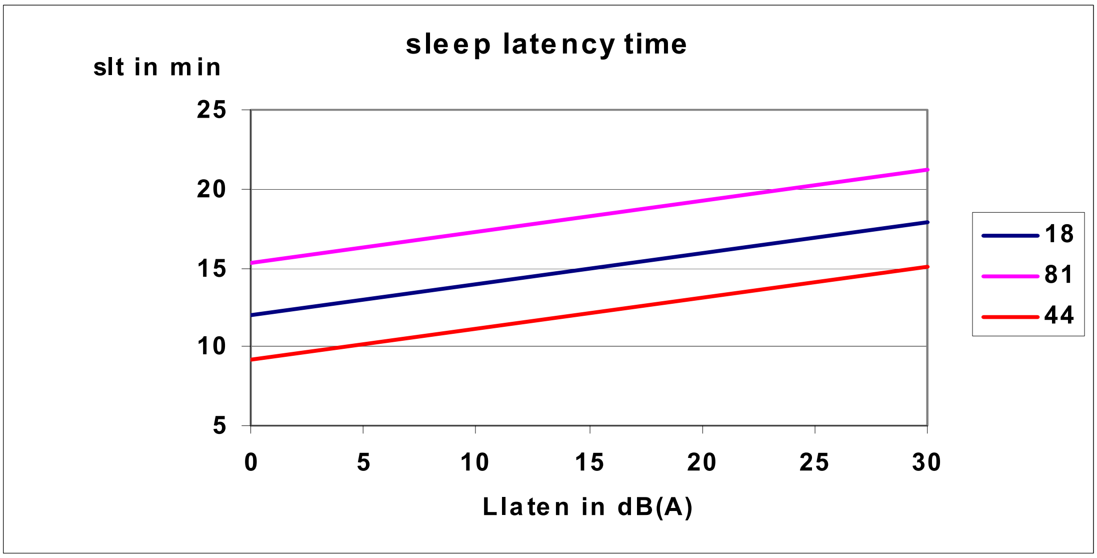


*Figure D23:* *Sleep latency time in minutes as a function of Llaten for age 18, 81 and 44 years (slt being smallest).*

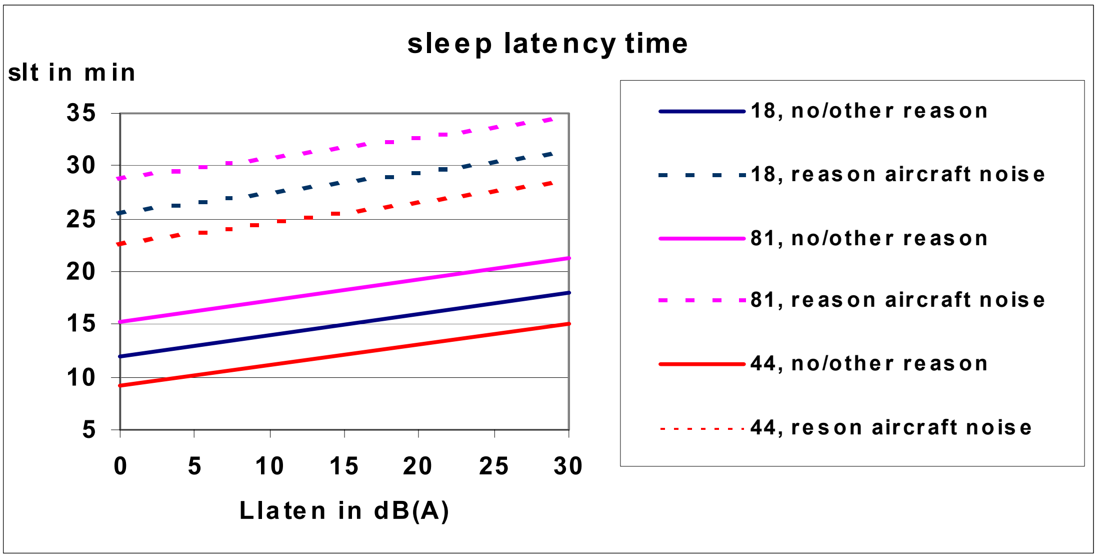


*Figure D24:* *Sleep latency time in minutes as a function of Llaten for age 18, 81 and 44 years (slt being smallest) and whether or not subjects consider aircraft noise the reason for not falling asleep.*

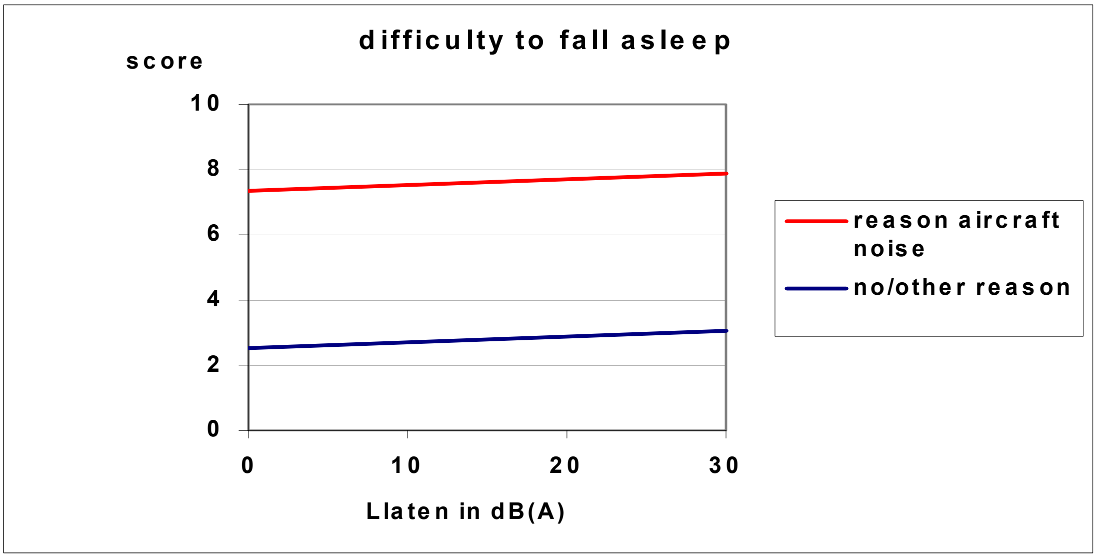


*Figure D25: Score of difficulty to fall asleep (on an 11 point scale: 0 not difficult at all, 10: extremely difficult) as a function of Llaten and whether or not subjects consider aircraft noise as reason for difficulty to fall a sleep.*

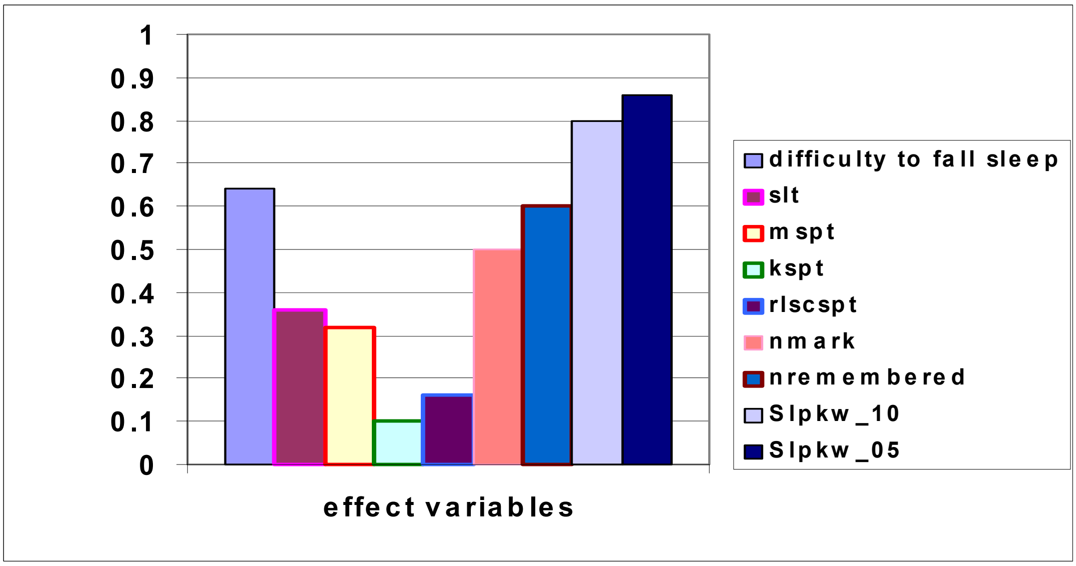


*Figure D26: Increase in sleepiness score (on a 9 points scale) during time awake due to a maximal change in an effect variable.*

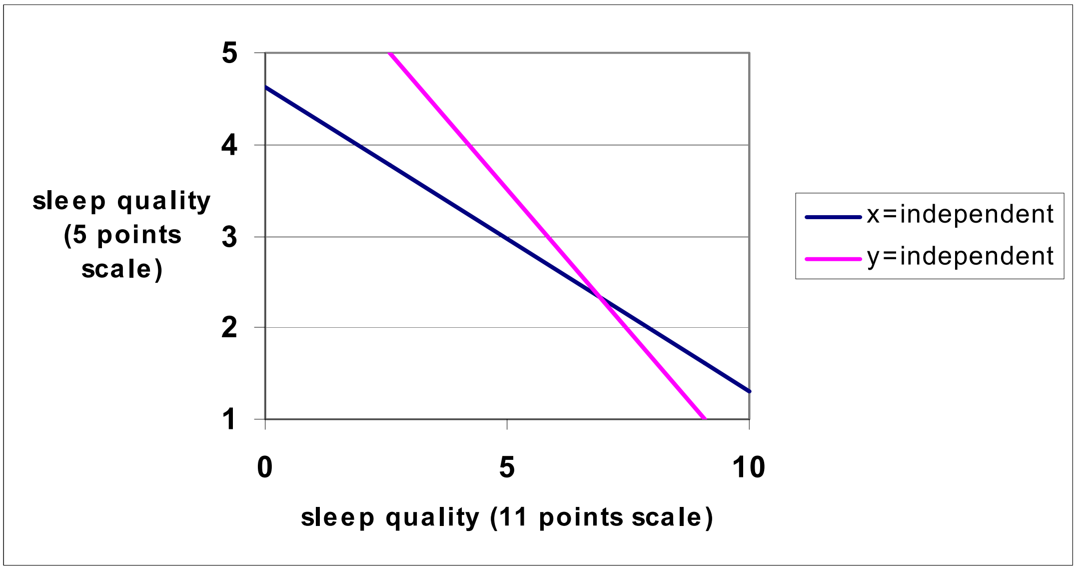


*Figure D27:* *Association between sleep quality on a 5 points scale and sleep quality on an 11 points scale. The straight line with label x=independent is the regression line with sleep quality on the 11 points scale as independent variable. The other straight line has sleep quality on a 5 points scale as independent variable.*

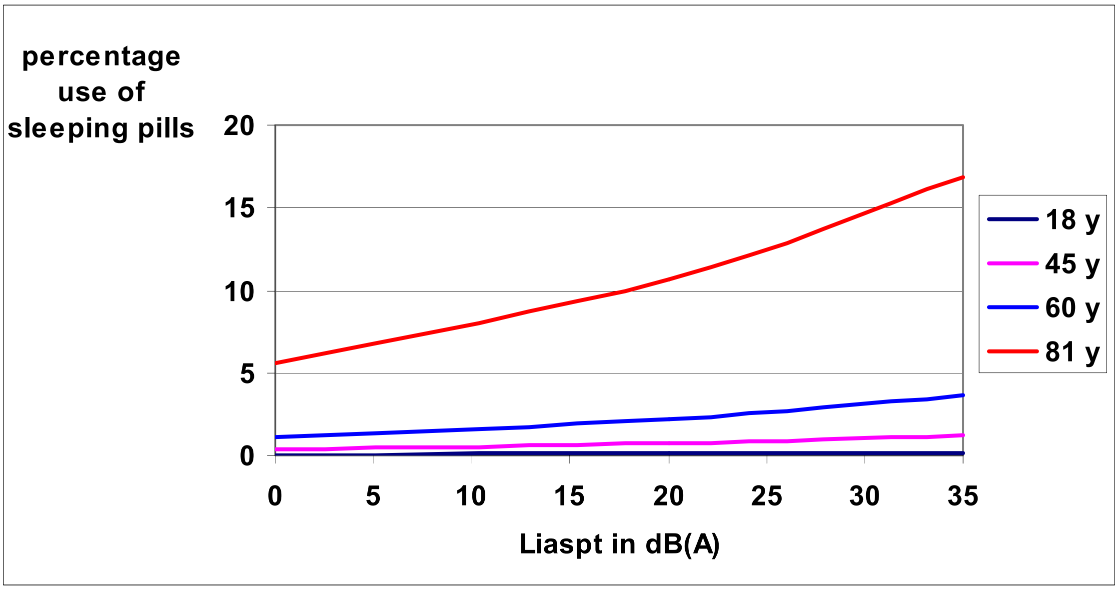


*Figure D28:* *Percentage of subject nights sleeping pills or other medication with a sleep-inducing and/or sleep-deepening effect are used, as a function of Liasp, with age as effect-modifier.*

# Appendix E Analyses for relationships of long-term variables

## E.1 Introduction

This Appendix concerns variables on a long-term basis. Sections E.2 and E.3 are related to data obtained by questionnaire subjects filled out in the week before the start of the participation in the field study. In TNO report 2001.205 (chapter 2 and 3) detailed information is given about the results obtained from the questionnaires. That report also contains information about long-term night-time aircraft noise exposure at the 15 locations. The main objective of the questionnaire has been to obtain information about variables that might be determinants, effect-modifiers, or con-foundersfor instantaneous and 24 hours relationships. It is not the aim of the questionnaire to assess general applicable long-term exposure-effect relationships, such as between Lden and percentage of subjects highly annoyed by aircraft noise. Much larger data bases are available than our data base of the questionnaire responses of 418 subjects. Nevertheless, the long-term data from the questionnaire are elaborated to obtain on a small scale a detailed picture of relationships, determinants, effect-modifiers, and confounders. Section E2 provides information about effect variables, aircraft noise exposure variables, and possible determinants. In section E.3 the results of the analyses are given. Section E.4 compares rating of sleep quality and noise disturbance by questionnaire and by morning and evening diaries.

In section E.5 effect variables aggregated over the 11 sleep period times, such as mean motility, or over 11 24 hours periods, such as sleepiness during day- and evening-time, have been related to aircraft noise exposure during sleep. Also relationships among these aggregated variables and variables from the questionnaire have been assessed. Section E.6 compares instantaneous prob-ability of motility with long-term motility. Section E.7 and E.8 include tables and figures.

## E.2 Model for relationships between long-term variables

Chapter 4 presents a simple model which is the basis of the analyses in this Appendix.

**Noise exposure variables**

RIVM calculated on data obtained from NLR (night-time) aircraft noise exposure in the years 1999 and 2000 at the position of the outdoor noise monitor at each location. The results are given in table 2 of report 2001.205. The results for 1999 and 2000 are much the same. Since the field study has been carried out mainly in 2000, the data of 2000 have been used in the analyses. The data for 2000 include Lbi23-06h, Lbu23-07h, Lbu06-07h, Lden and Ke. Lbi23-07h has been obtained by subtracting 21 dB(A) from Lbu23-07h and Lday has been calculated from Lden and Lbu23-07h.

On the basis of the noise measurements performed outside at a location and inside bedrooms during 11 nights including the 11 sleep period times of a subject, one outdoor and one indoor aircraft noise equivalent sound level during the 11 sleep period times of a subject have been calculated, Lo and Li respectively (see Appendix B). In these calculations, the durations of the sleep period times have been taken into account. Li is a good reflection of the individual aircraft noise exposure during the 11 sleep period times of a subject. Li is, however, only a small sample of night-time aircraft noise exposure of subjects when considered on a long-term basis, such as a year. The question is, therefore, whether Li is representative for the *long-term* individual night-time aircraft noise exposure of subjects. Indoor individual aircraft noise exposure during sleep is mainly determined by two factors:

- sleep patterns of subjects;
- aspects related to aircraft traffic and sound insulation of the bedroom.

*Sleep patterns of subjects*

During weekends sleep patterns (time of falling asleep, time of awakening) are somewhat different from those at weekdays, see figures 3.1 to 3.3. Li is the aircraft equivalent sound level over 11 nights: 2 weekend nights and 9 weekday nights. Considered on a long-term basis, there is in Li an under-representation of weekend nights. Therefore, the first question is whether Li is representative for a week, consisting of 2 weekend nights and 5 weekday nights. To respond to this question, first for each subject Li_first_7_nights (Li over the first 7 nights: 2 weekend nights and 5 weekday nights) and Li_last_7_nights (Li over the last 7 nights: also 2 weekend nights and 5 weekday nights) has been determined. Then, for each subject the difference between Li and Li_first_7_nights, and between Li and Li_last_7_nights has been calculated. The mean values of these differences over all subjects are respectively 0.10 and –0.03 dB(A). These differences are not statistically significant. Therefore, Li is also an appropriate measure of the aircraft equivalent sound level over seven nights, including 2 weekend nights.

Information is available about nine weekday nights. Sleep patterns of subjects during these nights are quite stable: on average, per subject, times of falling asleep and times of awakening have a 95%-range of respectively 25 and 19 minutes. Since there is information about only two weekend nights, it is not possible to get insight in the variation in sleep patterns during weekends. Although we assume that the variation of sleep patterns during weekends is larger than during weekdays, we consider the effect of this variation during two out of seven nights on aircraft noise exposure during seven sleep period times of no importance. Therefore, to our opinion, individual variation in sleep patterns does not have a relevant impact on aircraft noise exposure during sleep period times.

*Aspects related to aircraft traffic and sound insulation of the bedroom*

With respect to the ventilation of the bedroom, important with respect to the sound insulation of the bedroom and the actual indoor aircraft noise exposure of subjects, during more than half the nights the bedroom windows are not closed completely. Also, most bedroom windows have the same position during each night in the study, and the percentage of (slightly) opened windows is about the same for each season. Therefore, seasonal differences in ventilation behaviour of subjects with regard to their bedroom window, and effects on sound insulation of this behaviour are assumed to be small.

The remaining question is whether aircraft traffic at the time of measurement at a location is

representative for a longer period of time. Anyhow, no specific measures have been taken to influence night-time aircraft noise exposure at the various locations at the time of the study. On the other hand, a substantial variation in number of night-time aircraft operations occur in the course of a year. At location Spaarndam (location 42, measurement time in January), a considerable number of subjects stated during their participation, especially during the first interval, that night-time aircraft was much less than usual. Their observations are in line with the following data. The difference between Lbi23-07h and Li is on average (all subjects) equal to 1.4 dB(A) (standard error of the mean equal to 0.3 dB(A)). The regression equation in formula B25 shows that the difference between Lbi23-07h and Li is a decreasing function of Lbi23-07h: at Lbi23-07h = 10 dB(A), Lbi23-07h - Li = -2 dB(A) and at Lbi23-07h = 31 dB(A): Lbi23-07h - Li = +3 dB(A). The difference between Lbu23-07h and Lo is on average (all subjects) irrespective of Lbu23_07h, equal to 1.3 dB(A) (standard error of the mean equal to 0.24 dB(A)). For subjects at Spaarndam the difference between Lbi23-07h and Li is on average (30 subjects) equal to 10.9 dB(A) (following the regression equation it would be 1.5 dB(A)), and the difference between Lbu23-07h and Lo equal to 10.5 dB(A). For other locations the mean differences are all between –5 and +5 dB(A). Therefore, we conclude that at location 42 night-time aircraft operations over the location were much less frequent than should be expected from the yearly average.
Schedules of night-time aircraft traffic show that number of aircraft operations during spring and summer are higher than during autumn and winter (AAS, 2000). For locations visited in spring and summer the difference between Lbi23-07h and Li is on average equal to 0.0 dB(A) and for locations visited in autumn and winter equal to 2.2 dB(A). For outdoor differences (differences between Lbu23-07h and Lo) values of 0.3 dB(A) and 1.7 dB(A) apply. If we exclude Spaarndam, the indoor and outdoor differences for locations visited in autumn and winter are equal to 1.1 and 0.5 dB(A). These values are not statistically significant different from 0.0. This implies that on average, with the exception of location 42, there is a good correspondence between mean Li and Lbi23-07h and between mean Lbu23-07h and Lo, and that there are no systematical differences in Lo or Li with period of the year.
From these observations we conclude that Li is also representative of the long-term aircraft noise exposure during sleep of subjects, with the exception of Li of subjects at location 42.

The following four night-time aircraft noise exposure metrics have been used in the analyses in this chapter:

- Lbi23-07h;
- Lbi23-06h;
- Lo;
- Li.

Correlation coefficients between these aircraft noise exposure metrics are given in table E1.

Effect variables from the questionnaire can be classified as follows:

Type 1: night-time aircraft noise specific effect variables, such as awakening by night-time aircraft noise
Type 2: effect variables related to 24 hours aircraft noise exposure, such as fear for aircraft;
Type 3: general effect variables, such as number of health complaints and sleep quality.

Twenty-one self-reported effect variables have been considered. These variables are of the following types:

| | |
|---|---|
| - Perception of aircraft noise during 24 hours | type 2; |
| - Annoyance by aircraft noise during 24 hours | type 2; |
| - Perception of night-time aircraft noise | type 1; |
| - Awakening by night-time aircraft noise | type 1; |
| - Annoyance by night-time aircraft noise | type 1; |
| - Fear because of aircraft noise | type 2; |
| - Frequency of being afraid of aircraft noise | type 2; |
| - Dissatisfaction with aircraft noise around the house | type 2; |
| - Fear for health impact by aircraft noise | type 2; |
| - Experienced health | type 3; |
| - Sleep quality | type 3; |
| - Number of general sleep disturbances | type 3; |
| - Number of night-time aircraft noise complaints | type 1; |
| - Number of health complaints (voeg) | type 3; |
| - Use of sleeping pills which induce sleepiness/increase sleep depth | type 3; |
| - Use of medicication | type 3; |
| - Sum reasons frightened of aircraft noise | type 2; |
| - Recognising own situation as living under a flight path | type 2; |
| - Recognising own situation living in the vicinity of a large airport | type 2; |
| - Worried about living under a flight path | type 2; |
| - Worried about living in the vicinity of a large airport | type 2; |
| - Number of effects per week on sleep by aircraft noise | type 1. |

**Associated variables, determinants, effect-modifiers, confounders**

In first instance demographic variables have been taken into consideration as possible determinants and effect-modifiers in the analyses. Then, other variables from the questionnaire have been considered as possible variables associated with the effect variable and possible determinants and effect-modifiers. Finally possible confounders are discussed.

## E.3 Analyses of long-term variables

The analyses consist of the following steps:

*Step 1*
Each of the 21 effect variables have been entered as dependent variable in a linear multi-variate regression analysis with any of the night-time aircraft noise exposure metrics as independent variable and age and age*age as determinants. In case the regression coefficient of age and/or of age*age turned out to be not statistical significant different from 0 ($P > 0.05$), a regression analysis has been performed without (one of) these variables. Results of the analyses are given in table

E2. The table gives R (overall regression coefficient), and the standardised regression coefficient of the effect variable (this value is the slope of the straight line giving the standardised change in effect for a standardised change in exposure). If age and age*age are no determinants, the aircraft noise exposure metric is the only independent variable and the absolute value of the regression coefficient of the effect variable is equal to R. If age and/or age*age are determinants, R is larger than the absolute value of the standardised regression coefficient of the effect variable. The larger R and the larger the standardised regression coefficient of an effect variable, the stronger the relationship between effect and exposure. From the results in table E2 the night-time aircraft noise exposure variable has been assessed that gives overall the strongest relationship with the effect variables. Table E2 shows the following results:

- All but two statistical significant relationships have regression coefficients that are in agreement with the model that adverse effects increase with increasing night-time aircraft noise exposure. The two exceptions are f6a (afraid of aircraft noise) and f6b (frequency of being afraid of aircraft noise). These relationships will not be considered further, which leaves 19 effect variables for consideration;
- Comparing the results for Lbi23-06h with those for Lbi23-07h, for all but two of the 19 variables (e1_3n and e_3) the standardised coefficient of Lbi23-07h is somewhat higher than the value for Lbi23-06h. Therefore Lbi23-07h is preferred over Lbi23-06h;
- Comparing the results for Lo with those for Li, for all but two variables (d3b -night-time aircraft noise annoyance- and slelt_cl) the standardised coefficient of Lo is somewhat higher than the value for Li;
- Comparing the results for Lbi23-06h and Lbi23-07h with the results for Li and Lo, for nine variables the standardised coefficients of Lbi23-06h and Lbi23-07h are somewhat higher than the standardised coefficients for Lo and Li, and for 7 variables somewhat lower;
- For four variables (health, medall, slsom and e1_7n) none of the regression coefficients are statistical significant different from 0;
- For two variables (slelt_cl and e_7) the regression coefficients are statistical significant different from 0 for only one night-time aircraft noise exposure metric;
- Voeg is related to Lo and Li, but not to Lbi23-07h or Lbi23-06h;
- The variables d2b (awakened by aircraft noise) and e1_3n (recognizing own situation as living under a flight path of a large airport) show the highest R and standardized slopes;
- Of all statistical significant variables sleep quality has the lowest R and standardised slope.

Further analyses have been carried out mainly with Lbi23-07h as night-time aircraft noise exposure variable, because it does give overall the best relationships with effect variables from the questionnaire. It concerns 12 effect variables if we exclude f6a, f6b (not in agreement with model) and e-7 (e1-7n not significant). With respect to voeg and slelt_cl, analyses have been carried out with Lo and Li as night-time aircraft noise metrics.

The results of the multi-variate regression analyses with each of the twelve effect variables with a statistical significant relationship with Lbi23-07h, are given in table E3.
The equation of a relationship between effect variable y, and Lbi23-07h with age and age*age as determinants is given by:

y = constant + b1*Lbi23-07h + b2*age + b3*age*age [E1]

If b3 is negative, the function b2*age + b3*age*age has a maximum, if b3 is positive, the function b2*age + b3*age*age has a minimum. The last row of table E3 gives, where appropriate, the age at which this function is minimal or maximal. The age for which an adverse effect is maximal or minimal is between 44 and 60 years, depending upon the effect considered. Figures are given in figure E1 to E12.

The results of the analyses with effect variables voeg and slelt_cl and Li are given in table E4. Figures are presented in figure E13 and E14. If slelt_cl is dichotomised, a logistic regression analysis shows that whether or not a subject uses sleeping pills increases statistically significant with Li and age turns out to be an important effect-modifier.

S*tep 2*
Multi-variate regression analyses have been performed with the 12 effect variables as dependent variable, Lbi23-07h and demographic variables, including where appropriate age and age*age, as possible determinants. In table E5 the regression coefficients are shown for relationships in which other demographic variables turned out to have a statistical significant regression coefficient ($P < 0.05$, tested two-sided). It concerns only in some cases some demographic variables.

*Step3*
For the 12 effect variables multi-variate backward linear regression analyses have been performed with age, age*age, other statistical significant demographic variables and a series of other possible associated variables and determinants. The regression coefficients of possible associated variables and determinants are shown in table E6. In table E7 the change in the effect variables are given for the maximal difference in Lbi23-07h in the present study (first row) and for the maximal change in a associated variable or a determinant. Demographic variables included in table E5 are in many instances not included in table E6 and E7, since their regression coefficients turned out to be not statistical significant after the inclusion of other variables.

*Step 4*
There is a high correlation between long-term day and night-time exposure of subjects. E.g., the correlation coefficients of Lbi23-07h and Lden, Lday and Ke are 0.96, 0.89 and 0.88 respectively. To assess whether Lden, Lday and/or Ke his are confounders, each of the 12 effect variables from the questionnaire have been related to Lden, Ke and Lday. Since there is a strong association, this implies that Lden, Ke and Lday are confounders of the 12 exposure-effect relationships. In the Introduction of this Appendix it has been stated that it is not the aim of the analyses performed in this section to assess exposure-effect relationships that are general applicable. Therefore, no attempt has been made to estimate the confounding effects.
Voeg and slelt_cl are not associated with the long-term day- and 24 hours aircraft noise exposure metrics Lden, Ke and Lday. This implies that Lden, Ke and Lday are not confounders of the relationships of these variables with Li.

## E.4 Relationships between 24 hours and long-term variables

In the questionnaire and in the morning diary sleep quality is rated on the same 11 points scale. In figure E16 two regression lines are shown: one with the average value of slpkw_10 from the diaries as dependent variable and one with sleep quality obtained from the questionnaire as dependent variable. The ranges of the axes correspond to the lowest and highest score from subjects. It is obvious that subjects score on average less extreme in the morning diary than in the questionnaire.

Annoyance due to day-time noise has been rated in the evening diary and in the questionnaire. In figure E16 two regression lines are given with score of noise annoyance obtained from the questionnaire and average noise annoyance score obtained from the evening diaries (noise annoyance 24h). In the evening diaries average noise annoyance has a range from 0 to 3 (on an 11 points scale), noise annoyance in the questionnaire has a range from 0 to 8 (also on an 11 points scale). The correlation coefficient is 0.41. Again subjects score less extreme on average in the evening diary than in the questionnaire.

## E.5 Aggregated effect variables over participation nights

For each subject the mean value over the eleven sleep period times of subjects of the following variables have been calculated: mspt, kspt, rlscspt, fragmentation index, number of marker pressings, number of remembered awakenings, sleepiness before going to sleep, sleep quality on an 11- and 5-points scale, sleeping pills or drugs effective to induce sleep, sleepiness during day- and evening-time assessed by sleepiness strip, results obtained with the reaction time test, sleep latency time (slt), and duration of sleep period time. These aggregated values of each subject are assumed to be an estimate of the long-term values of the subject. A linear regression analysis has been performed with each of these effect variables as dependent and Li as independent variable. In the second step a linear regression analysis has been performed with age and age*age as determinants. There turned out to be a statistical significant relationship ($P < 0.05$, tested one-sided, with the model that adverse effects increase with increasing aircraft noise exposure) only for mspt, kspt, rlscspt and slt. The coefficients of the regression equations are given in table E8.

In section E.3 of this Appendix it has been shown that effect variables obtained from the questionnaire relate better to Lbi23-07h than to Li. Therefore for mspt, kspt, rlscspt and slt, also relationships have been assessed with Lbi23-07h as independent variable. In each case it turned out that multiple R and F are larger if Li is taken as aircraft noise metric than if Lbi23-07h is taken as noise metric (see lower part of table E8). Therefore mspt, kspt, rlscspt, and slt relate better to Li than to Lbi23-07h.

The aggregated variables have also been related to age. Regression analyses have been performed with age and age*age as independent and the mean values of the effect variables as dependent variables. There turned out to be no relationship between age (and/or age*age) and the two measures of sleep quality slpkw_10 and slpkw_05. The mean values of slpkw_10 and slpkw_05 are 6.9 and 2.3 respectively.

Possible relationships have been considered between motility and variables obtained from the questionnaire and aggregated effect variables assesed on a 24 hours time scale. Linear multivariate regression analyses have been performed with mspt (averaged over all sleep period times of a subject) as independent variable, variables obtained from the questionnaire, by marker pressings, and morning diaries as dependent variable, and where appropriate with age and age*age as determinants. Statistical significant relationships exist between mspt and the following variables: number of times remembered to have been awake during sleep period time, number of marker pressings during sleep period times, use of sleeping pills (effective to induce sleepiness or increase sleep depth), sleep quality from the questionnaire, number of general sleep complaints, frequency of times awake due to aircraft noise, number of aircraft noise induced effects a week, and voeg score. Figures are given in figure E17 to E23.

## E.6 Instantaneous aircraft noise induced increase in probability of motility and long-term motility

In Appendix C relationships have been given between instantaneous aircraft noise induced increase of probability of (increase of) motility during the 15-s intervals e4 to e10. Equations for resp_m and resp_k at e6 as a function of Lmax_i are given in Table C1. The total increase in the 15-s intervals e4 to e10 of m is about 4.6 times resp_m at e6 and about 4.2 times resp_k at e6. The total instantaneous increase in m and k during n aircraft noise windows with Lmax_i over 32 dB(A) is given by:

$$\text{increase\_m (n aircraft noise events)} = 4.6*(\sum [b*(\text{Lmax\_i}(p) - a) + c*(\text{Lmax\_i}(p) - a)^2]) \quad [E2]$$

$$\text{increase\_k (n aircraft noise events)} = 4.2*(\sum [b*(\text{Lmax\_i}(p) - a) + c*(\text{Lmax\_i}(p) - a)^2]) \quad [E3]$$

with: Lmax_i(p) Lmax_i of aircraft noise event p;

∑ summation over n aircraft noise windows (with Lmax_i over 32 dB(A)) during sleep period time;

a, b, and c values given in table C1.

The equation for the average value of the instantaneous increase in m or k over all 15-s intervals during all sleep periods times (respectively instant_increase_m and instant_increase_k) is:

$$\text{instant\_increase\_m} = \text{increase\_m (n aircraft noise events)}/(\sum(\text{slp})/15) \quad [E4]$$

$$\text{instant\_increase\_k} = \text{increase\_k (n aircraft noise events)}/(\sum(\text{slp})/15) \quad [E5]$$

with: slp sleep period time in s

∑ summation over all sleep period times

For each subject instant_increase_m and instant_increase_k have been calculated.

A linear regression analysis has been performed with instant_increase_m and instant_increase_k as dependent variables and Li as independent variable. Age and age*age did not turn out to be statistical significant determinants. The results have been compared with the results of the regression analyses of the aggregated values of m and k over all sleep period times, as a function of Li, assuming instant_increase_m and instant_increase_k to be 0 at Li equal to 0 dB(A). The results are given in figures E24 and E25. The figures show that the increase in mspt and kspt as a function of Li cannot be explained by the instantaneous increase in (onset of) motility during aircraft noise events. This implies that there is, in addition to an instantaneous effect on motility, also a long-term component which increases with increasing long-term night-time aircraft noise exposure. For the highest Li values, the long-term aircraft noise induced increase in (onset of) motility is about 12% for motlity and 10% for onset of motility relative to the values at Li equal to 0 dB(A).

It is quite likely that such a long-term component needs a certain time to build up. Therefore analyses have been performed in which years living in the present house and years living in the present neighbourhood have been considered as possible determinants. The analyses are complicated by the strong association between age and years living in the present house or neighbourhood: young subjects (less than 35 years) usually live less than 5 years in the present house and neighbourhood and older subjects (50 years and over) usually live more than 15 years in the present house and neighbourhood. The only statistical significant impact of duration of living in the present neighbourhood or present house was shown for duration of living in the present neighbourhood (at most 5 years and more than 5 years) for subjects with age between 36 and 50 years. The results are given in figures E26 and E27. The effect of living more or less than 5 years in the present neighbourhood has been added to the straight lines representative for the age at which mspt or kspt are minimal (45 and 47 years). The results are in conformity with the hypothesis that subjects living for a shorter time in an environment with a high night-time aircraft noise exposure have a smaller value of mspt and kspt. However, also for the subjects living not more than 5 years in the present environment the increase in mspt and kspt cannot be fully explained by the instantaneous increase in m or k during aircraft noise exposure.

## E.7 Tables

*Table E1 Correlation coefficients night-time aircraft noise exposure variables.*

| | Lbi23-07h | Lbi23-06h | Li | Lo |
|---|---|---|---|---|
| Lbi23-07h | 1 | 0.97 | 0.57 | 0.79 |
| Lbi23-06h | 0.97 | 1 | 0.52 | 0.73 |
| Li | 0.57 | 0.52 | 1 | 0.80 |
| Lo | 0.79 | 0.73 | 0.80 | 1 |

*Table E2 Results (R and standardised regression coefficient of the effect variable) of linear regression analyses with 21 effect variables,4 noise exposure variables and where appropriate with age and age*age as determinants.*

| Effect variable | Lbi23-06h | | Lbi23-07h | | Li | | Lo | |
|---|---|---|---|---|---|---|---|---|
| | R | Stand coeff | R | Stand coeff | R | Stand coeff | R | Stand coeff |
| c1b | 0.391 | -0.391 | 0.394 | -0.394 | 0.359 | -0.359 | 0.383 | -0.383 |
| c2b | 0.400 | 0.369 | 0.415 | 0.387 | 0.367 | 0.334 | 0.394 | 0.363 |
| d1b | 0.368 | -0.368 | 0.372 | -0.372 | 0.355 | -0.355 | 0.361 | -0.361 |
| d2b | 0.425 | -0.373 | 0.426 | -0.373 | 0.408 | -0.349 | 0.421 | -0.364 |
| d3b | 0.360 | 0.306 | 0.383 | 0.334 | 0.363 | 0.310 | 0.357 | 0.303 |
| f6a | 0.271 | -0.201 | 0.266 | -0.194 | 0.237 | -0.146 | 0.281 | -0.210 |
| f6b | 0.231 | -0.198 | 0.214 | -0.176 | 0.226 | -0.190 | 0.268 | -0.238 |
| f7 | 0.387 | 0.351 | 0.399 | 0.366 | 0.342 | 0.301 | 0.351 | 0.312 |
| f8 | 0.344 | 0.284 | 0.370 | 0.317 | 0.275 | 0.197 | 0.329 | 0.268 |
| health | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. |
| sleep quality | 0.165 | 0.096 | 0.169 | 0.103 | 0.182 | 0.011 | 0.217 | 0.170 |
| slsom | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. |
| vliegsom | 0.322 | 0.274 | 0.324 | 0.278 | 0.320 | 0.268 | 0.348 | 0.301 |
| voeg | not sign. | not sign. | not sign. | not sign. | 0.123 | 0.123 | 0.156 | 0.156 |
| medall | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. |
| slelt_cl | not sign. | not sign. | not sign. | not sign. | 0.167 | 0.100 | not sign. | not sign. |
| f6b_sum | 0.199 | 0.175 | 0.204 | 0.181 | 0.187 | 0.156 | 0.233 | 0.210 |
| e1_3n | 0.496 | 0.496 | 0.488 | 0.488 | 0.273 | 0.273 | 0.380 | 0.380 |
| e1_7n | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. | not sign. |
| e_3 | 0.346 | 0.325 | 0.353 | 0.334 | 0.249 | 0.219 | 0.324 | 0.302 |
| e_7 | not sign. | not sign. | 0.171 | 0.110 | not sign. | not sign. | not sign. | not sign. |

*Table E3* *Regression coefficient and constant obtained by linear regression analyses with effect variables given in the heading of the columns and Lbi23-07h as night-time aircraft noise variable, together with regression coefficients of age and age*age, if these variables are determinants.*

| | Perception day-time aircraft noise | Annoyance day-time aircraft noise | Perception night-time aircraft noise | Awakening night-time aircraft noise | Annoyance night-time aircraft noise | Dissatisfaction aircraft noise around house | Worries about effects of aircraft noise on health | Number of reasons for being afraid of aircraft noise | Recognition of living under a flight path | Worried about living under a flight path | Sleep quality | Number of adverse effects a week due to aircraft noise at night |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| constant | 2.174 | -2.308 | 3.155 | 7.655 | -4.205 | -1.738 | -3.973 | 0.551 | -0.138 | -4.110 | 9.876 | -5.772 |
| Lbi23-07h (b1) | -0.039 | 0.174 | -0.062 | -0.085 | 0.169 | 0.161 | 0.137 | 0.034 | 0.036 | 0.164 | -0.029 | 0.278 |
| age (b2) | | 0.158 | | -0.081 | 0.231 | 0.151 | 0.193 | | | 0.135 | -0.093 | 0.076 |
| age*age (b3) | | -0.002 | | 0.001 | -0.003 | -0.002 | -0.002 | -0.000 | | -0.001 | 0.001 | |
| age in years at which the function is maximal or minimal | | 46 | | 60 | 46 | 45 | 45 | | | 55 | 46 | |

*Table E4* *Regression coefficient and constant obtained by linear regression analyses with effect variables given in the heading of the columns and Li as night-time aircraft noise variable.*

| | Slelt_cl | Voeg |
|---|---|---|
| constant | -0.03585 | 2.48 |
| Li | 0.005205 | 0.042 |

*Table E5* *Regression coefficient and constant obtained by linear regression analyses with effect variables given in the heading of the columns and Lbi23-07h as night-time aircraft noise variable, together with regression coefficients of the demographic variablesthat are determinants.*

| | Perception day-time aircraft noise | Annoyance day-time aircraft noise | Perception night-time aircraft noise | Awakening night-time aircraft noise | Annoyance night-time aircraft noise | Dissatisfaction aircraft noise around house | Worries about effects of aircraft noise on health | Number of reasons for being afraid of aircraft noise | Recognition of living under a flight path | Worried about living under a flight path | Sleep quality | Number of adverse effects a week due to aircraft noise at night |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| constant | 2.145 | -3.718 | 3.202 | 8.148 | -5.586 | -3.519 | -3.984 | -0.455 | -0.324 | -7.502 | 10.863 | -18.097 |
| Lbi23-07 | -0.038 | 0.182 | -0.064 | -0.087 | 0.184 | 0.169 | 0.142 | 0.041 | 0.037 | 0.174 | -0.034 | 0.283 |
| gender | | | | | -0.589 | | | 0.439 | 0.079 | 0.496 | | |
| age | | 0.140 | | -0.082 | 0.233 | 0.131 | 0.199 | -0.368 | | 0.143 | -0.111 | 0.377 |
| age* age | | -0.001 | | 0.001 | -0.003 | -0.001 | -0.002 | | 0.000 | -0.001 | 0.001 | -0.003 |
| citizenship | 1=mar, 2=alone | 1.515 | | | | | | | | | | 3.020 |
| household | 1=1, 2=more | | | | | | -1.155 | | | 0.762 | | |
| children | | | | 0.126 | | | | | -0.022 | -0.339 | 0.171 | -0.593 |
| country of birth | 1=neth, 2=other | | | -0.589 | | 1.898 | 1.921 | | 0.101 | 1.141 | -0.743 | 3.063 |
| education | 1=no, 4=high | | | | 0.600 | | | | -0.021 | | | |

*Table E6* *Regression coefficient obtained by linear regression analyses with effect variables given in the heading of the columns and Lbi23-07h as night-time aircraft noise variable, together with regression coefficients of associated variables and determinants.*

| Description of determinants | Perception day-time aircraft noise | Annoyance day-time aircraft noise | Perception night-time aircraft noise | Awakening night-time aircraft noise | Annoyance night-time aircraft noise | Dissatisfaction aircraft noise around house | Worries about effects of aircraft noise on health | Number of reasons for being afraid of aircraft noise | Recognition of living in the vicinity of a large airport | Worried about living in the vicinity of a large airport | Sleep quality | Number of adverse effects a week due to aircraft noise at night |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lbi2307h | -0.043 | 0.130 | -0.056 | -0.063 | 0.133 | 0.140 | 0.095 | 0.036 | 0.037 | 0.142 | -0.029 | 0.217 |
| age | | | | -0.021 | | 0.071 | 0.103 | | -0.002 | 0.011 | -0.075 | 0.048 |
| age*age | | | | | | -0.001 | -0.001 | | | | 0.001 | |
| gender | | | | | -1.031 | | | 0.368 | | 0.306 | | |
| daily noise disturbance | -0.024 | 0.202 | | | 0.219 | | 0.138 | 0.103 | -0.007 | 0.040 | | |
| number of years in environment | | | | 0.237 | | | | | 0.041 | | | -0.468 |
| satisfaction with house | | | | | -0.447 | 0.090 | | | | | | -0.871 |
| purchase or rent of house | -0.245 | 0.965 | -0.339 | | 1.213 | 0.205 | | | 0.094 | | | |
| insulation bedroom window | | -0.442 | | | -0.902 | -0.386 | | | | | | |
| satisfaction with living environment | | 0.420 | | | 0.941 | 0.748 | 0.310 | | | -0.104 | | 1.387 |
| satisfaction insulation outdoor noises | 0.028 | -0.255 | 0.065 | 0.114 | -0.191 | -0.734 | -0.039 | | -0.022 | -0.151 | 0.139 | -0.224 |
| ventilation | | -0.474 | 0.114 | 0.350 | -0.763 | 0.609 | -0.692 | | -0.043 | -0.350 | 0.232 | -1.287 |
| attitude towards Schiphol | | 0.191 | | | 0.128 | -0.120 | 0.283 | 0.037 | 0.017 | 0.189 | | 0.238 |
| sum action againstantaneous Schiphol | | 0.363 | | | 0.432 | -0.448 | 0.644 | | -0.066 | | 0.205 | |
| job related to Schiphol | | | | | | 0.330 | -0.500 | | 0.065 | | | |
| use hearing protection | | | | | | 0.314 | | | -0.064 | | -0.500 | 2.313 |
| sleeping pills | | | | | | | | | 0.044 | | -0.690 | |
| classified noise sensitivity | | 0.188 | | -0.152 | 0.268 | | | 0.212 | 0.021 | 0.262 | | 0.528 |
| ucl-active | | | | -0.198 | 0.823 | | | 0.398 | | 0.612 | -0.374 | 1.404 |
| ucl-laisser faire | | | | -0.315 | 0.677 | 0.259 | | 0.253 | 0.089 | | | 1.316 |
| ucl-support | 0.096 | | | | | | | | 0.056 | | | |

*Table E7* ***Maximal change in effect variables given in the heading of the columns due to a maximal change in associated variables and determinants.***

| Description of determinants | Values of variables in first column | Expected change relative to change in noise exposure | Perception daytime aircraft noise | Annoyance daytime aircraft noise | Perception nighttime aircraft noise | Awakening nighttime aircraft noise | Annoyance nighttime aircraft noise | Dissatisfaction aircraft noise around house | Worries about effects of aircraft noise on health | Number of reasons for being afraid of aircraft noise | Recognition of living in the vicinity of a large airport | Worried about living in the vicinity of a large airport | Sleep quality | Number of adverse effects a week due to aircraft noise at night |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Range of variable | | | -5 | +11 | -5 | -5 | +11 | +11 | +11 | +10 | +1 | +11 | -11 | +56 |
| Lbi23-07h | | | -1.08 | 3.24 | -1.40 | -1.59 | 3.33 | 3.49 | 2.36 | 0.90 | 0.73 | 2.83 | -0.72 | 5.42 |
| age | | | | | | -1.35 | | | | | -0.10 | 0.68 | | 2.99 |
| age*age | | | | | | | | | | | | | | |
| gender | 1=man 2=wom | | | | | | -1.03 | | | 0.37 | | 0.31 | | |
| daily noise disturbance | 0=not 10=very much | + | -0.24 | 2.02 | | | 2.19 | | 1.38 | 1.03 | -0.07 | 0.40 | | |
| number of years in environment | | | | | | 0.95 | | | | | 0.16 | 0.82 | | -1.87 |
| Satisfaction with house | 1=very 5=not sat | + | | | | | -1.79 | 0.36 | | | | | | -3.48 |
| house owned or rented | 1=rent 2=owned | | -0.25 | 0.96 | -0.34 | | 1.21 | 0.21 | | | 0.09 | | | |
| Insulation bedroom window | 0=not 1=yes | - | | -0.44 | | | -0.90 | -0.39 | | | | | | |
| Satisfaction with living environment | 1=very 5=not sat | + | | 1.68 | | | 3.76 | 2.99 | 1.24 | | | -0.42 | | 5.55 |
| Satisfaction insulation outdoor noises | 0=not 10=very sat | - | 0.28 | -2.55 | 0.65 | 1.14 | -1.91 | -7.34 | -0.39 | | -0.22 | -1.51 | 1.39 | -2.24 |
| ventilation | 1=more 5=never | - | | -1.90 | 0.46 | 1.40 | -3.05 | 2.44 | -2.77 | | -0.17 | -1.40 | 0.93 | -5.15 |
| attitude to | 0=pos 10=neg | + | | 1.91 | | | 1.28 | -1.20 | 2.83 | 0.37 | 0.17 | 1.89 | | 2.38 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Schiphol | 10=neg | | | | | | | | | | | | | |
| action againstantaneous Schiphol | | + | | 1.45 | | | 1.73 | -1.79 | 2.58 | | -0.27 | | 0.82 | |
| job related to Schiphol | 1=yes 2=no | - | | | | | | 0.33 | -0.50 | | 0.06 | | | |
| use hearing protection | 1=no 2=yes | + | | | | | | 1.57 | | | -0.32 | | -2.50 | 11.56 |
| sleeping pills | 0=not 4=imp | + | | | | | | | | | 0.18 | | -2.76 | |
| noise sensitivity | | + | | 1.32 | | -1.06 | 1.88 | | | 1.48 | 0.15 | 1.83 | | 3.69 |
| ucl-active | | + | | | | -0.59 | 2.47 | | | 1.19 | | 1.84 | -1.12 | 4.21 |
| ucl-laisser faire | | + | | | | -0.95 | 2.03 | 0.78 | | 0.76 | 0.27 | | | 3.95 |
| ucl-support | | - | 0.29 | | | | | | | | 0.17 | | | |

*Table E8* *Coefficients of linear regression equations with Li as independent variable and mspt, kspt, rlscspt and slt as dependent variable, age, and age*age as determinants (upper part of the table), R and F if Li is independent variable (middle part of table) and if Lbi23_07 is independent variable (lower part of table).*

| | mspt | kspt | rlscspt | slt |
|---|---|---|---|---|
| constant | 0.058787 | 0.032711 | 0.077799 | 17.18345 |
| Li | 0.000172 | 0.00053 | 0.000323 | 0.069975 |
| age | -0.00131 | -0.00053 | -0.00178 | -0.40057 |
| age*age | 0.000015 | 0.000006 | 0.000021 | 0.004574 |
| | | | | |
| R if Li is noise variable | 0.262 | 0.173 | 0.246 | 0.217 |
| F if Li is noise variable | 9.98 | 4.20 | 8.77 | 6.75 |
| | | | | |
| R if Lbi23_07 is noise variable | 0.238 | 0.149 | 0.215 | 0.214 |
| F if Lbi23_07 is noise variable | 8.16 | 3.08 | 6.60 | 6.56 |

## E.8 Figures

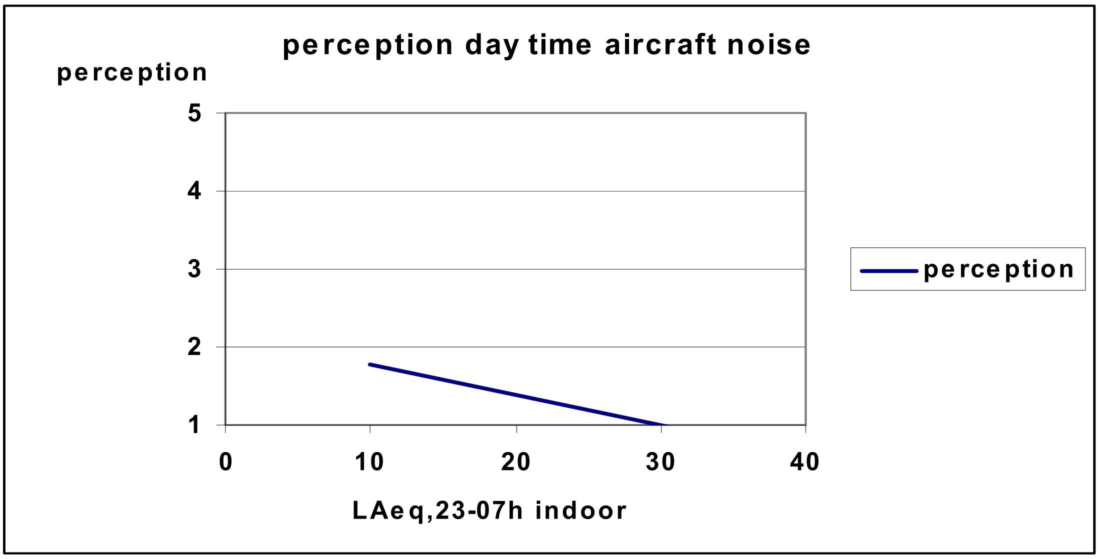


*Figure E1: Perception day time aircraft noise as a function of Lbi23_07h. Labels perception:5 never, 1 each day.*

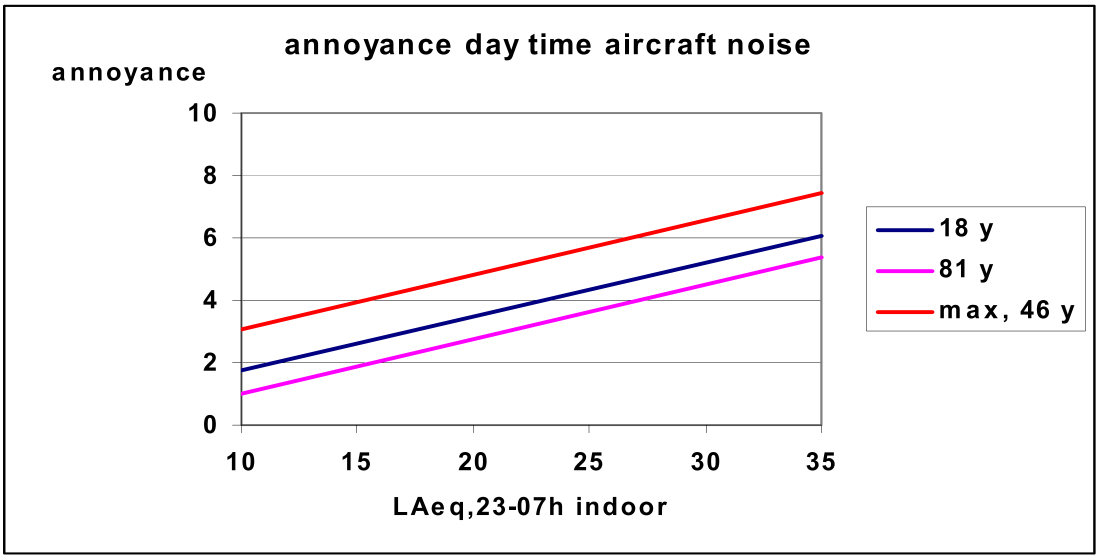


*Figure E2: Annoyance day time aircraft noise as a function of Lbi23_07h. Scale: 0 = not annoyed at all,... 10=very much annoyed.*

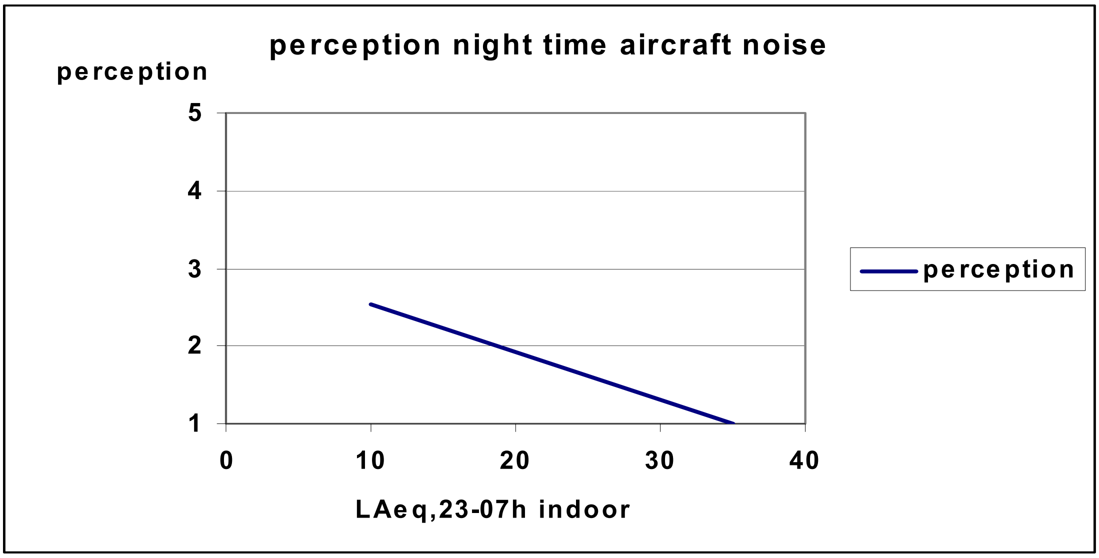


*Figure E3: Perception night time aircraft noise as a function of Lbi23_07h. Labels perception: 5 never, 1(nearly) each night.*

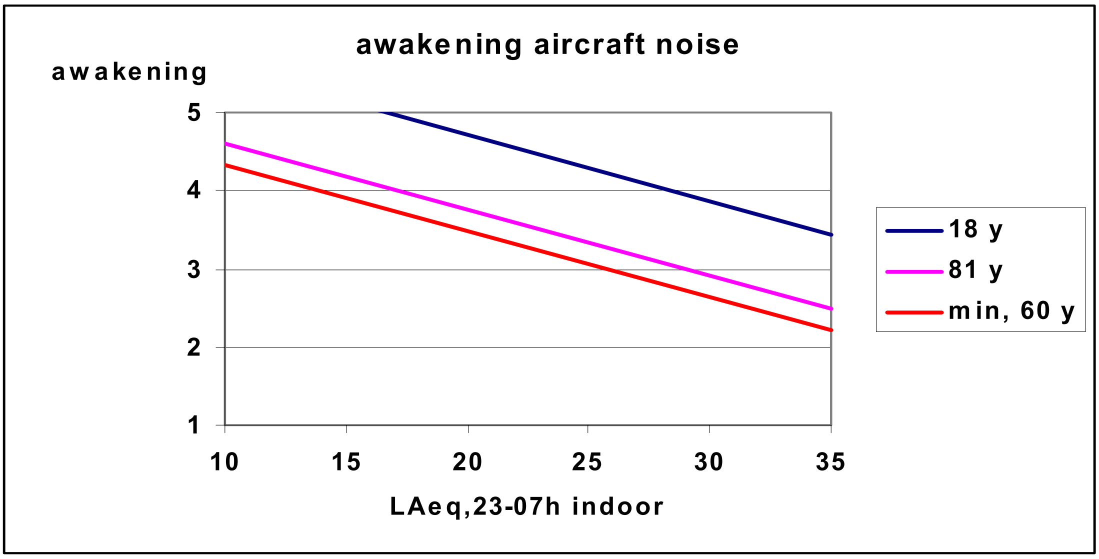


*Figure E4: Awakening due to aircraft noise as a function of Lbi23_07h. Labels: 5 never, 1(nearly) each night.*

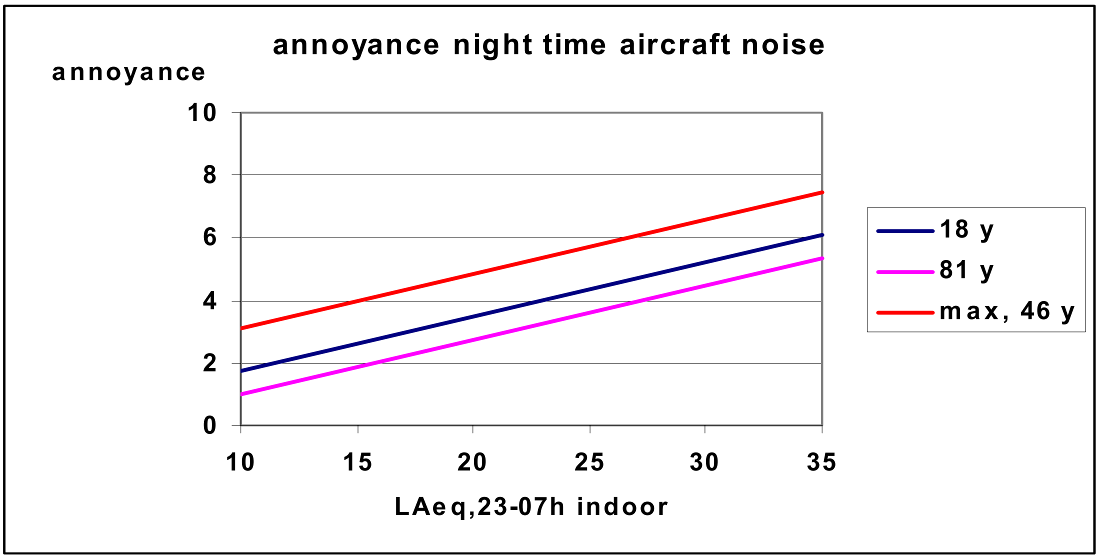


*Figure E5: Annoyance night time aircraft noise as a function of Lbi23_07h. Scale: 0 = not annoyed at all,… 10=very much annoyed.*

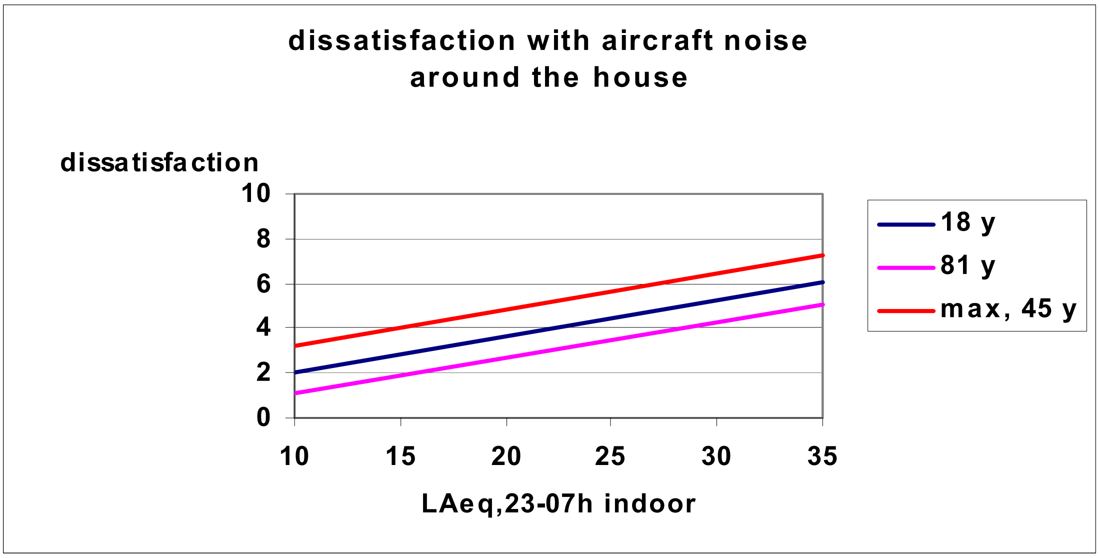


*Figure E6: Dissatisfaction with aircraft noise around the house as a function of Lbi23_07h. Scale: 0 = not dissatisfied at all,… 10=very much dissatisfied.*

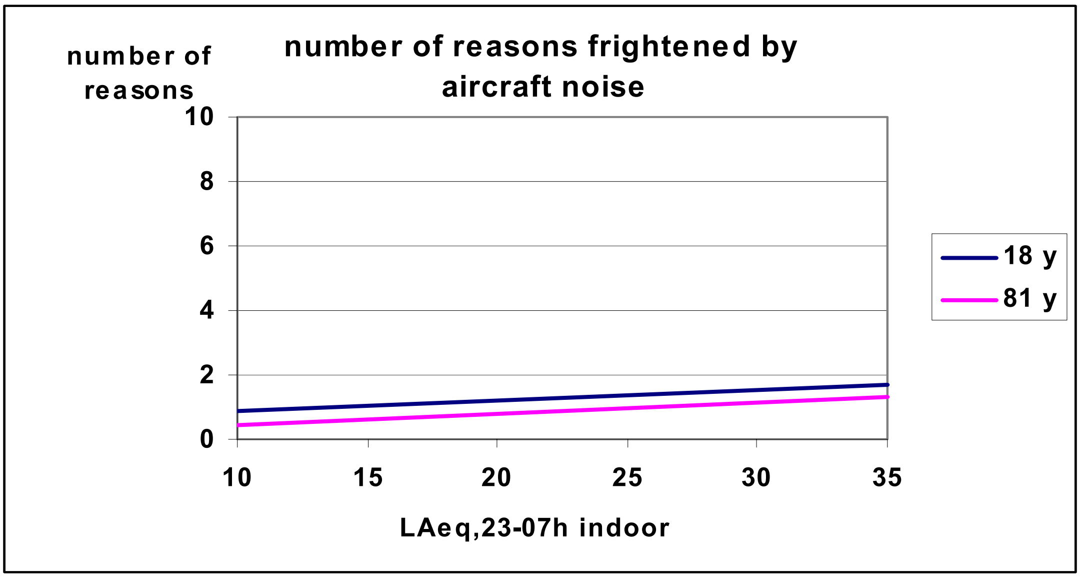


*Figure E7: Number of reasons subjects are frightened by aircraft noise as a function of Lbi23_07h. Scale: number from 0 to 10.*

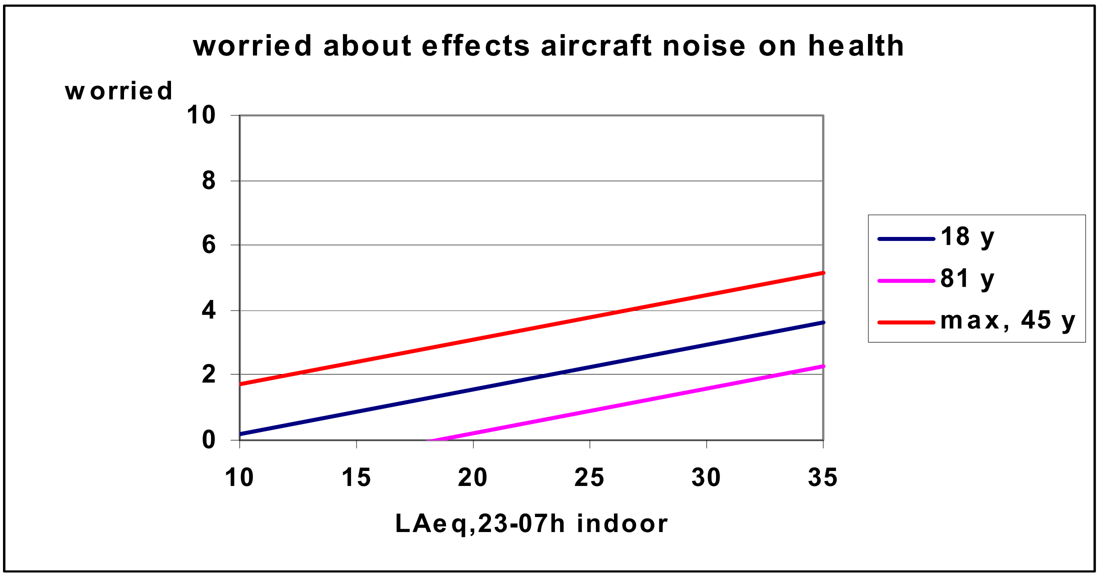


*Figure E8: Worried about adverse effects of aircraft noise on health as a function of Lbi23_07h. Scale: 0 = not worried at all,… 10=very much worried.*

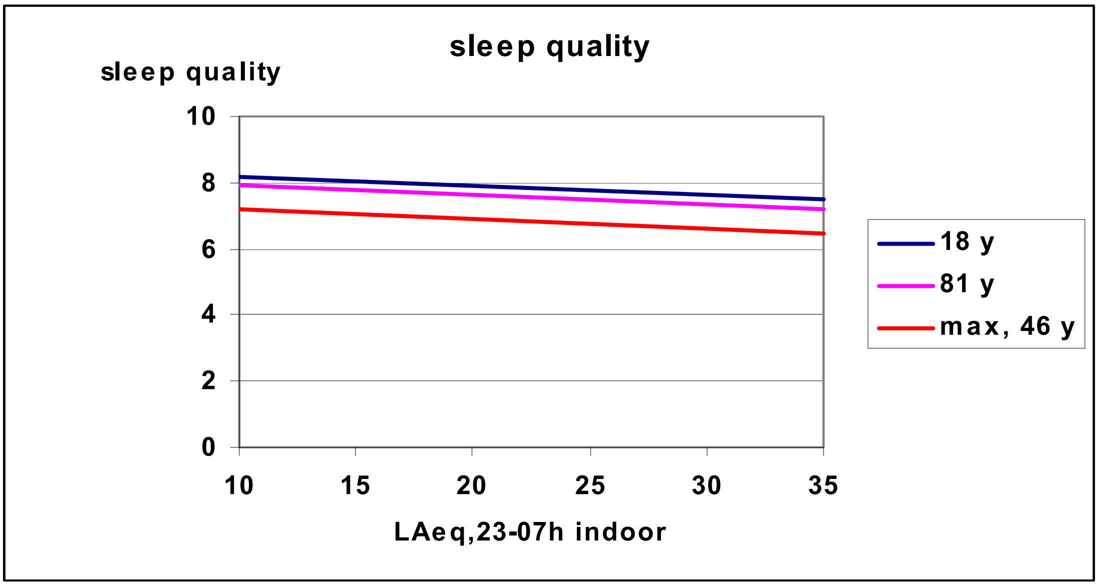


*Figure E9: Sleep quality as a function of Lbi23_07h. Scale: 0 = very bad,... 10=excellent.*

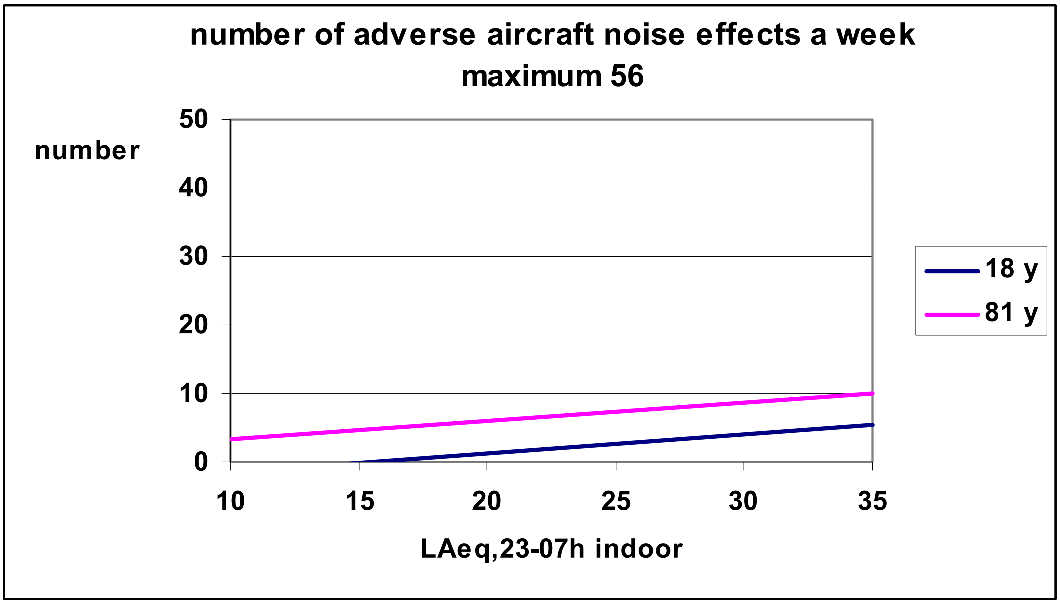


*Figure E10: Frequency of number of adverse effects experienced during a week due to aircraft noise at night as a function of Lbi23_07h.*

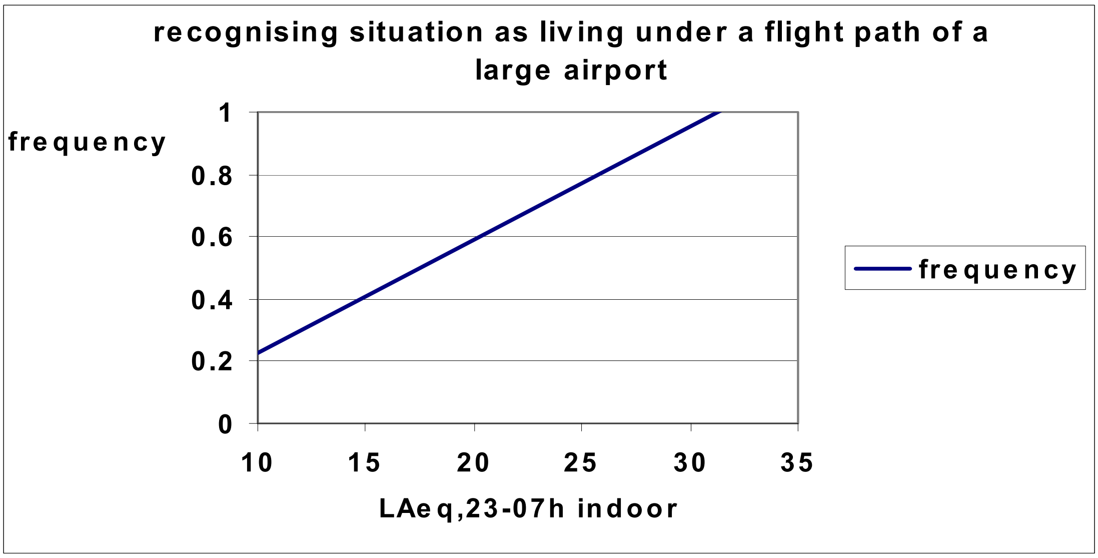


*Figure E11: Frequency of recognising situation as living under a flight path of a large airport.*

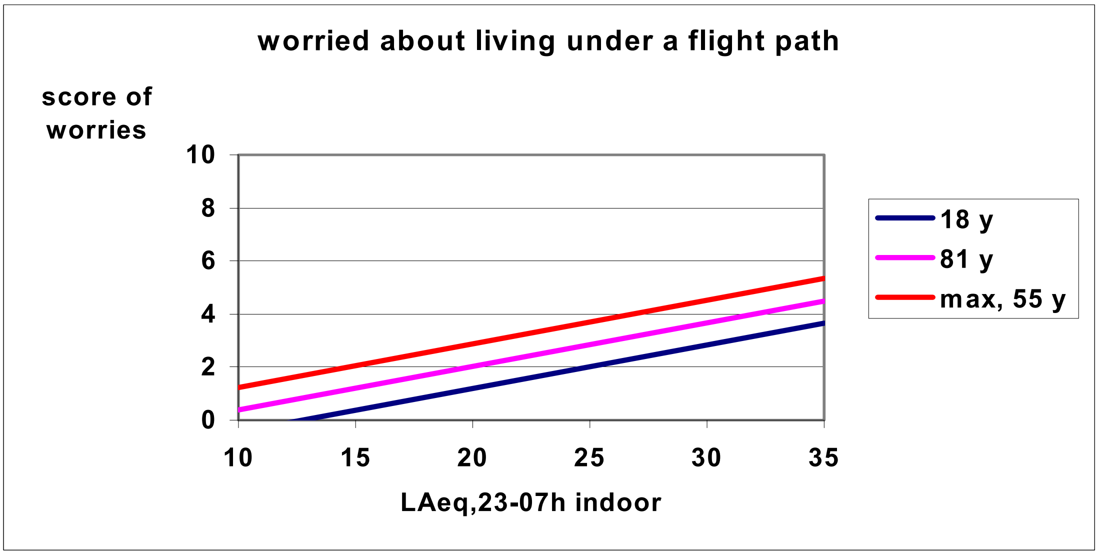


*Figure E12: Worried about living under a flight path of a large airport.*

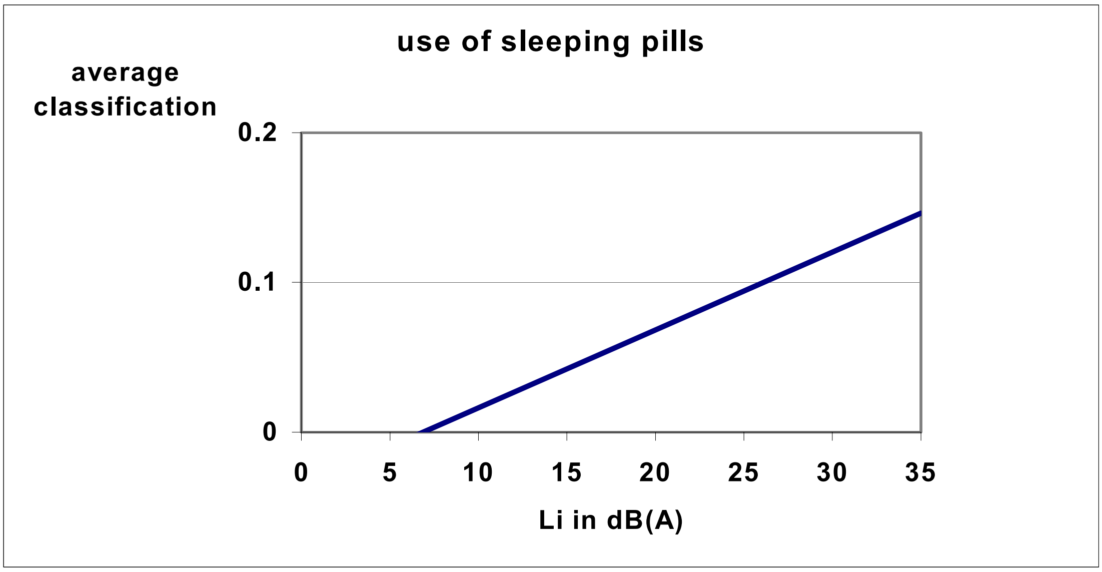


*Figure E13:* *Average classification of sleeping pillsand other medication with sleep inducing and/or sleep deepening effects (0 no used, not sleep inducing, 4 sleep induction main effect; classification 2 not used) as a function of Li.*

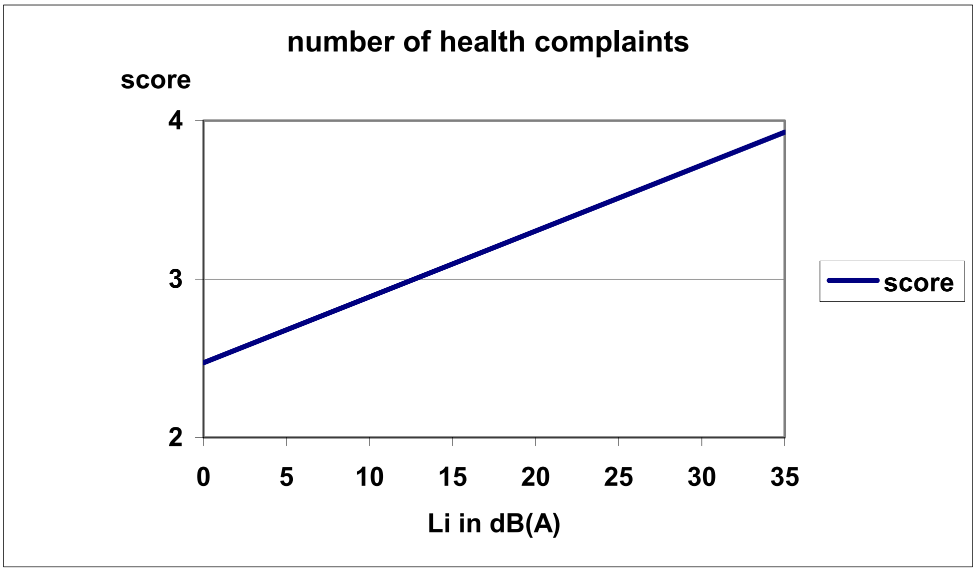


*Figure E14:* *Number of health complaints (voeg) as a function of Li (score = 0, no complaints, score = 13, maximal number of complaints).*

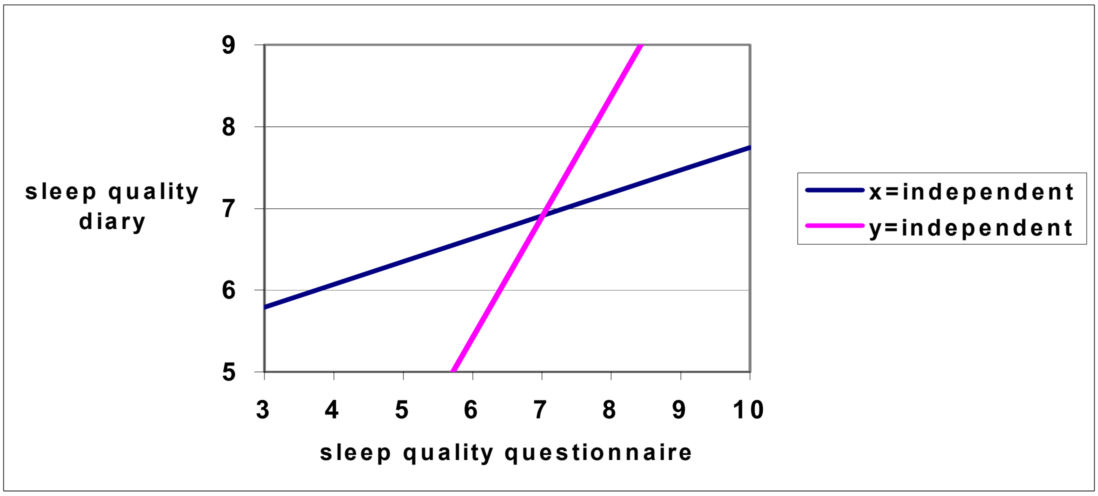


*Figure E15:* *Association between sleep quality from the morning diary (sleep quality 24 hours) and sleep quality from the questionnaire. The straight line with label x=independent is the regression line with sleep quality from the questionnaire as independent variable. The other straight line has sleep quality from the morning diary as independent variable*

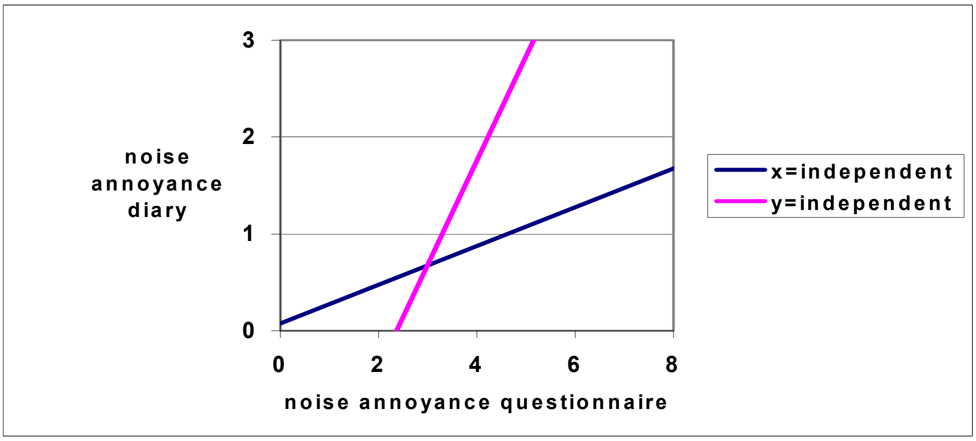


*Figure E16:* *Association between day time noise annoyance from the evening (noise annoyance 24h) and day time noise annoyance from the questionnaire. The straight line with label x=independent is the regression line with noise annoyance from the questionnaire as independent variable. The other straight line noise annoyance from the evening diary as independent variable*

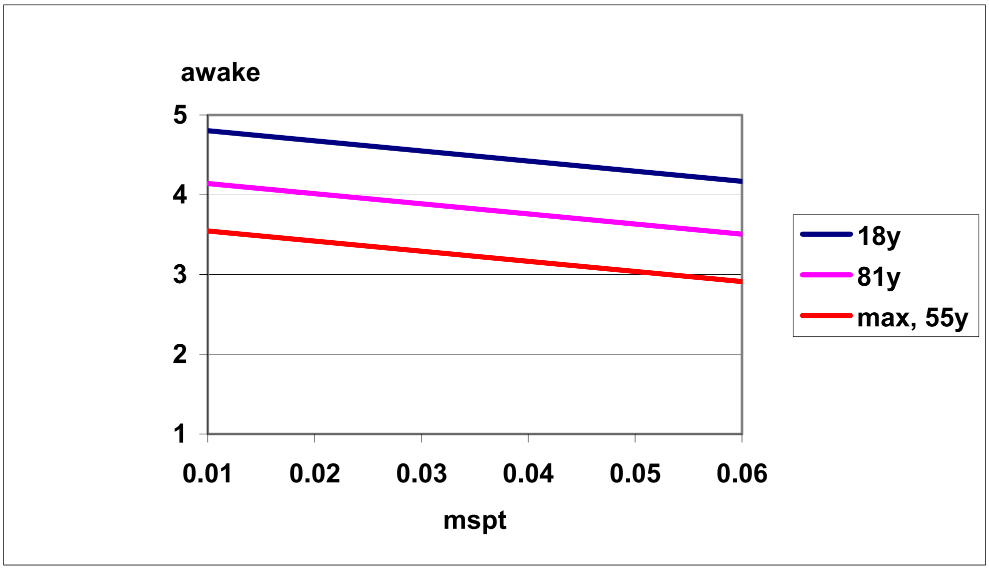


*Figure E17: Frequency of being awake (5= never, 1 = (nearly) each night) as a function of mspt (average value over sleep period times of subjects) for the three ages 18 years, 81 years, and the age at which the frequency of awakening is maximal.*

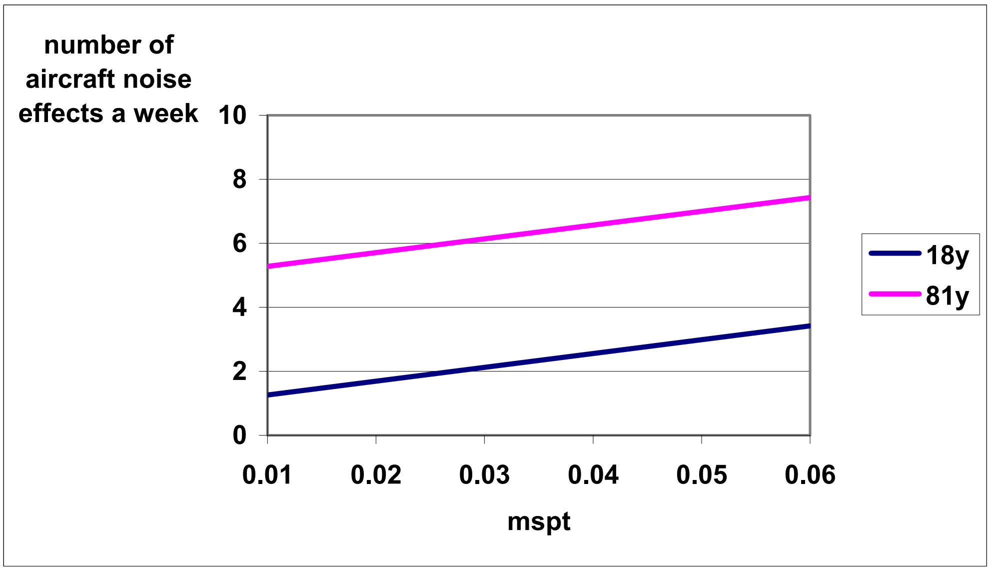


*Figure E18: Number of aircraft noise effects on sleep during one week (maximum is 56) as a function of mspt (average value over sleep period times of subjects) for the 18 years and 81 years.*

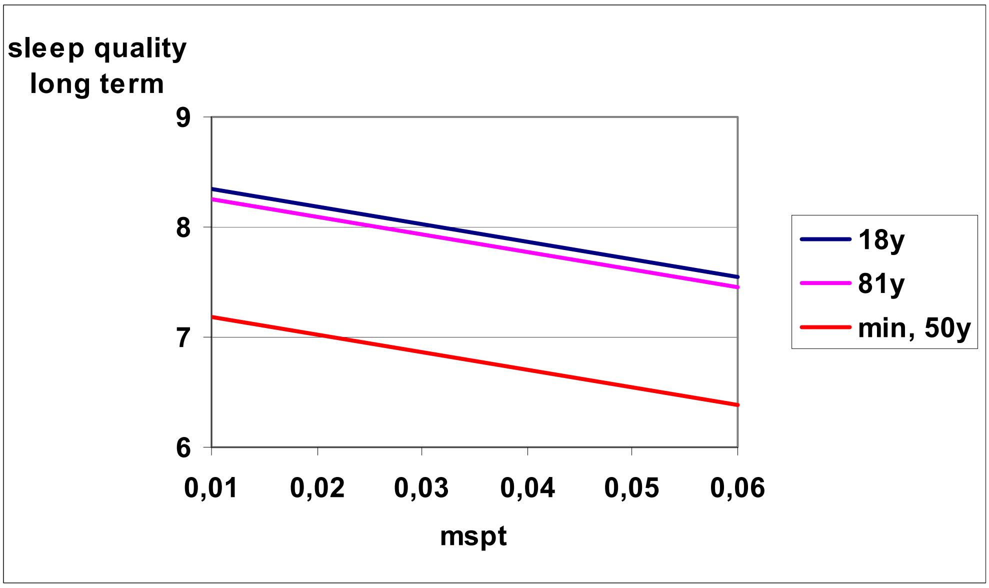


*Figure E19: Sleep quality from the questionnaire as a function of mspt (average value over sleep period times of subjects) for the three ages 18 years, 81 years, and the age at which sleep quality is minimal*

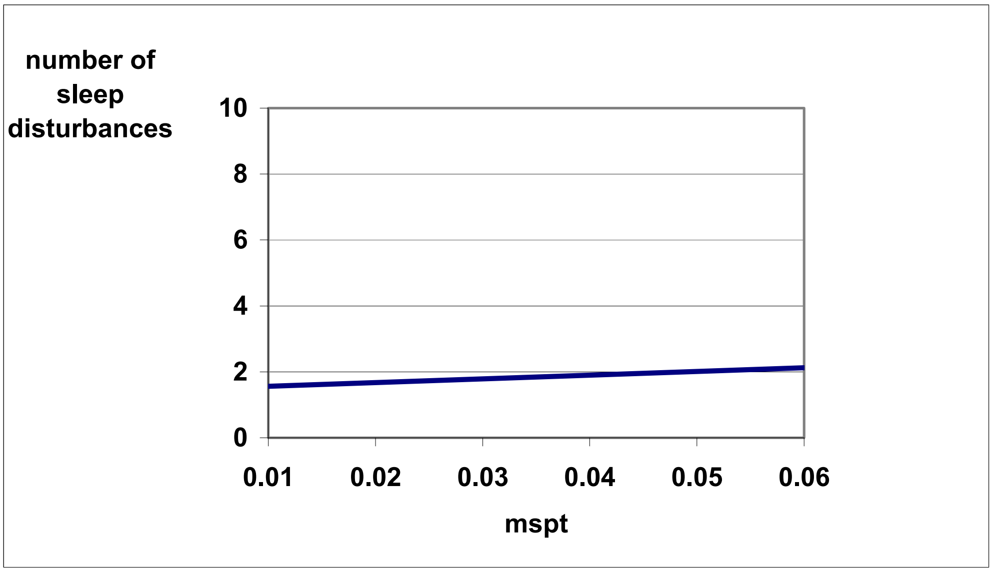


*Figure E20: Number of general sleep disturbances (range 0 to 10) from the questionnaire as a function of mspt (average value over sleep period times of subjects.*

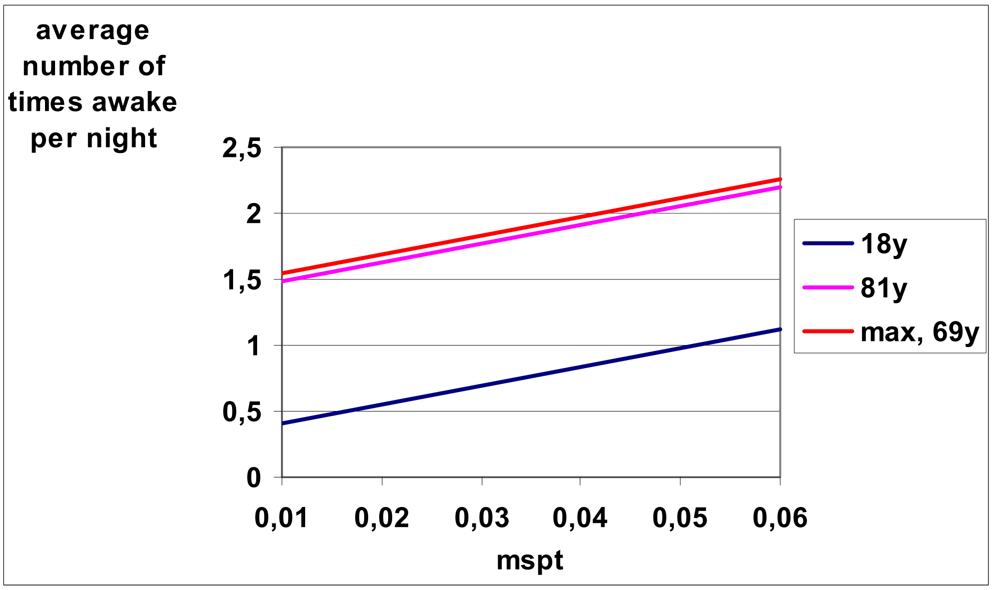


*Figure E21: Average number of times remembered to have been awakened per night obtained from the morning diaries as a function of mspt (average value over sleep period times of subjects) for the three ages 18 years, 81 years, and the age at which the average number is maximal.*

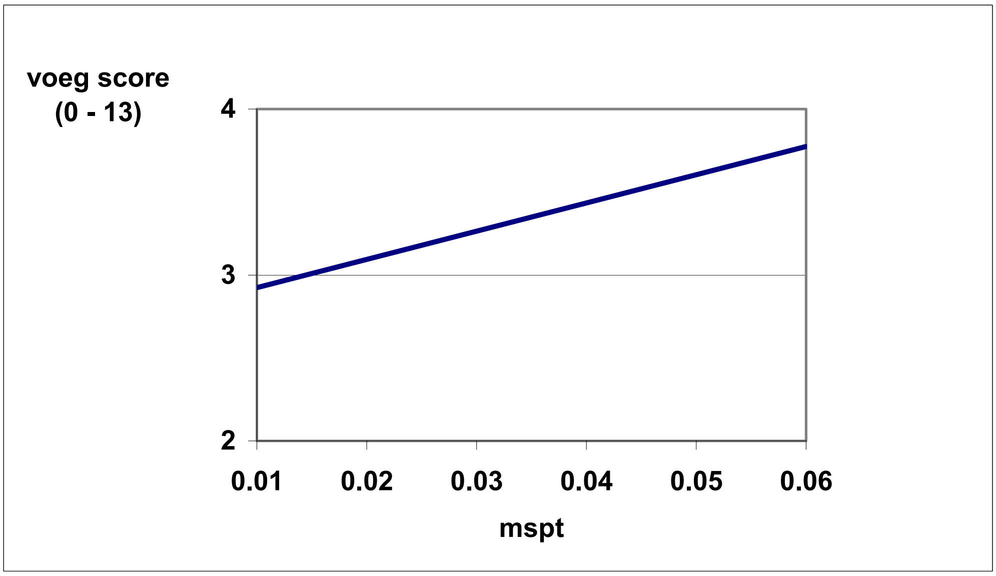


*Figure E22: Voeg score as a function of mspt (average value over sleep period times of subjects).*

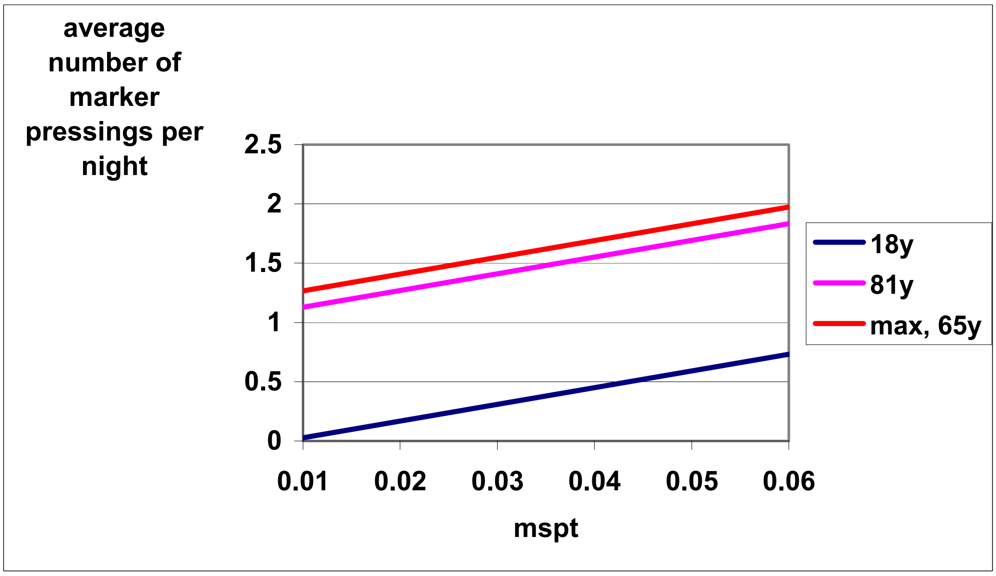


*Figure E23: Average number of marker pressings per night as a function of mspt (average value over sleep period times of subjects) for the three ages 18 years, 81 years, and the age at which the average number is maximal.*

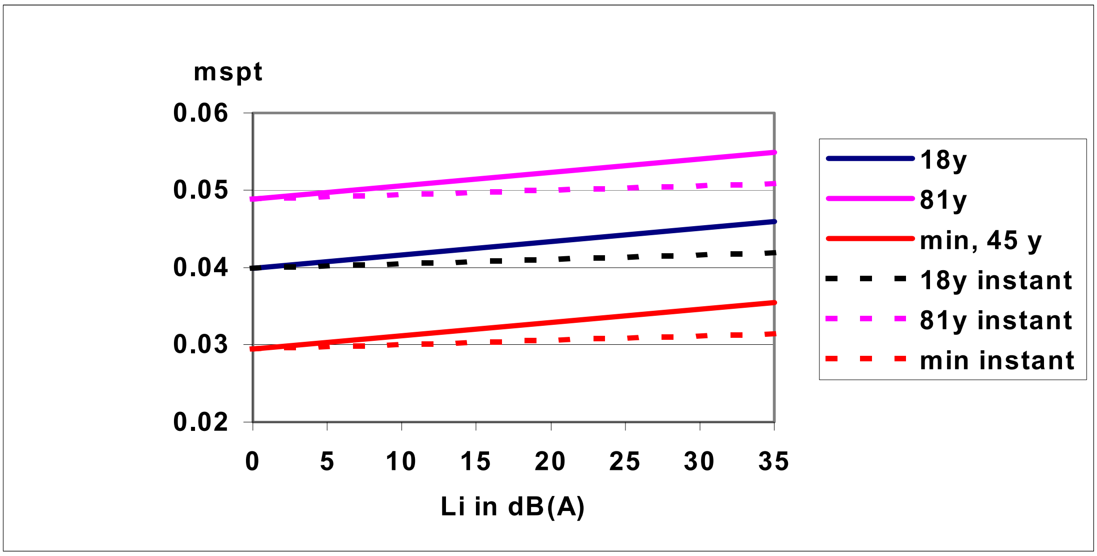


*Figure E24: The average value of mspt over sleep period times as a function of Li (uninterrupted straight lines) and aircraft noise induced values of mspt, assuming this increase to be absent if aircraft noise is absent (if Li equal to 0 dB(A)) (interrrupted straight lines).*

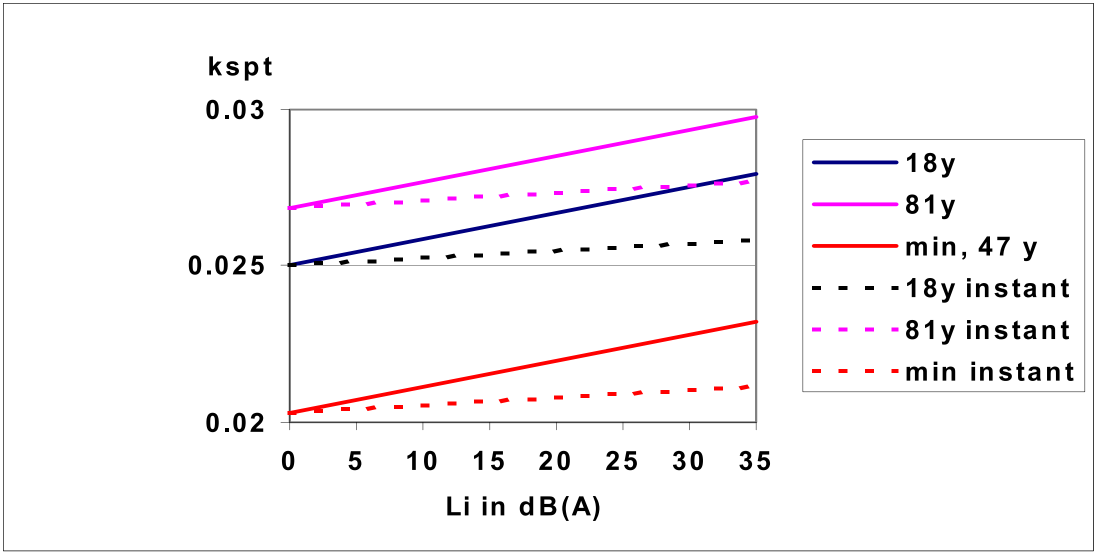


*Figure E25: The average value of kspt over sleep period times as a function of Li (uninterrupted straight lines) and aircraft noise induced values of kspt, assuming this increase to be absent if aircraft noise is absent (Li equal to 0 dB(A)) (interrupted straight lines).*

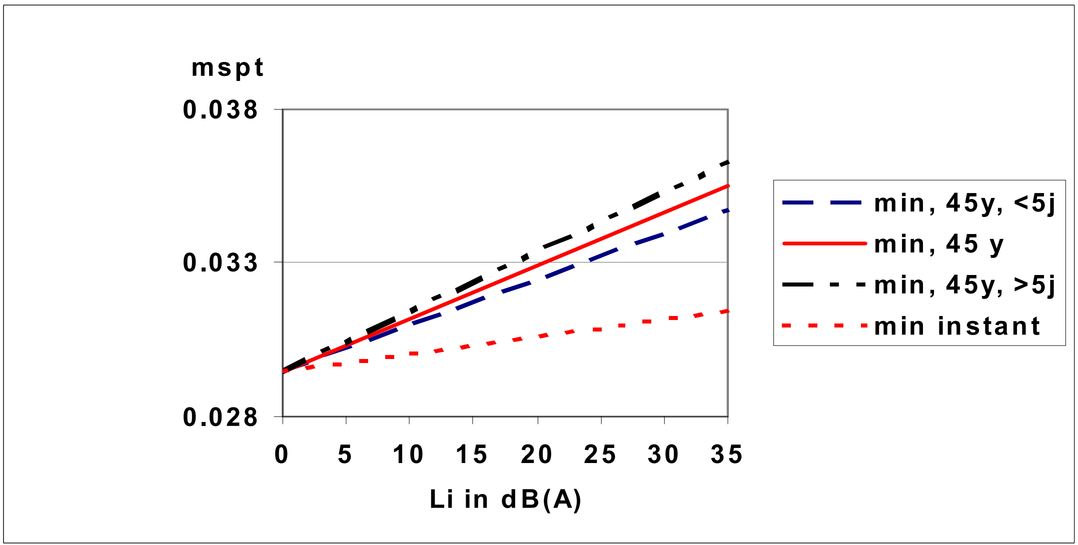


*Figure E26: The average value of mspt over sleep period times as a function of Li (uninterrupted straight line) if years living in the environment is not taken into account and for two classes of years living in the present environment (interrupted dark straight lines) and aircraft noise induced values of mspt, assuming this increase to be absent if aircraft noise is absent (if Li equal to 0 dB(A)) (interrupted straight line).*

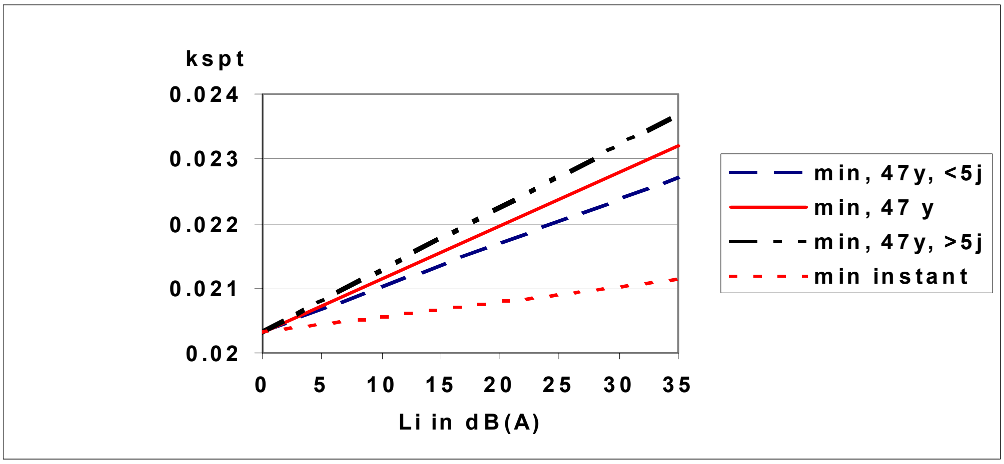


*Figure E27:* *The average value of kspt over sleep period times as a function of Li (uninterrupted straight line) if years living in the environment is not taken into account and for two classes of years living in the present environment (interrupted dark straight lines) and aircraft noise induced values of mspt, assuming this increase to be absent if aircraft noise is absent (if Li equal to 0 dB(A)) (interrupted straight line).*

# Appendix F Comparison of subjects and non-respondents

## F.1 Introduction

One of the aims of the study is to provide information on basis of which the prevalence of adverse effects of night-time aircraft noise exposure on the population in the vicinity of Schiphol can be estimated. The non-response study has been undertaken to estimate a possible selection bias of subjects by first establishing differences in the distribution of variables in the population of subjects and in the population of non-respondents, and then assessing the consequences of the observed differences on exposure-effect relationships. First, the variables with a distribution in the population of subjects that is statistically significant different from the distribution in the population of non-respondents will be assessed. These variables can be one of the effect variables, specified in the first row of table 4.1, or one of the determinants or variables associated with effect variables, specified in the first column of table 4.1.
For the effect variables, it is first assessed whether there is a statistically significant difference in exposure-effect relationships for subjects and non-respondents, taking also into account possible determinants and variables associated with the effect variable. In case of a difference, exposure-effect relationships for non-respondents are provided.
For the variables that are determinants or variables associated with effect variables, first the effect variables are assessed of which the variable is a determinant or is associated. For these effect variables, it is assessed whether there is a statistically significant difference in exposure-effect relationships for subjects and non-respondents, taking into account possible determinants and variables associated with the effect variable. In case of a difference, exposure-effect relationships for non-respondents are provided.

## F.2 Analyses

Non-respondents filled out a questionnaire with a large number of questions that also have been included in the subject questionnaire. It concerns in total 67 variables. In total the distributions of 21 variables are statistically significant different (tested 2-sided, level of significance 95%, One way ANOVA, or Independent Sample T-Test). Age is one of these variables These 20 variables plus age are given in table F1. Four of the 20 variables concern road traffic noise (indicated in the third column) and are not relevant for the present analysis. For six of the remaining 16 variables, the difference in distribution between subjects and non-respondents could be explained by the difference in age composition of the group of subjects and the group of non-respondents (indicated in the fourth column) (linear regression analysis with age and dummy of participation as independent variables).

Three of the remaining 10 variables are variables (fifth column of table F1 under the heading yes). Each of the three exposure-effect relationships for subjects and non-respondents (with where appropriate determinants and associated variables included in the analyses) turned out to be different. Coefficients of these three exposure-effect relationships for non-respondents, including the coefficients for age and age*age, if appropriate, are specified in table F2.

Five of the remaining seven variables (indicated in the sixth column) have an impact on the effect variables specified in table E4 and the difference between subjects and non-respondents may therefore have an impact on exposure-effect relationships. These five variables are citizenship, composition of household, satisfaction with sound insulation against outdoor noises, job related to Schiphol, and use of sleeping pills. Of which effect variable they are a determinant or are associated with is also indicated in the last column of table F1. Since satisfaction with sound insulation against outdoor noises is a determinant of or is associated with most effect variables in table E4, linear backward step regression analyses have been performed with any of the twelve effect variables given in table E4 as dependent variable, and Lbi23-07h, dummy of participation (subject/non-respondent), age, age*age and the other variables as independent variables. It turned out that the dummy variable has a statistical significant coefficient ($P < 0.05$, tested two sided) only for the three relationships specified in table F2. This implies that only the three variables given in table F2 have a statistical significant different exposure-effect relationships for subjects and non-respondents. For these relationships none of the variables considered in the backward step regression analyses, apart from age and age*age, have statistically significant coefficients.

In figure F1 to F3 the three different exposure-effect relationships, for both subjects and non-respondents, are given.

## F.3 Tables

*Table F1 Information about variables with a statistical significant different distribution among subjects and non-respondents.*

| Label | Variable | Relation with road traffic noise | Difference explained by age | Remaining 10 variables | Relationship with night-time aircraft noise exposure | | Impact on effect variable(s) (- no impact, + impact) |
|---|---|---|---|---|---|---|---|
| | | | | | yes | no | |
| a2 | age | | | | | | + (most effect variables) |
| a3 | citizenship | | - | + | | + | + (g28) |
| a4 | composition of household | | - | + | | + | + (f8) |
| a5 | number of children | | + | | | | |
| b1 | number of years in environment | | + | | | | |
| b3 | type of dwelling | | - | + | | + | - |
| b8 | satisfaction with insulation against outdoor noises | | - | + | | + | + (most effect variables |
| b9 | satisfaction with insulation against neighbouring noises | | - | + | | + | - |
| d1a | night-time perception road traffic noise | + | (+) | | | | |
| d2b | awakening by aircraft noise | | + | | | | |
| d3a | annoyance night-time road traffic noise | + | (+) | | | | |
| e1_3n | recognition 'living under a flight path' | | - | + | + | | |
| e1_6 | recognition 'living at a busy street' | + | (+) | | | | |
| e_6 | worried about 'living at a busy street' | + | (+) | | | | |
| f4 | sum actions against Schiphol | | + | | | | |
| f5 | job related to Schiphol | | - | + | | + | + (f8) |
| f8 | worried about health impact from aircraft noise | | - | + | + | | |
| g1 | experienced health | | + | | | | |
| g8 | hearing problems | | + | | | | |
| g19b | use of sleeping pills | | - | + | | + | + (sleep quality) |
| g28 | aircraft noise consequences on sleep | | - | + | + | | |

*Table F2 Regression coefficient and constant obtained by multi-variate linear regression analyses with effect variables given in the heading of the columns and Lbi23-07h as night-time aircraft noise variable, together with age and age*age as determinants, where appropriate. Results for non-respondents.*

| | Worries about effects of aircraft noise on health | Recognition of living under a flight path | Number of adverse effects a week due to aircraft noise at night |
|---|---|---|---|
| constant | -3.281 | -0.0099 | -5.261 |
| Lbi23_07h | 0.139 | 0.028 | 0.275 |
| age | 0.189 | | 0.098 |
| age*age | -0.002 | | |

## F.4 Figures

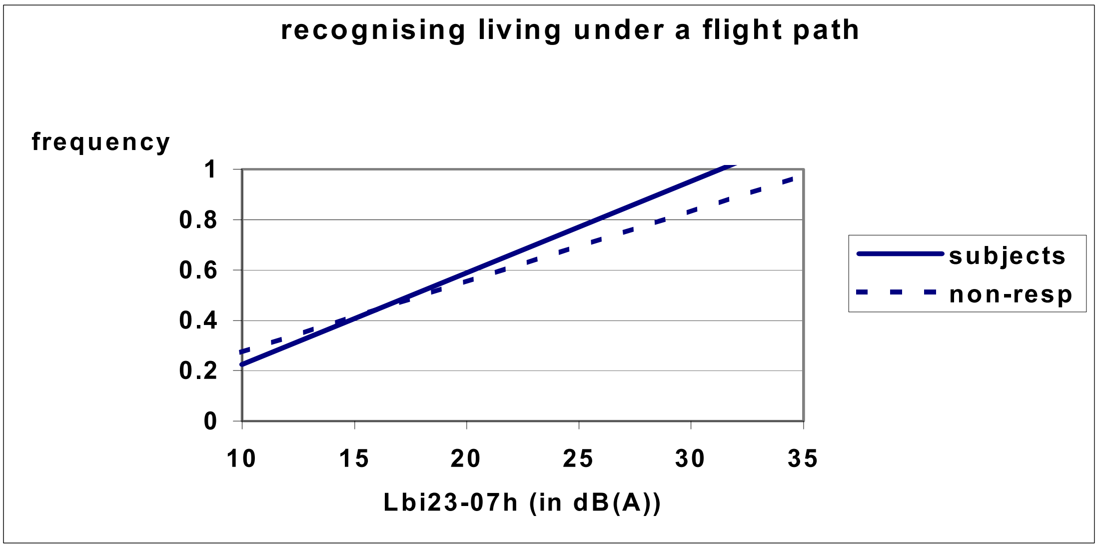


*Figure F1:* *Relationship for subjects and for non-respondents between frequency of recognising their situation as living under a flight path of a large airport (0: 0% , :1 100% of subjects or non-respondents) and Lbi23-07h.*

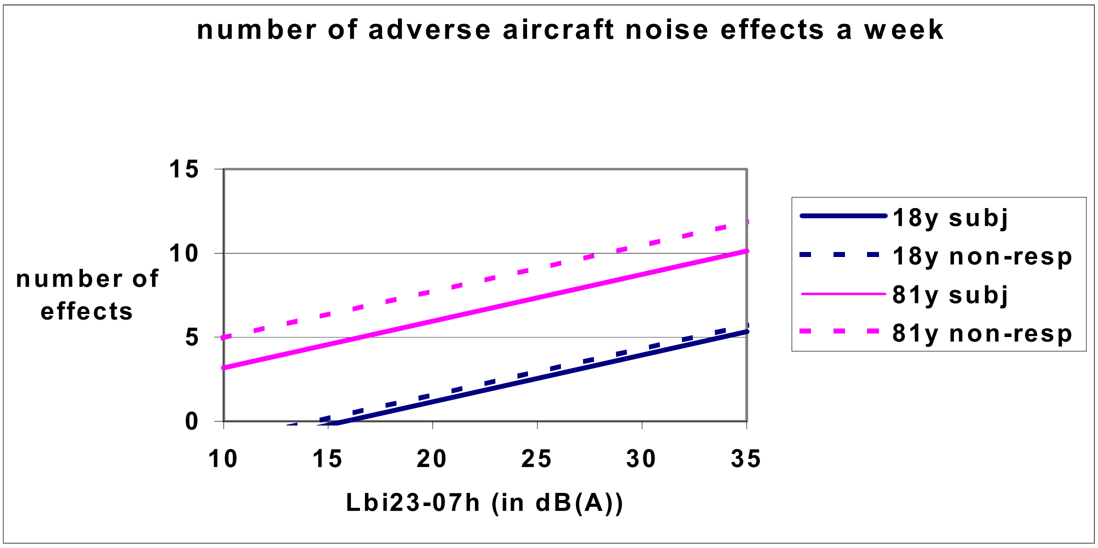


*Figure F2:* *Relationship for subjects and for non-respondents between number of adverse aircraft noise effects a week (maximum 56 times) and Lbi23-07h.*

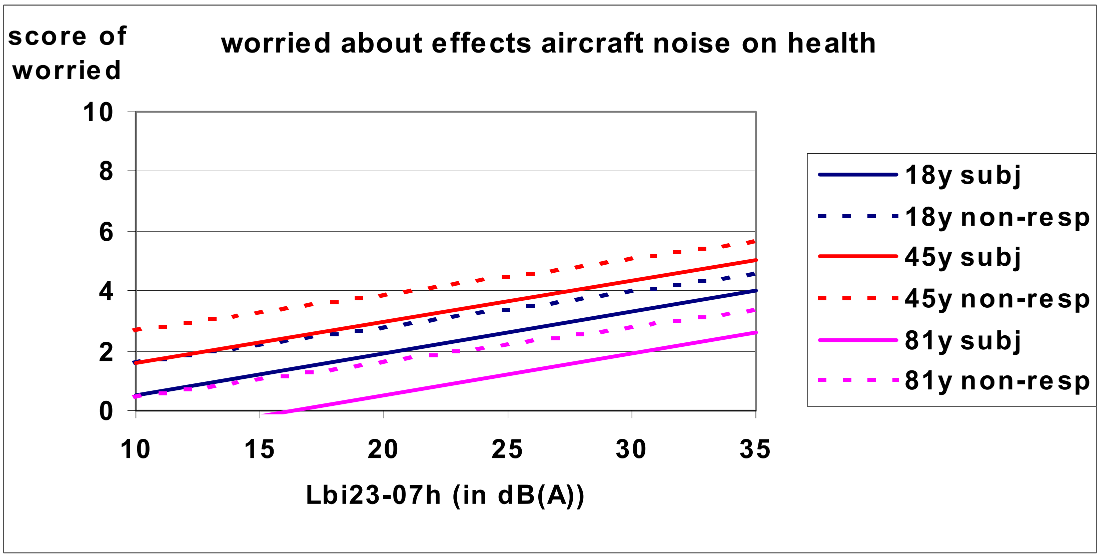


*Figure F3:* *Relationship for subjects and for non-respondents between score of being worried about effects of aircraft noise on health and Lbi23-07h.*

# Appendix G Overview of field studies on traffic noise-induced increase in probability of motility

## G.1 Introduction

In the present study motility is measured in succeeding measurement time intervals of 15 s. In other studies other measurement time intervals are chosen. The results in terms of probability of motility or onset of motility depend on the measurement time interval chosen. E.g., in the present study probability of motility during sleep is 0.0366. The number of 15-s intervals in the average sleep period time of 7 h and 10 minutes is 1720. Therefore, the number of 15-s intervals with motility during the average sleep period time is 63 and the number without motility 1657. The average number of 15-s intervals during sleep with onset of motility is equal to 40 (probability of onset of motility is equal to 0.0234). For other measurement intervals, other values of (onset of) probability of motility during sleep are appropriate. E.g., for 30-s intervals the probability of motility and of onset of motility would have been on average respectively 0.060 and 0.047.

Reviews of the quantitative literature on noise-induced instantaneous motility or awakenings found major differences between the results of laboratory and field studies, showing a much lower motility response in persons used to sleep in conditions with noise exposure than in test subjects in the laboratory (Pearsons, 1989; Pearsons et al., 1995). This marked difference between results of field and laboratory studies strongly suggests that laboratory findings about noise-induced sleep disturbance do not suffice for reliable assessment of noise-induced sleep disturbance in habituated residential populations. Therefore, this Appendix only takes the results of field studies into account.
Several (large-scale) field investigations, apart from the one reported here, have been undertaken during the last decade. They are:

- Ollerhead et al, 1992;
- Fidell et al., 1995;
- Fidell et al., 1998;
- Griefahn et al., 1999
- Flindell et al., 2000
- Smith et al., 2001?

The publicatio of Flindell et al. refers to a research trial on sleep disturbance to evaluate research options for further investigation. In the field pilot investigation 18 subjects participated for 5 nights. The publication did not aim at presenting any exposure-effect relationships and will not be considered further in this Appendix.
In a part of the field study by Smith et al. actimetry has been performed with 90 subjects for three nights. The results over sleep period times of the actimetric outcomes have been compared with results of indoor noise measurements. Exposure-effect relationships on an instantaneous time scale have not been established. The other results will not be considered in this Appendix.

Table G1 gives information about some aspects of the studies. A short overview of the studies is given in section G.2 and a comparison of their results with the present study in section G.3. Only general information is included and information about exposure-effect relationships between (measures of) motility and traffic noise exposure. Results obtained by questionnaires, morning and evening diaries and results obtained by polysomnography or other physiological measurement methods are not included in these sections.

## G.2 Overview

### G.2.1 Ollerhead et al., 1992, Horne et al., 1994

In the UK, the first large scale field study on sleep disturbance assessed the effects of night-time aircraft noise on motility in 211 women and 189 men, 20-70 years of age, habitually living at one of eight locations adjacent to four UK airports, with different levels of night flying. Subjects wore actimeters for 15 nights. A sample of 178 nights of EEG's were recorded synchronously with actigrams.
A 30-s interval with onset of motility was called an A-blip.
Noise measurements have been performed outdoors only. Any outdoor noise event that exceeded 60 dB(A) and simultaneously triggered three outdoor noise monitors was compared with air traffic control logs to identify aircraft movements and to determine landing/taking-off, route and aircraft type.
The probability of an A-blip in a 30-s interval in which Lmax of an aircraft noise event occurred, designated as noise (n), and was given as a percentage. The probability of the occurrence of an A-blip in all other 30-s intervals was designated as quiet (q). The value of q turned out to be 5.1%. According to Ollerhead et al. n – q gives the probability of an aircraft noise event causing an A-blip. The result is given in figure G1. Ollerhead et al. state that n – q is statistical significant larger than 0 from outdoor Lmax values of 82 dB(A). Horne et al. (1994) suggest that the difference between outdoor and indoor Lmax at the study locations is on average about 20 dB(A).

Ollerhead et al. did not specify relationships between aircraft noise exposure and mean motility during sleep.

### G.2.2 Fidell et al, 1995

A field study on aircraft noise induced disturbance was conducted in the vicinity of Stapleton International Airport (DEN) and of Denver International Airport (DIA) during the period of transition in flight operations between the two airports with closing of DEN and opening of DIA. Subjects lived at locations as close as feasible to the runway ends of the two airports. Fidell et al. state that because no effort was made to obtain a representative sample of any population, conclusions drawn from the study strictly apply to the test participants only.
Noise measurements have been performed outdoors and inside subject's bedrooms. An outdoor and an indoor noise event was only considered as such, if the sound level exceeded respectively 70 and 60 dB(A) for at least 2 s. No attempt was made to eliminate noise events from sources

other than aircraft.
Fidell et al. found a statistically significant relationship between indoor SEL and probability of motility measured within 5 minutes (i.e. 10 30-s intervals) during and after a noise event. The equation of the relationship is:

$$\% \text{ motility} = -23.74 + 1.23*\text{SEL} \qquad [G.1]$$

Mean motility during a 30-s interval is according to the report equal to 0.056 (5.6%). This implies probability of absence of motility in a 30-s interval of (1 – 0.056), and absence of motility during 10 consecutive 30-s intervals of $(1 - 0.056)^{10} = 0.562$. The probability of motility during 10 consecutive 30-s intervals is therefore equal to 1 - 0.562 = 0.438 (43.8%). This value corresponds according to the formula to a SEL value of 54.9 dB(A). The *noise-induced* increase of % motility during 10 30-s intervals for indoor SEL values over 55 dB(A) can therefore be specified as 1.23*(SEL-55).

Fidell et al. also tried to replicate the analyses performed by Ollerhead et al., by using the data of 27 subjects, gathered prior to the closing of DEN. The probability of an A-blip in a 30-s interval could be predicted by four variables (individual susceptibility, age, self-reported tiredness, and sequential night of data collection), and no improvement in prediction was gained by including *outdoor* noise data (Lmax or SEL). This implies that it could not be proven that *outdoor* (aircraft) noise is a determinant of onset of motility. Fidell et al. did show that *indoor* noise event metrics (Lmax and SEL) are determinants of motility. A predictive model was based on two categories of *indoor* noise event levels (Lmax less than 65 dB(A), Lmax at least 65 dB(A)), individual sensitivity, age, months of residence, and self-reported tiredness.

### G.2.3 Fidell et al., 1998

A small field study was conducted in the vicinity of DeKalb-Peachtree Airport (PDK), a large general aviation airport north of Atlanta, Georgia, beginning 2.5 weeks before the start of the Olympic Games near Atlanta and ending one week after their closing. Indoor and outdoor measurements of aircraft and other night-time noises were made in twelve homes. The same thresholds (60 and 70 dB(A)) for indoor and outdoor noise events as in the 1995 study have been used. One exposure-effect relationship was found between indoor SEL and motility, calculated from an algorithm assessed by Cole et al. (1992).

### G.2.4 Griefahn et al., 1999

In Germany for railway traffic an adjustment of –5 dB(A) is applied to equivalent sound levels to obtain rating levels. This adjustment is 0 dB(A) for road traffic noise. These adjustments have been based on exposure-effect relationships for noise annoyance. The main objective of the German study was to determine whether this adjustment of –5 dB(A) for railway noise should also be applied with respect to sleep disturbance due to road and railway traffic.

The study has been carried out at eight locations, four locations with predominant road traffic noise and four locations with predominant railway noise. At each location subjects took part during ten nights (two times 5 nights from Sunday night to Friday morning). The subjects were about equally distributed with respect to rating levels of both noise sources. Ages of subjects were from 18 to 66 years and subjects lived for 1 to 64 years in the present neighbourhood. Motility was assessed using actimeters also applied in the UK field study on aircraft noise (Ollerhead et al., 1992; Horne et al., 1994). Also, polysomnography (EEG, EOG, EMG) was performed with 238 subjects during one night (225 registrations could be used for a comparison with motility results). From the stored actimetric data, several effect variables representative for a sleep period time have been derived, such as:

- Percentage of 2 s intervals with motility during a sleep period time relative to the total number of 2 s intervals during a sleep period time;
- Percentage of 30-s intervals with motility during a sleep period time relative to the total number of 30-s intervals during sleep period time;
- Percentage of 30-s intervals with *onset* of motility during sleep period time relative to number of 30-s intervals during sleep period time (the A-blips in the UK aircraft noise study).

The acoustic measurements showed that road and railway traffic on Monday through Thursday nights was about the same, but that equivalent sound levels of railway traffic during Sunday nights was about 10 dB(A) lower than on other nights. To meet the requirement of about equal rating levels for road and railway noise, only the actimetric data obtained on Monday through Thursday nights have been analysed (consisting of 2648 of the original 3263 usable actigrams).

With respect to the effect variables for a sleep period, it was found that subjects exposed to railway noise show on average (averaged over subjects and sleep period times) motility in 6.7±2.3 percentage of the 30-s intervals at railway locations, and in 6.5±2.2 percentage of the 30-s intervals at road traffic locations. The difference between these percentages is not statistically significant.

Tn the German study no exposure-effect relationships have been established, since this was outside the scope of the study.

## G.3 Comparison of results of field studies

### G.3.1 Ollerhead et al., 1992, Horne et al., 1994

In figure G2 the results of the UK and the present aircraft noise study have been compared. The results of the present study with respect to probability of onset of motility in 15-s intervals have been recalculated for 30-s intervals. From the outdoor Lmax values in the UK study 20 dB(A) has been subtracted to obtain Lmax_i (Horne et al., 1994). If the actual sound insulation would have been 5 dB(A) larger, the UK curve in figure G2 would have te be shifted 5 dB(A) to the left.

Several factors in the UK study have contributed to an underestimation of the effect of aircraft noise on onset of motility. These factors are:

- The threshold for a noise event of 60 dB(A) outdoors implies that all 30-s intervals with (aircraft) noise events below 60 dB(A) are considered as quiet. The possible effects on onset of motility of these lower (aircraft) noise events increase q. The same applies to noise events over threshold, if they have not been identified as aircraft noise events;
- Noise-induced motility starts, especially at the higher noise events, also in the interval before the interval during which Lmax occurs (present study). In those cases *onset* of motility is absent in the 30-s interval with Lmax. This implies that the aircraft noise-induced increase of onset of motility has not been completely attributed to n, but in part has been added to q;
- In the analysis, aircraft noise events, which occurred within 5 minutes of a preceding event, were omitted. It is unclear whether the 30-s intervals have been considered as quiet and possible effects attributed to q;
- Due to limitations of computer facilities in 1992, only aircraft noise events that occurred between 23.30 and 5.30 hours have been considered. However, probability of aircraft noise-induced motility increases according to the present study with sleep onset, which implies an underestimation of the overall effect of noise exposure;
- There may be a small effect of aircraft noise events assigned to the wrong 30-s interval. It is stated that all recording instrumentation, noise, EEG, and actimetry were synchronised. The test design aim was to ensure that no instrument ever had a time drift exceeding 15 s. This implies that time differences between noise monitors and actimeters may have exceeded 30-s in presumably exceptional cases;
- No indoor noise measurements have been performed. Other studies considered here showed that indoor noise event measures have a much stronger relationship with (onset of) motility than outdoors measures (Fidell et al, 1995, 1998; present study).

### G.3.2 Fidell et al, 1995

The relationship between indoor SEL and probability of motility measured within 5 minutes (i.e. 10 30-s intervals) is given by:

$$\% \text{ motility} = 1.23*(SEL - 55)$$

To be able to compare this result with the exposure-effect relationships in the main text, the following reasonable assumptions obtained from the present study are made:

- 30% of the noise-induced increase in motility within 5 minutes after noise event onset occurs during the *15-s* interval at which Lmax occurs;
- indoor SEL of 80 dB(A) corresponds to an indoor Lmax of 70 dB(A).

Then, resp_m, probability of noise-induced increase in motility, during the 15-s interval at which Lmax occurs is equal to 0.30*1.23*(Lmax – 45)/100 = 0.0037*(Lmax – 45). Thus, for Lmax = 45 dB(A), resp_m m is equal to 0 and for 68 dB(A) equal to 0.0851. Bearing in mind that subjects lived at locations very close to the runway ends of the airports, it is reasonable to assume that subjects are highly exposed to aircraft noise. In figure G3 the result can best be compared with exposure-effect relationships for Li equal to 26 and 40 dB(A).

According to Fidell et al., probability of motility onset in the 68832 30-s intervals with Lmax below 65 dB(A) (including intervals without noise events) is 0.056, and for the 72 30-s intervals with Lmax at least 65 dB(A) 0.240. This is an increase in probability of motility onset of 0.18. For a measurement interval of 15 s, probability of motility onset would be 0.09. This value is in good agreement with the relationship specified in table 2.1: aircraft noise-induced increase of onset of motility is 0.09 at Lmax equal to 66 dB(A).

### G.3.3 Fidell et al., 1998

The exposure-effect relationship between indoor SEL and motility as calculated from an algorithm assessed by Cole et al. (1992) cannot be transformed to the exposure-effect relationship presented in this report.

### G.3.4 Griefahn et al., 1999

In the German study no exposure-effect relationships have been established, since this was outside the scope of the study.

## G.4 Table

*Table G1: Overview of field studies of the last decade.*

| | Ollerhead et al.,1992<br>Horne et al., 1994 | Fidell et al., 1995 | Fidell et al., 1998 | Griefahn et al., 1999 | The present study, 2002 |
|---|---|---|---|---|---|
| Noise source | Aircraft | Aircraft | Aircraft | Road traffic and railway | Aircraft |
| Number of subjects | 400 | 77 | 22 | 377 | 418 |
| Number of subject nights for analysis | 5742 | 2717 | 686 | 2648 (original number 3263) | 4528 |
| Number of outdoor or indoor noise events*subjects for analysis | Outdoor: 31000 (original number according to Ollerhead: 87729, according to Horne 121534) | Indoor: 43934 | Indoor: 1472 | Not applicable | Indoor: 63242 |
| Duration of measurement interval of actimetry | 30 s | 30 s | 30 s | 125 ms, 2 s,<br>30 s | 15 s |
| Effects considered during: | Sleep period times between 23.30 and 5.30 hours | Sleep period times between 22 and 7 hours | Sleep period times between 22 and 7 hours | Full sleep period time | Sleep period times between 22 and 9 hours |

## G.5 Figures

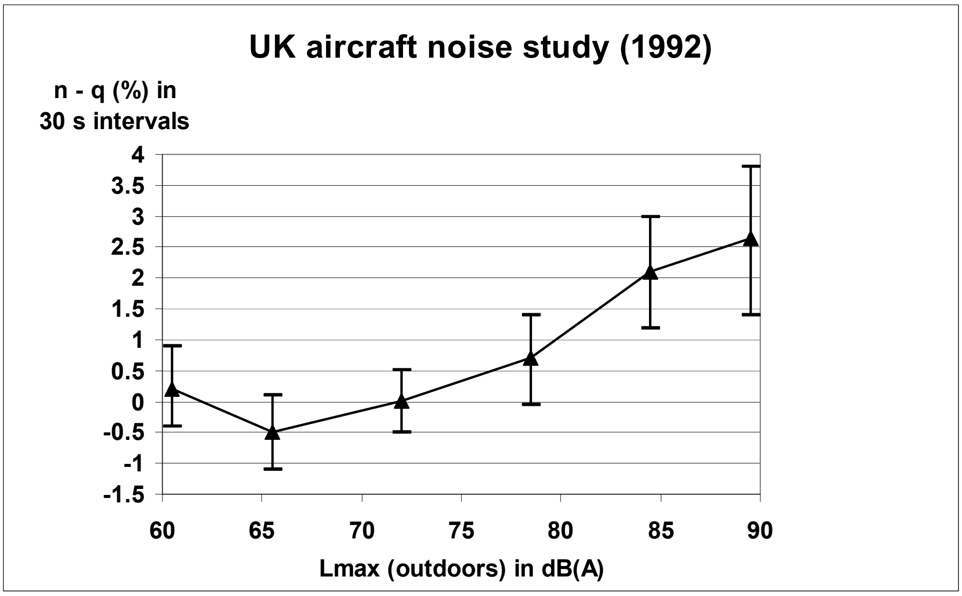


*Figure G1: N-q (in %) as a function of outdoor Lmax. Vertical bars are 95% confidence intervals (Ollerhead et al., 1992).*

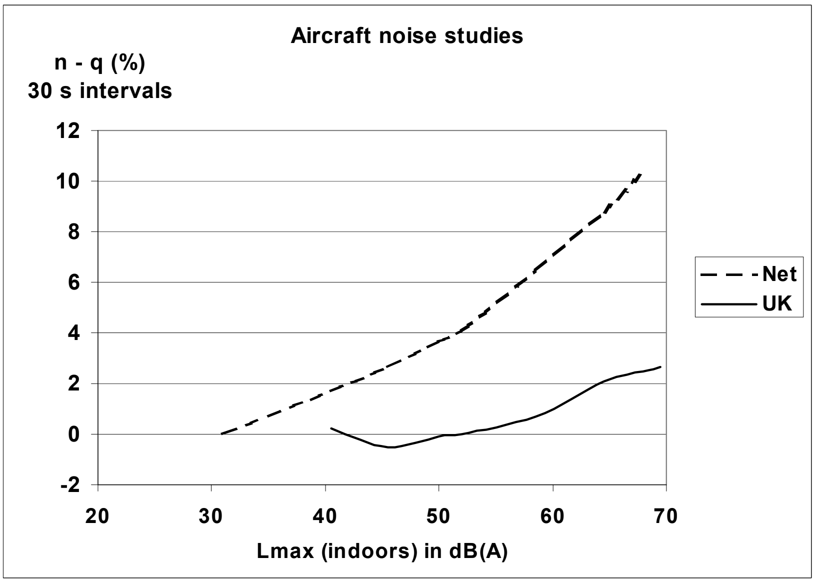


*Figure G2: Comparison of relationships assessed in the UK aircraft field study (UK) and in the present study (Net).*

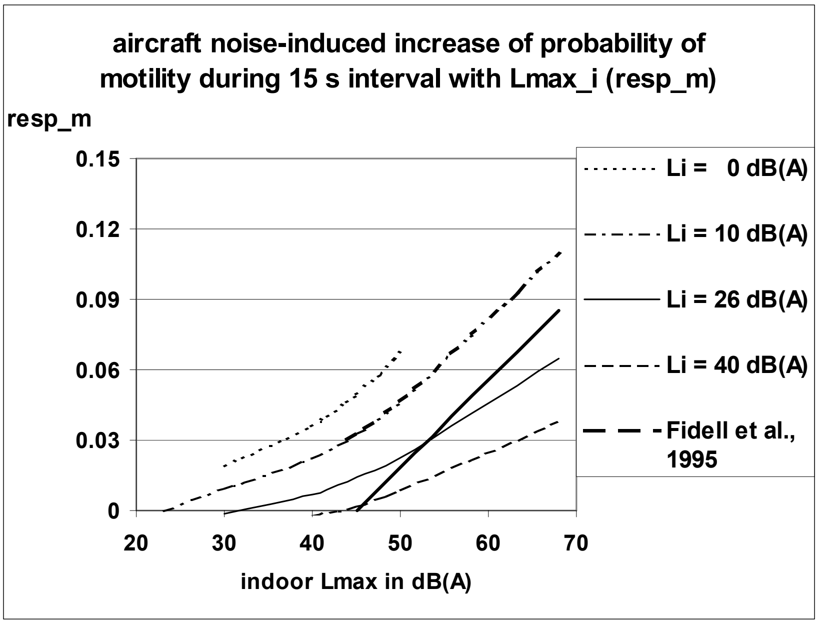


*Figure G3: Comparison of relationships assessed by Fidell et al., 1995 and in the present study.*