TNO Inro

Schoemakerstraat 97
P.O. Box 6041
2600 JA Delft
Nederland

www.tno.nl

T +31 15 269 68 29
F +31 15 262 43 41
inro@inro.tno.nl

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Night-time noise events and awakening

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Authors W. Passchier-Vermeer

City Delft

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TNO Inro
Institute for Traffic and Transport,
Logistics and Spatial Development

ABSTRACT

This report presents a secondary analysis to obtain relationships between probability of behavioural awakening due to noise events and an indoor noise metric (*SEL_i*) of these noise events. The database used in the analysis consists of 110 aggregated data points, derived from eight field studies. In the report a relationship for commercial aircraft noise events has been assessed, based on 175000 of such events. No general applicable relationship could be established for military aircraft, railway, and other ambient noise events.

EXECUTIVE SUMMARY

Preparation of database

This report presents a secondary analysis to obtain relationships between probability of behavioural awakening due to noise events and indoor SEL (*SEL_i*) of these noise events. The database used in the analysis consists of 110 aggregated data points, derived from eight field studies. The aggregated data points presented by Fidell et al. (1998) have been taken as basis, with one of these data points excluded. Added to the database are 10 data points derived from the Netherlands aircraft noise sleep disturbance study (Passchier-Vermeer et al., 2002a).

In four of the studies subjects indicated awakening by pressing during sleep period a marker (behavioural awakening). In three studies EEG-awakenings have been recorded by polysomnography and in one study onset of motility has been obtained from actimetric recordings. Probability of EEG-awakening and probability of onset of motility have been converted to probability of behavioural awakening (hereafter called awakening) by applying preliminary relationships derived in this report.

In general, a data point has been obtained as follows. In a study, noise events have been identified and a *SEL_i* value has been assigned to each noise event. In each study the noise events have been divided in classes according to their *SEL_i* value. A data point includes the midpoint of a *SEL_i* class or the mean value of *SEL_i* of the noise events in a class.

To each noise event a *noise event interval* of 5-min duration has been attributed, and for each 5-min interval it was assessed whether a subject pressed the marker (or whether EEG-awakening or onset of motility occurred) during that interval or not. From this information, for each class of noise events the percentage awakenings (or EEG-awakenings or onsets of motility) in a 5-min noise interval has been derived.

From the information in the studies percentage awakenings in 5-min intervals *without noise events* has been estimated. For each data point, the difference between percentage awakenings in a 5-min noise interval and percentage awakenings in 5-min intervals without noise events specified for each of the studies has been taken as percentage *noise-induced* awakenings.

The 110 data points in the database concern 192077 noise events. The number of noise events and average number of events per subject night for each type of noise source are as follows:

Type of noise source	Number of events	Number of events per subject night
• Commercial aircraft:	174285	12
• Military aircraft:	4104	6
• Ambient noise events:	12793	4
• Railway traffic:	895	44

Results for commercial aircraft noise

In the report an exposure-effect relationship has been assessed for commercial aircraft noise events. With respect to commercial aircraft, data have been obtained from seven studies, with over 25 locations from far away from the airport to very close to the main runways. Also, subjects with very different demographic and situational characteristics were participating in the studies. In the original publications of the two largest studies it has been made plausible that in these studies subjects are a representative sample of the population in the vicinity of the airports in the studies. Ages of subjects varied between 18 and 81 years, in most studies about 50% of the participants were male subjects. The

relationship is based on more than 174000 aircraft noise events. Responses of over 1000 subjects exposed to commercial aircraft noise have been used in the analyses. Therefore, it is likely that the relationship for commercial aircraft noise is applicable to general populations exposed to such type of noise. The equation of the relationship for $54 < SEL\_i < 90$ dB(A) is as follows:

percentage noise-induced awakenings = $-0.564 + 1.909 * 10^{-4} * SEL\_i^2$.

If $SEL\_i < 54$ dB(A), the percentage noise-induced awakenings is 0.

The data points in the database are aggregated values. The original values in each study consisted of binary values: if a marker was pressed by a subject (or an EEG-awakening or onset of motility was observed) in a specified time interval of 5-min, a value 1 has been given to the test result, if the marker was not pressed (or an EEG-awakening or onset of motility was not observed) the test result has been given a value 0. With such a set of data, usually a logistic regression analysis is performed to assess the probability of awakening (EEG-awakening or onset of motility) as a function of a noise metric. In the present analyses, mean probability of awakening (EEG-awakenings or onsets of motility) has been used in linear or curvilinear regression analyses performed with the method of least squares. By using the original data of the Netherlands aircraft noise sleep disturbance study (Passchier-Vermeer et al., 2002a) in this report a comparison has been made between the model based on the logistic regression analysis on the binary test outcomes and the result of a curvilinear regression analysis with aggregated test results. There is hardly any difference between both models. The relationship presented in this report, therefore, has not been influenced to a substantial degree by the choice of aggregated values instead of binary values.

Since the present analyses have been based on aggregated data points, it was not possible to assess whether individual factors have an effect on the relationships. An analysis in this report of the original data of the Netherlands aircraft noise sleep disturbance study (Passchier-Vermeer et al., 2002a) shows that age is an important effect-modifier of (noise-induced) awakening during sleep period. It is quite likely that in populations consisting of older people, awakening is more frequent than would be expected on the basis of the formula given above.

A comparison has been made between the relationship for aircraft noise obtained with the aircraft noise data points of all studies, irrespective of the effect measure used in the study, and the relationship if only the data points are used from the four studies with marker pressing as effect measure. The relationship based on all aircraft noise data points is nearly identical to the relationship based on the data points in the four studies.

Results for military aircraft noise
The results for military aircraft noise are of limited applicability: the data pertain to only one study and one situation, in which subjects lived near the end of the main runway of a military airfield.

Results for railway noise
The few observations on railway noise showed no effect of noise exposure on probability of awakening. Therefore, there is some evidence, be it very limited, that railway noise events, in the range of *SEL_i* considered (up to 80 dB(A)), do not increase probability of awakening.

Results for ambient noise events

The observations on ambient noise events also showed no effect of ambient noise events on probability of awakening. Although it is not unlikely that a substantial part of the ambient noise was road traffic noise, the uncertainties in the ambient noise data do not allow any conclusion about road traffic noise.

Results for nights with commercial aircraft noise events

Commercial aircraft noise exposure during a night has been specified by L_{night}_i: the indoor equivalent sound level caused by commercial aircraft noise events over a night of 8-hours duration. For a given L_{night}_i there is a situation in which the number of noise-induced awakenings is maximal, the so-called worst-case situation. By using a simplified model, the number of *noise-induced awakenings in a year* due to commercial aircraft for an average person in the worst-case situation has been estimated as a function of L_{night}_i: at L_{night}_i equal to 20 dB(A), this number is 1, at L_{night}_i equal to 30 dB(A) 13, and at L_{night}_i equal to 40 dB(A) 132. Therefore, the model shows that there is a substantial effect of aircraft noise on number of awakenings only at the higher commercial aircraft noise exposures at night. The estimation for situations with L_{night}_i below about 30 dB(A) seems to be in contrast with results from socio-acoustic surveys. E.g. a questionnaire survey in the vicinity of Schiphol Airport in 1998 showed that percentage persons highly sleep disturbed by aircraft noise increases from 9 to 32% if L_{night}_i increases from 21.5 to 31.5 dB(A). This seemingly discrepancy has been explained in the report by also taking into account awakenings due to causes other than exposure to noise events. An estimate of the average number of awakenings over a year for 8-hour sleep periods without any noise events is 606. This implies that the *number of awakenings* in a year in the worst-case situation is at L_{night}_i equal to 21.5 dB(A) 608, and at L_{night}_i equal to 31.5 dB(A) 625. In the worst case situation, there is every 9 minutes an overflight if L_{night}_i is equal to 31.5 dB(A) and every 89 minutes if L_{night}_i is equal to 21.5 dB(A). It is therefore likely that periods during which people are awake, coincide by about a factor 10 more with the presence of an overflight in the situation with L_{night}_i = 31.5 dB(A) than in the situation with L_{night}_i = 21.5 dB(A). This coincidence of being awake and perceiving an aircraft overflight, may result in attributing the awakening to aircraft noise, while in fact awakening occurred for other reasons.

Comparison with earlier results

The result of the present analysis has been compared with the result of an analysis by Finegold and Elias (2002). Both models differ substantially. In contrast with the analysis by Finegold and Elias, the present analysis takes the following factors into account:

- number of noise events in each of the data points;
- differences between probability of awakening on the one hand, and probability of EEG-awakening or of onset of motility on the other hand;
- differences between studies in the length of the time interval around a noise event for which an effect is considered to be related to the event;
- noise source (commercial aircraft, military aircraft, ambient, railway traffic);
- probability of awakening during intervals without noise events.

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1 INTRODUCTION

Sleep is an active physiological process, and not only the absence of wakefulness. Sleep is necessary for the restoration of body systems and during sleep information obtained during day-time is stored systematically in the brain. Because sound is processed during sleep, sound has the potential to interfere with these processes and to awake sleeping persons. The instantaneous reaction of sleeping persons is often more subtle than awakening and may involve instantaneous changes from a deeper to a lighter sleep stage, increase in heart rate and blood pressure, release of stress hormones in blood, increase in muscle tension which results in onset of small movements of the extremities. In Miedema, Passchier-Vermeer and Vos (2003) relationships of self-reported sleep disturbance and instantaneous and long-term motility with night-time noise exposure are given. This report focuses on awakening during the sleep period.

Awakening can be assessed by polysomnography and by behavioural indication of awakening (usually the pressing of a button). In this report, awakening during the sleep period assessed by polysomnography is called ‘EEG-awakening’ and behavioural awakening during the sleep period ‘awakening’. Awakening and EEG-awakening are not identical phenomena, as can be readily understood if we look at the number of times they occur during a sleep period. A meta-analysis of the data from four studies on populations exposed to aircraft noise (Fidell et al., 1995a,b,1998; Passchier-Vermeer et al., 2002a) gives on average about 1.8 awakenings during a sleep period (Table B.1 of Appendix B). Ollerhead et al. (1992) show for a population, also exposed to aircraft noise during sleep, on average 17 EEG-awakenings during a sleep period.

On the basis of meta-analyses, several (groups of) researchers (Pearsons et al, 1989; FICON, 1992; Passchier-Vermeer, 1993; Finegold et al., 1994; Bullen et al., 1996; Fidell, 1998; Finegold and Elias, 2002) have proposed exposure-effect relationships that give the probability of awakening, EEG-awakening, or a combination of awakening and EEG-awakening, as a function of the noise event descriptor indoor L_{max} (L_{max}_i) or indoor *SEL* (*SEL_i*). The early review by Pearsons et al. (1989) showed that exposure-effect relationships derived from laboratory and (a few) field studies are very different. At the same L_{max}_i or *SEL_i*, stronger effects have been observed in laboratory studies compared to field investigations. These differences have been explained by habituation to night-time noise of subjects in field studies in contrast to the unusual exposure of subjects in laboratory studies (Pearsons et al., 1989).

Fidell et al. (1998) derived 100 aggregated data points from eight *field* studies (Fidell et al., 1995a, 1995b, 1998; Pearsons et al., 1973; Rylander et al., 1972; Vernet, 1979; Vallet et al., 1980; Ollerhead et al., 1992). These data points are pairs consisting of the percentage of subjects ‘awakened’ during a time interval around a noise event, and the class mean of a noise event descriptor (*SEL_i*). Finegold and Elias (2002) replaced the data point of the study of Rylander et al. (1972) by the data point derived by them from the study of Öhrström et al. (1988) and fitted a power function through the 100 data points.

The present analysis uses the data points presented by Fidell et al. (1998) as basis. Added to these data points are 10 data points derived from Passchier-Vermeer et al. (2002a).

In chapter 2 of this report the database used in the present analyses is discussed. Chapter 3 presents relationships between noise-induced awakening and noise event exposure metric *SEL_i*. In chapter 4 the results are discussed, and chapter 5 presents the conclusion. The report contains three Appendices. Appendix A concerns information obtained from the Netherlands sleep disturbance study (study 9) (Passchier-Vermeer et al., 2002a). In section A.2 information is given about the derivation of the 10 data points of study 9 that have been included in the present database. In section A.3, a comparison is made between a model based on a logistic regression analysis of the original data with binary test outcomes and a model based on a curvilinear regression analysis by the method of least squares of aggregated test results. Section A.4 gives information about the time of marker pressings during the intervals with aircraft noise events. In section A.5 the possible effect of longer-term aircraft noise exposure on the probability of marker pressing during the intervals with aircraft noise is considered. Section A.6 presents 95%-confidence intervals of the probability of marker pressings based on the logistic regression model. Section A.7 summarizes the conclusions of Appendix A. In Appendix B details of the preparation of the database are given. Appendix C presents information about the data points in the database.

This chapter is concluded with a brief overview of the studies that have been included in the present analyses and of the reasons why the study by Rylander et al. (1972) and by Öhrström et al. (1998) have not been included. General information is given in table 1.1, and details after the table. All studies are field studies: subjects were exposed to noise (from specific noise sources) as it usually occurred in their bedrooms during sleep. The noise sources are given in column 3 of table 1.1.

Column 4 of table 1.1 shows that the size of the studies varies from small (20 subject nights) to large (5742 subject nights). Also, the numbers of noise events in the studies are very different: from 70 to 87688. In the last column of table 1.1 the type of effect measure has been specified. It concerns for 101624 events behavioural awakening assessed by marker pressing, for 2766 events EEG-awakenings, and for 87688 events onset of motility assessed by actimetry.

Table 1.1: Information about the studies included in the present analyses and about the study by Öhrström et al. (1988), not included in the present analyses

Number of study	Reference	Noise source	Number of subject-nights	Number of events	Type of effect measurement
1	Pearsons et al., 1973	commercial aircraft	50	70	EEG
2	Vernet, 1979	railway traffic	20	895	EEG
3	Vallet et al., 1980	commercial aircraft	143	1800	EEG
not included	Rylander et al., 1972	sonic booms, one heavy truck	945 189	945 189	Behavioural and bed movement
not included	Öhrström et al., 1988	road traffic	?	?	Questionnaire
5	Ollerhead et al., 1992	commercial aircraft	5742	87688	Actimetry*
6	Fidell et al., 1995a	commercial aircraft, military aircraft, ambient noise sources	1887	10120	Behavioural
7	Fidell et al., 1995b	commercial aircraft, ambient noise sources	2717	26654	Behavioural**
8	Fidell et al., 1998	commercial aircraft	686	1472	Behavioural**
9	Passchier-Vermeer et al., 2002a	commercial aircraft	4511	63378	Behavioural**

* In this study also EEG measurements have been performed. The results of these measurements have, however, not been related to aircraft noise events.

** In this study also actimetry has been performed. In the present analyses the data regarding marker pressings have been used.

Study 1: information obtained from Fidell et al. (1998): 5 nights, 5 couples, 1.4 commercial aircraft noise events per night, which results in a total of 70 events.

Study 2: twenty test subjects, 10 at a site at Macon, 10 at a site at Domarin, one measuring night. At one site about 80 trains, at the other site about 10 trains during sleep of subjects. Effect measurements have been made by polysomnography and plethysmography. The values presented by Fidell et al. (1998) correspond to percentages EEG-awakenings given in Vernet (1979). *SEL_i* has been set 11.8 dB(A) higher than *Lmax_i* given in Vernet (1979).

Study 3: 40 male subjects, 143 completed nights have been analyzed. Effect measurements have been made by polysomnography and ECG. Vallet et al. (1980) specified 4 categories of responses: 1 no change in EEG, 2 transient activation, 3 sleep stage change, 4 EEG-awakening. Vallet et al. (1980) present a relationship between noise and the sum of responses in category 3 and 4: $y = 0.30*SEL\_i - 5.6$, with y presumably the percentage of responses. The data in Fidell et al. (1998) show that they counted about 20% of the responses as EEG-awakenings.

Study by Rylander et al.: Subjects in the study were 189 soldiers exposed in a field experiment to 6 sonic booms, with one sonic boom hardly perceivable, and one passing heavy truck. The researchers state “It was realized at the outset of the experiments that the military population did not constitute a representative sample of the general population” and “However, lighter sleep might not have been present in the population studied, where hard physical exercise throughout fairly long days results in heavy sleep throughout the night.” Therefore, the results may not be applicable to the general population. The results for the sonic booms could also not be used, since the noise metric used cannot be converted to the metric used in the present analyses.

Study by Öhrström et al.: the study has been carried out at two noisy areas (25000 vehicles per 24 hours) and one control area, about 300 m away from the noisy areas. Outdoor equivalent sound levels were about 72 dB(A) and 53 dB(A) respectively. The number of vehicles during the night with *Lmax_i* over 45 dB(A) was 639, including 54 vehicles with *Lmax_i* over 55 dB(A) and 9 with *Lmax_i* over 60 dB(A). Öhrström et al. (1998) state “The number of respondents was 106: 69 at the noisy sites and 37 at the control site. The response rate was 80%.”. Results are expressed in terms of difficulty of falling asleep, sleep quality, tiredness in the morning during the day, and number of self-reported awakenings. The number of self-reported awakenings is (on average?) equal to 2.2 at the noisy sites and 1.1 at the control site. The study has been excluded from the present analyses, mainly since the effect measure is self-reported awakening. Although there is an association between number of self-reported awakenings after a sleep period and number of behavioural awakenings during a sleep period (correlation coefficient 0.58 in Passchier-Vermeer et al., 2002a), this association is considered too weak to replace number of self-reported awakenings by number of behavioural awakenings. Based on the study by Öhrström et al. (1998), Finegold and Elias (2002) added a data point to their database with average percentage behavioural awakenings 3.2 and *SEL_i* equal to 65 dB(A). It is unclear how these values have been obtained from the data.

Study 5: In the UK, the first large scale field study on sleep disturbance investigated the effects of night-time aircraft noise on motility in 211 women and 189 men, 20-70 years of age, living at one of eight locations near four UK airports with different levels of night flying. Subjects wore actimeters for 15 nights. In a sample of 178 nights, EEG’s were recorded synchronously with actigrams. Noise measurements have been performed outdoors only. A noise event that exceeded 60 dB(A) and simultaneously triggered three outdoor noise monitors was compared with air traffic control logs to identify aircraft overflights. Horne et al. (1994) suggest that the difference between outdoor L_{max} and L_{max}*_i* at the study locations is on average about 20 dB(A). In Fidell et al. (1998) *SEL_i* is assumed to be 20.3 dB(A) lower than *outdoor SEL*. However, most likely the difference between *outdoor SEL* and *SEL_i* is dependent on *outdoor SEL*, since at the two locations with the highest night-time aircraft noise exposure (66.5 and 61.5 dB(A)) 90% of the dwellings had bedroom windows with double or triple glazing, and at the locations with lower exposure (between 43 and 55 dB(A)) the percentages of double-glazed bedroom windows varied from 10 to 90%, with an average of 50%.
Onset of motility has been considered in 30-s intervals. Ollerhead et al. (1992) state that at 40% of the 30-s intervals with onset of motility an EEG-awakening occurs. In Fidell et al. (1998) probability of awakening has been taken as 40% of probability of onset of motility.

Study 6 to 8: in these three studies the effect measure is pressing a button (awakening). Noise measurements have been performed outdoors and inside subject’s bedrooms. A

noise event was defined as a time series of noise levels that began when a pre-set threshold was exceeded for at least 10 seconds, and that continued until the level remained more than 2 dB(A) below the pre-set threshold.
In Fidell et al. (1995a) subjects participated who lived near Castle Air Force Base (632 subject nights), near Los Angeles International Airport (783 subject nights), and in suburban Los Angeles (472 subject nights), some adjacent to major freeways or at busy streets and some in neighbourhoods with lesser urban noise exposure.
The study reported in Fidell et al. (1995b) was conducted in the vicinity of Stapleton International Airport (DEN) and of Denver International Airport (DIA) during the period of transition in flight operations from DEN to DIA. Subjects were selected from locations as close as feasible to the runway ends. Fidell et al. (1995b) 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.
In 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 the end of the Games.

Study 9: This study has been carried out at 15 locations within a distance of 20 km from Schiphol Airport. The locations were selected so that there was a variation from relatively few aircraft at night up to the highest exposure in residential areas close to the airport. 418 subjects participated during 11 days and nights. Ages of subjects varied between 18 and 81 years, 50% of the subjects was male, 6% lived less than 1 year in the present neighbourhood, 44% over 15 years and the remaining 50% between 1 and 15 years. Subjects wore an actimeter during night- and day-time. The actimeter was equipped with a small button (marker presser), that subjects used to indicate times of going to sleep, times of awakening, and time of intermittent awakening during sleep period.
To assess night-time (aircraft) noise exposure of subjects, noise measurements have been performed from 22 – 9h with indoor noise monitors in the bedroom of each subject and with one outdoor noise monitor. The noise monitors stored continuously the 1-s equivalent sound level. Aircraft noise events were identified by comparing the noise and time data stored in the indoor and outdoor noise monitors with information obtained from the aircraft identification system of the Ministry of Transport in the vicinity of Schiphol (FANOMOS).

The present database concerns 192077 noise events. The number of noise events and average number of events per subject night for each type of noise source is given in Table 1.2.

Table 1.2: Number of noise events and number of noise events per subject night for each of the four noise sources

Type of noise source	number of events	number of events per subject night
Commercial aircraft	174285	12
Military aircraft	4104	6
Ambient	12793	4
Railway traffic	895	44

2 DATABASE

2.1 Preparation

2.1.1 Data points

The database consists of 110 aggregated data points. Information about these 110 data points is given in Appendix C. The database encompasses the 100 data points given in Fidell et al. (1998), except the data point from Rylander et al. (1972). In Fidell et al. (1998), the two data points from Ollerhead et al. (1992) with the lowest *SEL_i* values were joined. In the present database these two data points have been included separately. Also included in the database are 10 data points from study 9. The preparation of the final database, on which the analyses have been carried out, is described in Appendix A and B.

In table 2.1, the variables used in the analyses are given. For each data point the following variables are specified: study, *SEL_i*, source, number of 5-min intervals in the data point (n_5min), and percentage noise-induced (behavioural) awakenings (mrkke_no). On the basis of these variables, several dummy and interaction variables have been defined, which are also included in table 2.1.

Table 2.1 Variables used in the analyses

Variable	Description or definition
study	number of study (1…9)
SEL_i	mean indoor SEL value of the noise events in a data point (in dB(A))
source	type of noise source (1=commercial aircraft, 2=military aircraft, 3=ambient, 4=rail traffic)
n_5min	number of 5-min intervals in a data point
mrkke_no	percentage noise-induced awakenings in a data point
cair	dummy (value = 1 if source=1; value = 0 otherwise)
mair	dummy (value = 1 if source=2; value = 0 otherwise)
amb	dummy (value = 1 if source=3; value = 0 otherwise)
rail	dummy (value = 1 if source=4; value = 0 otherwise)
mod_cair	cair*SEL_i in dB(A)
mod_mair	mair* SEL_i in dB(A)
mod_amb	road* SEL_i in dB(A)
mod_rail	rail* SEL_i in dB(A)
air	dummy (value = 1 if source=1 or 2; value = 0 otherwise)
surf	dummy (value = 1 if source=3 or 4; value = 0 otherwise)
mod_air	air*sel_i (in dB(A))
mod_surf	surf*sel_i (in dB(A))

2.1.2 Determination of SEL_i

On the basis of noise measurements and other information, a noise event was identified in the original studies, and a *SEL_i* or L_{max}*_i* value assigned to each noise event. In each study the noise events were divided in classes according to their *SEL_i* or L_{max}*_i* value. The midpoints of a *SEL_i* or L_{max}*_i* class or the mean value of *SEL_i* or L_{max}*_i* of the noise events in a class were reported in the original studies. From the reported L_{max}*_i*

Fidell et al. (1998) estimated *SEL_i*. In all but the study by Ollerhead et al. (1992) noise measurements were carried out indoors in the bedroom of subjects. The conversion in this report of outdoor noise levels presented in Ollerhead et al. (1992) into indoor values is given in section B.4 of Appendix B.

2.1.3 *Determination of probability of noise-induced awakening*

In the studies with pressing a button as indicator of awakening (studies 6 to 9), the following procedure has been used to obtain percentage noise-induced awakenings in a data point:

1. In the original studies to each noise event a *noise event interval* of 5-min duration has been attributed. In study 9 a noise event interval consists of 5 15-s intervals before the interval during which L_{max}_i occurs, the 15-s interval with L_{max}_i, and 14 15-s intervals thereafter. It is assumed that in the studies 5 to 8 similar 5-min intervals have been attributed to the noise event intervals.
2. In the original studies for each 5-min interval it was assessed whether the marker was pressed during that interval by a subject or not. From this information, for each class of noise events the percentage marker pressings in a 5-min noise interval has been assessed in the original studies.
3. From the information in the publications, in this report percentage marker pressings in 5-min intervals without noise events has been estimated (see section B.3.1 of Appendix B).
4. The difference between the two percentages specified in step 2 and 3 for the data points of studies 6 to 9 has been taken in this report as percentage noise-induced awakenings.

In study 5, onset of motility has been assessed in 30-s intervals, and from these observations percentage onset of motility in a noise class has been calculated in Ollerhead et al. (1992). In section B.3.2 of Appendix B a relationship has been assessed between probability of *aircraft noise-induced awakening* and probability of *aircraft noise-induced onset of motility*. This relationship has been used in this report to estimate probability of noise-induced awakening.

In studies 1, 2, and 3, EEG-awakenings have been presented as indication of awakening. In section B.3.2 of Appendix B a conversion rule has been obtained that specifies how probability of *aircraft noise-induced awakening* can be estimated from probability of *aircraft noise-induced EEG-awakening.* In this report, this conversion rule is used to estimate probability of noise-induced (behavioural) awakening. The conversion rule is assumed to hold also for *railway* noise events (study 2).

2.1.4 *Determination of number of noise events in a data point*

In the studies 4 to 9 the number of events is given in the publications.

For study 1, 2, and 3 the total number of noise events in the study is known, but not the distribution of noise events over the noise classes. In section B.2 this distribution has been estimated with a model based on the distributions in studies 5, 6, 7, and 8.

2.2 Result

Figures 2.1 and 2.2 give the percentage noise-induced awakenings is given as a function of *SEL_i*: in figure 2.1 with study and in figure 2.2 with type of noise source as parameter. Appendix C gives the number of 5-min intervals in each data point. These numbers vary from 3 to 21933.

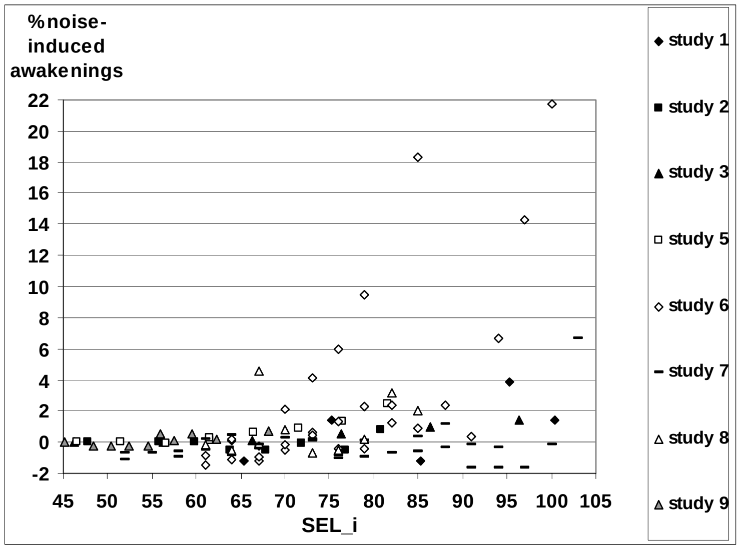

Figure 2.1: Percentage noise-induced awakenings as a function of SEL_i. Data points specified by study

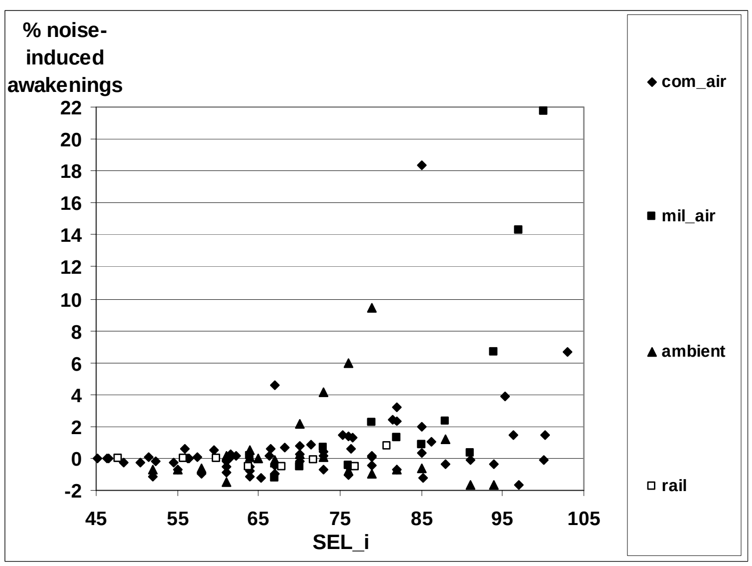

Figure 2.2: Percentage noise-induced awakenings as a function of SEL_i. Data points specified by type of noise source

In table 2.2 the number of 5-min intervals with noise events and the number of noise-induced awakenings during these intervals are given for each of the four noise sources.

The total number of 5-min intervals with noise events is 192077. The last column shows that there are in total 304 noise-induced awakenings in the 192077 5-min intervals with noise events, which corresponds to 0.16%.

Table 2.2: Number of 5-min intervals with noise events and number of noise-induced marker pressings during these intervals, specified according to source

Source	n_5min	Number of noise-induced awakenings
Commercial aircraft	174285	248 (0.14%)
Military aircraft	4104	82 (2.00%)
Ambient	12793	-25 (-0.20%)
Railway traffic	895	-1 (-0.13%)
Total	192077	304 (0.16%)

Figure 2.1 and 2.2 show a large scatter of data points. For eleven data points noise-induced awakening is over 3%. In table 2.3 information is given about these 11 data points. The last row of the table shows that the total number of 5-min intervals in these 11 data points is 897 (less than 0.5% of all 5-min intervals with noise events).

Table 2.3: Information about data points with noise-induced awakening over 3%

Study	*SEL_i* in dB(A)	Number of 5-min intervals in data point (n_5min)	Source	Percentage noise-induced awakenings
1	95.3	12	Commercial aircraft	3.9
6	73	124	Ambient	4.2
6	76	60	Ambient	6.0
6	79	34	Ambient	9.5
6	94	233	Military aircraft	6.7
6	97	157	Military aircraft	14.3
6	100	79	Military aircraft	21.8
6	85	29	Commercial aircraft	18.4
7	103	24	Commercial aircraft	6.7
8	67	63	Commercial aircraft	4.6
8	82	82	Commercial aircraft	3.2
Total number of 5-min intervals with over 3% noise-induced awakenings		897 (0.47% of 192077)		

Table 2.4 gives information about the data points with *SEL_i* over 90 dB(A). Only 479 (0.25%) 5-min intervals have a *SEL_i* value over 95 dB(A) and only 1866 (0.97%) over 90 dB(A).

Table 2.4: Information about data points with SEL_i over 90 dB(A)

Study	*SEL_i* in dB(A)	Number of 5-min intervals in data point (n_5min)	Source	Percentage noise-induced awakenings
1	95.3	12		3.9
1	100.3	7	Commercial aircraft	1.5
3	96.3	24	Commercial aircraft	1.5
6	91	291	Military aircraft	0.4
6	94	233	Military aircraft	6.7
6	97	157	Military aircraft	14.3
6	100	79	Military aircraft	21.8
7	91	536	Commercial aircraft	-0.1
7	94	230	Commercial aircraft	-0.3
7	97	109	Commercial aircraft	-1.6
7	100	67	Commercial aircraft	-0.1
7	103	24	Commercial aircraft	0.7
7	91	63	Ambient	-1.6
7	94	34	Ambient	-1.6
Total over 95 dB(A)		479 (0.25% of 192077 intervals)		
Total over 90 dB(A)		1866 (0.97% of 192077 intervals)		

2.3 Model based on aggregated points

The data points in the database are aggregated observations. The original observations in each study consisted of binary values: if a marker was pressed by a subject in a specified time interval of 5-min, a value 1 has been given to the result, if the marker was not pressed the result has been given a value 0. With such a set of data, usually a logistic regression analysis is performed to assess the probability of a marker pressing as a function of a noise metric. In the present database, mean values of marker pressings have been obtained and linear or curvilinear regression analyses (by using the method of least squares) have been performed. In Appendix A, section A2, for the original data of study 9, a comparison has been made between the result of the logistic regression analysis on the data with binary outcomes and the result of a curvilinear regression analysis with aggregated results. In figure 2.3 both models are given. There is hardly any difference between both models. Therefore, it is not likely that the final model in chapter 3 has been influenced to a substantial degree by the use of average values instead of binary values.

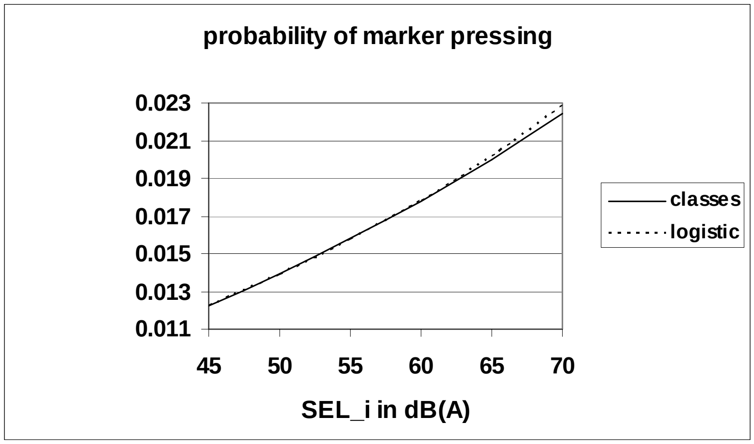

Figure 2.3: Probability of awakening (marker pressing) in a 5-min interval with aircraft noise as a function of *SEL_i*, obtained from two analyses. One analysis is a logistic regression analysis with binary data and the other analysis is a regression analysis according to the method of least squares with aggregated data in classes (source: Passchier-Vermeer et al., 2002a)

3 REGRESSION ANALYSES

3.1 Introduction

Mutivariate regression models can be specified as follows:

y = a + b1*x1 + b2*x2+ …+.bg*xg,

with 'y' the dependent variable, 'a' a constant, 'x1' to 'xg' independent variables, 'b1' to 'bg' coefficients of the independent variables. In the following analyses the significance of a coefficient of an independent variable is tested two-sided with $\alpha \leq 0.05$.
In the following descriptions, y is percentage noise-induced awakenings, x1 and where appropriate x2 are the noise exposure descriptors *SEL_i* and SEL_i^2, and x3 (or x2) to xg are dummy and possible interaction variables specified in table 2.1.
Information about the goodness of fit of the models is expressed in R and F. R is the multiple correlation coefficient. The larger R and F, the better the model fits the data.
The following 7 steps describe how the best model of the percentage noise-induced awakenings as a function of a noise descriptor has been obtained.

3.2 Noise-induced awakening as a function of SEL_i

Step 1
Regression analyses have been performed with percentage noise-induced awakenings as dependent variable, and *SEL_i*, SEL_i^2, or a combination of *SEL_i* and SEL_i^2 as independent variables. The numbers of 5-min intervals in the data points have been taken as weighting factor.
In figure 3.1 the percentage noise-induced awakenings has been plotted as a function of *SEL_i*, with in the models *SEL_i* or SEL_i^2 as independent variable. If both *SEL_i* and SEL_i^2 are used as independent variables, both coefficients are not statistically significant. The results of both models are as follows:

Linear relationship:	F=16.47	R=0.396	a = -1.953	b1 = 0.0345
Quadratic relationship	F=18.08	R=0.439	a = -0.905	b1 = 0.0002774.

Since F and R are larger if percentage noise-induced awakenings is a function of SEL_i^2 than if percentage noise-induced awakenings is a function of *SEL_i*, the quadratic model fits better than the linear model.

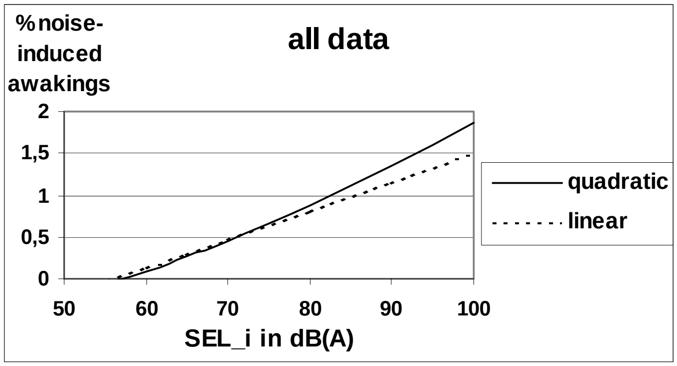

Figure 3.1: Percentage noise-induced awakenings as a function of *SEL_i*, if *SEL_i* is taken as independent variable in the model (indicated by linear), and if SEL_i^2 is taken as independent variable in the model (indicated by quadratic)

Step 2

Regression analyses have been performed with percentage noise-induced awakenings as dependent variable, *SEL_i*, or SEL_i^2, and the source-related dummies mair, amb, rail as independent variables. The numbers of 5-min intervals in the data points have been taken as weighting factor. The dummies of ambient noise and rail traffic do not have statistically significant coefficients.
If the data points of source 3 are selected and regression analyses are performed with percentage noise-induced awakenings as dependent variable, *SEL_i* or SEL_i^2 as independent variable, and the numbers of 5-min intervals in the data points as weighting factor, the coefficients of the independent variables are not statistically significant. The same result is obtained if the data points of source 4 are selected.

Step 3

To investigate whether statistically significant coefficients are obtained if the ambient noise and railway data points are combined to surface noise sources, regression analyses has been performed with percentage noise-induced awakenings as dependent variable, *SEL_i*, or SEL_i^2, and dummy surf as independent variable. The numbers of 5-min intervals in the data points have been taken as weighting factor. The dummy surf does not have a statistically significant coefficient.

Step 4

To investigate whether type of combined noise sources (surface or aircraft) is an effect modifier, regression analyses have been performed with percentage noise-induced awakenings as dependent variable, *SEL_i*, or SEL_i^2, and mod_surf as independent variables. The numbers of 5-min intervals in the data points have been taken as weighting factor. Both models did not show statistically significant coefficients, nor did the models if also surf was included in addition to mod_surf.

Step 5

In this step only aircraft noise events have been considered. The number of data points with aircraft noise events is equal to 78. Regression analyses have been performed with percentage noise-induced awakenings as dependent variable, *SEL_i*, SEL_i^2, and mair as independent variables. The numbers of 5-min intervals in the data points have been taken as weighting factor. Both models did not show statistically significant coefficients of mair.

Step 6
To investigate whether type of aircraft noise is an effect-modifier, regression analyses have been performed with the data points of aircraft noise with percentage noise-induced awakenings as dependent variable, SEL_i or SEL_i^2, mair, and mod_mair as independent variables. The numbers of 5-min intervals in the data points have been taken as weighting factor. The model with SEL_i^2 (but not the model with SEL_i) showed statistically significant coefficients of mair and mod_mair.
The model is given by:
F=18.38 R=0.629 a = -0.564, b1 (coefficient SEL_i^2) = 0.000191, b2 (coefficient of mair) = -21.33, b3 (coefficient mod_mair) = 0.282.
The result is illustrated in figure 3.2. The model without dummies and effect-modifiers is also included in figure 3.2 (all_air).

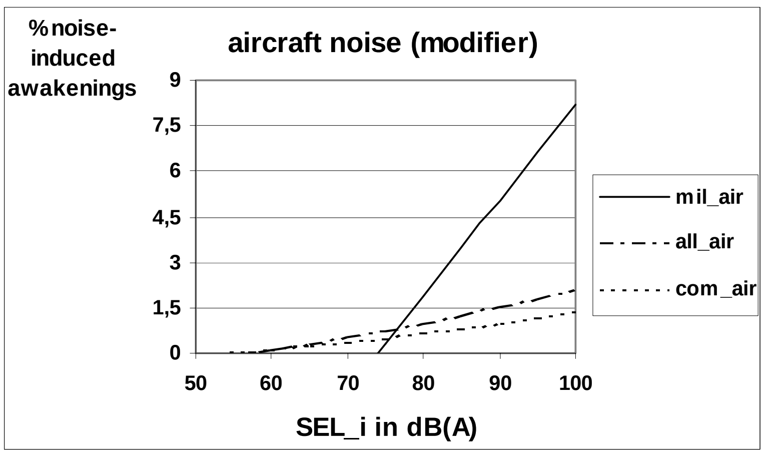

Figure 3.2: Percentage noise-induced awakenings as a function of SEL_i, if SEL_i^2 is taken as independent variable in the model, for commercial and military aircraft noise and all aircraft noise data points

Step 7
Separately, for each of the three sources military aircraft, commercial aircraft, and surface noise sources, regression analyses have been performed with percentage noise-induced awakenings as dependent variable, SEL_i and SEL_i^2 as independent variable. The numbers of 5-min intervals in the data points have been taken as weighting factor. The models for military and commercial aircraft with SEL_i^2 showed higher values of F and R than the model with SEL_i. The models with SEL_i^2 as independent variable are illustrated in figure 3.3. For surface noise events the coefficients of SEL_i and SEL_i^2 turned out to be not statistically significant. The average value of percentage noise-induced awakenings over all surface noise data points, weighted by n_5min, is -0.19.

In figure 3.4 and 3.5, for the two aircraft noise sources, the models of the combined data set has been compared with the models if the data of both sources are analysed separately. There is a very small insignificant difference between both sets of curves. The model of military aircraft if the datasets are combined is somewhat less steep than the model based on the separate data sets.

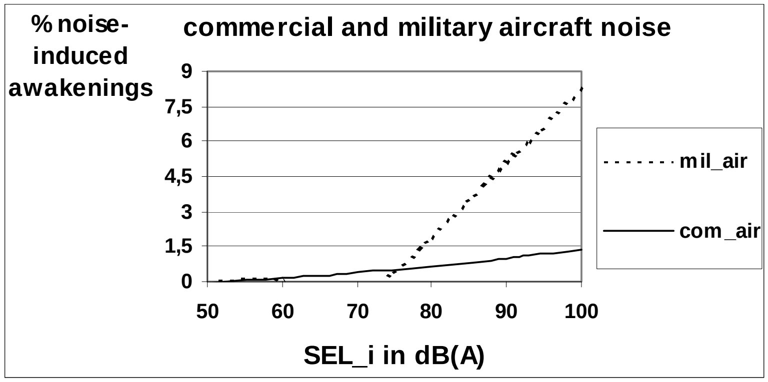

Figure 3.3: Percentage noise-induced awakenings as a function of SEL_i, for commercial aircraft, obtained by a regression analysis performed with the commercial aircraft noise data points, and for military aircraft, obtained with the military aircraft noise data points.

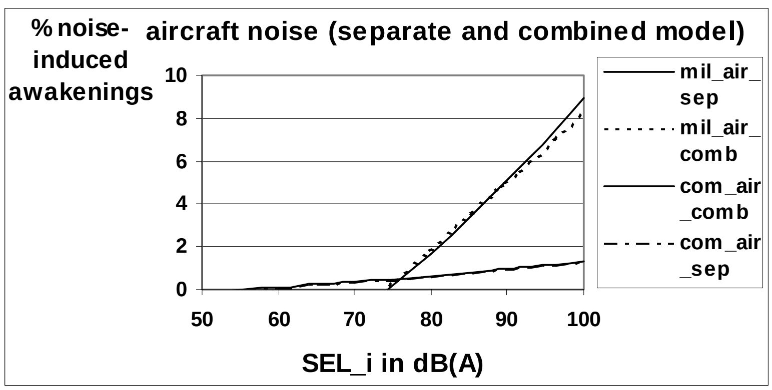

Figure 3.4: Comparison of the models for military and commercial aircraft, if the data of both sources are analysed as one data set (_comb), and if the data related to each source are analysed separately (_sep)

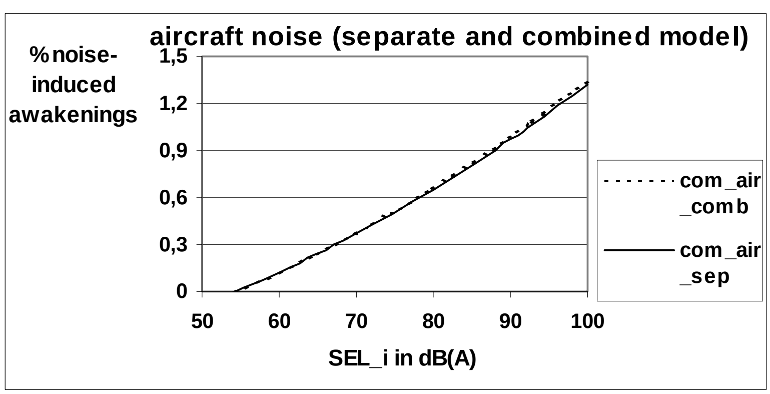

Figure 3.5: Comparison of the models for commercial aircraft, if the data of military and commercial aircraft are analysed as one data set (_comb), and if the data related to each source are analysed separately (_sep)

4 DISCUSSION

4.1 Exposure-effect relationships

The exposure-effect relationships derived for aircraft noise have been based on observations of subjects who have been exposed to (the specific type of) aircraft noise as it usually occurs in their bedroom. For commercial aircraft noise, the average number of overflights is 12 per sleep period and for military aircraft noise 6. Therefore, both types of noise sources are quite regularly present in the bedroom of subjects. With respect to commercial aircraft, data have been obtained from seven studies, with over 25 locations from far away from the airport to very close to the main runways. Also, subjects with very different demographic and situational characteristics were participating in the studies. In the publications of the studies 5 and 9 it has been made plausible that subject and information bias was negligible. Ages of subjects varied between 18 and 81 years, in most studies about 50% of the participants were male subjects. The relationship is based on more than 174000 aircraft noise events. Responses of over 1000 subjects exposed to commercial aircraft noise have been used in the analyses. Therefore, it is likely that the relationships for commercial aircraft noise are general applicable to populations exposed to such type of noise.
The coefficients in the model of probability of noise-induced awakening due to commercial aircraft noise as a function of *SEL_i* is given in table 3.1. For commercial aircraft noise, *SEL_i* is equal to 0 at 54.4 dB(A). Tables 2.2 and 2.4 show that only 1009 out of 174285 (0.6%) 5-min intervals with commercial aircraft have a *SEL_i* value of at least 90 dB(A). The upper limit of the model presented in this report for commercial aircraft is therefore taken as 90 dB(A), since the relationship at higher values of *SEL_i* is less reliable.

The final model for commercial aircraft is therefore given by the following equation, if $54 < SEL\_i < 90$ dB(A):
percentage noise-induced awakenings = $-0.564 + 1.909 \cdot 10^{-4} \cdot SEL\_i^2$,

The data for military aircraft have been obtained from only one study (study 6) (Fidell et al., 1995a). Fidell et al. (1995a) state that ‘sites with aircraft noise exposure were selected near the ends of the main runway at Castle Air Force Base’. The total number of subjects is limited to 27. Mean age of the 15 female and 12 male participants is 44 years (the age range is not specified in the publication). These subjects are also exposed to unusual high levels of military aircraft noise. In nearly 20% of the events, *SEL_i* is between 90 and 100 dB(A). Living in those circumstances suggests that subjects are ‘tougher’ than unexposed subjects. This is supported by the data of military aircraft with *SEL_i* below 76 dB(A) (1044 events). The probability of noise-induced awakening is equal to –0.0015, which is not statistically different from 0. This implies that subjects do not awake due to military aircraft noise events with *SEL_i* below 76 dB(A). For commercial aircraft noise events with *SEL_i* equal to 70 dB(A), percentage awakenings is 0.37.
The results for military aircraft noise are of limited applicability: they may only be applicable to people living near the end of runways of military airfields, and not to people living further away from a military airfield. Also, the data pertain to only one situation. Subjects in that situation may have special characteristics that are divergent from other populations in the vicinity of a military airfield. Therefore, the relationship on military

aircraft noise assessed in this report may or may not be applicable in situations other than the situation in Fidell et al. (1995a).
Although the relationship obtained for military aircraft noise may be applicable only in special circumstances, it is tempting to compare the results with those for commercial aircraft noise. At *SEL_i* equal to 76 dB(A) percentage noise-induced awakenings due to military and due to commercial aircraft are equal. At the higher *SEL_i* probability of awakening due to military aircraft noise is much higher than probability of awakening due to commercial aircraft noise. If the relationship for military aircraft noise would be general applicable, such an effect might be due to differences in shape of sound levels as a function of time during an overflight. Military aircraft noise events are of shorter duration, have smaller rise times and have higher maximal levels than commercial aircraft noise events.
The few observations on railway noise showed no effect of noise exposure on probability of awakening. The average percentage noise-induced awakenings in a 5-min interval for railway noise events is –0.13%. Therefore, there is some evidence, be it very limited, that railway noise events, in the range of *SEL_i* considered (up to 80 dB(A)), does not increase probability of awakening. Percentage awakenings during the 5-min railway noise events is 1.6% (95%-confidence limits 0.8 to 2.7% (Fleiss, 1981)), which is not statistically different from 1.73% estimated for 5-min intervals without noise events.
Also for ambient noise events, no exposure-effect relationships could be established. The average percentage noise-induced awakenings in a 5-min interval for ambient noise events is –0.20. The average percentage awakenings is 1.53% (95%-confidence limits 1.33 to 1.76%), which is not statistically different from 1.73% estimated for 5-min intervals without noise events. Although it is not unlikely that a substantial part of the ambient noise events considered road traffic noise, the uncertainties in the ambient noise data do not allow any conclusion about road traffic noise.

4.2 Inclusion of studies with onset of motility or EEG-awakening as effect measures

In section B.3.2 of Appendix B a preliminary relationship between the probability of noise-induced awakening and probability of noise-induced onset of motility has been derived. This relationship has been used to estimate the probability of noise-induced awakening from the probability of noise-induced onset of motility for the data points of study 5 (Ollerhead et al.,1992). The relationship needs further verification, since it is based on data on onset of motility from study 9 only. For the purpose of the estimation of probability of noise-induced awakening from probability of EEG-awakening a conversion rule has been derived in section B.3.2 of Appendix B. Taking into account the uncertainties in the derivation of this conversion rule, it should not be used for purposes other than the estimations used in the present analysis. In this respect it is important to take into account the minor contribution of the data points based on EEG-awakenings to the model, since the data points only concern 1869 (1%) of the 5-min intervals in the database.
In figure 4.1 a comparison has been made between the relationship for aircraft noise obtained with the aircraft noise data points of all studies (air_all), irrespective of the effect measure used in the study, and the relationship if only the data points are used from studies with marker pressing as effect measure (air_4). The relationship based on all aircraft noise data points is nearly identical to relationship based on the four studies.

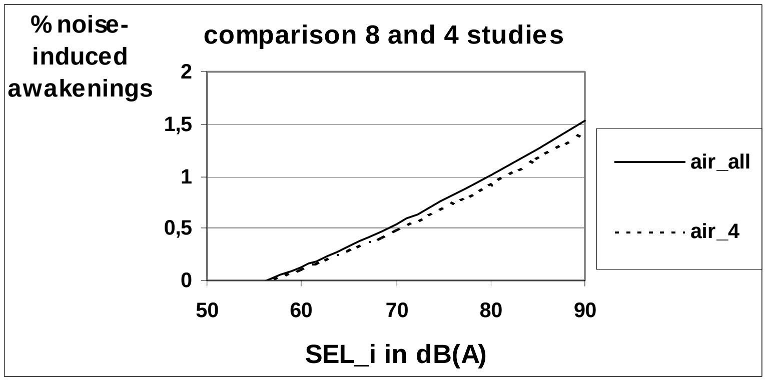

Figure 4.1: Percentage aircraft noise-induced awakenings as a function of *SEL_i* assessed with the aircraft noise data points of all studies and assessed with the aircraft noise data points of the four studies based on marker pressing as indication of awakening

4.3 Effect of factors other than SEL_i on probability of noise-induced awakening

The present analyses have been based on data points aggregated per class of *SEL_i*. Therefore it was not possible to investigate whether variables other than *SEL_i* have an effect on the relationship obtained in this report.

It is well established that age is related to many aspects of sleep quality. Results from study 9 on the effect of age and gender on number of *marker pressings during a sleep period* are given in figure 4.2. The figure shows the number of marker pressings during a sleep period as a function of the equivalent sound level due to aircraft noise during a sleep period in the bedroom of a subject (*LAeq_i*). Gender is a determinant of the number of marker pressings during sleep. Female subjects in study 9 press the marker 0.3 times more than male subjects, irrespective of *LAeq_i* during a sleep period. Age is an important effect-modifier: at low equivalent sound levels young subjects press the marker on average less than 0.5 times during a sleep period, and persons over 50 years of age on average 1 to 1.5 times. At the highest aircraft equivalent sound levels in the bedroom, the number of marker pressings increase from on average less than 1 time in young subjects to 2.5 to 3 times in the eldest subjects.

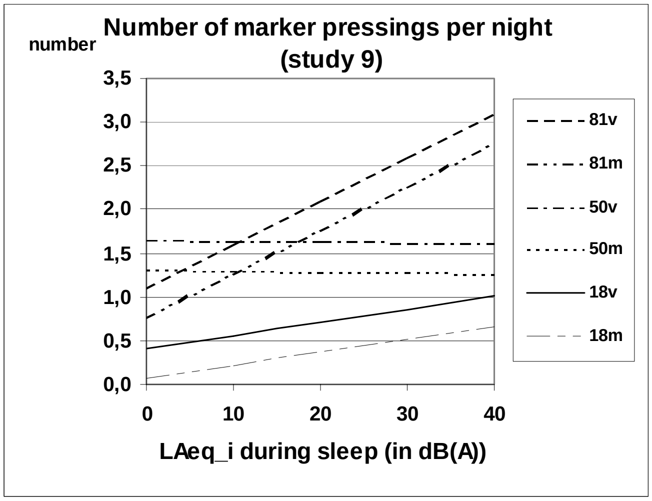

Figure 4.2: Number of marker pressings during a sleep period as a function of the equivalent sound level due to aircraft noise during a sleep period assessed in the bedroom of subjects. Age and gender are parameters

The number of marker pressings during a sleep period is likely influenced by the duration of a sleep period: the longer the duration, the more marker pressings. On average, women sleep 18 minutes longer than men (442.5 minutes compared to 424.6 minutes) (Passchier-Vermeer et al., 2002a). Also, younger and elder people sleep longer than people from 25 to 65 years. People over 65 years of age sleep about 30 minutes longer than people from 25 to 65 years. In figure 4.3, the average number of marker pressings during a 5-min interval is given. In the calculations, the dependency of the duration of the average sleep period with age and gender has been taken into account.

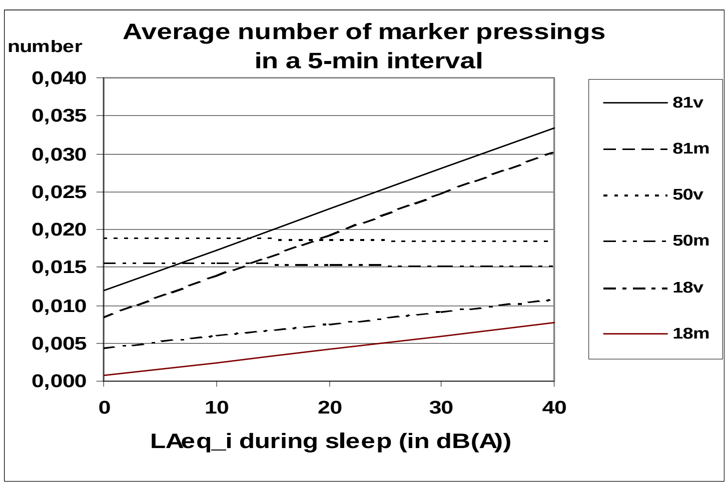

Figure 4.3: Average number of marker pressings in a 5-min interval during a sleep period as a function of the equivalent sound level due to aircraft noise during a sleep period assessed in the bedroom of subjects. Age and gender are parameters

In figure 4.4 the noise-induced components of the average number of marker pressings in a 5-min interval during the sleep period have been given. These values have been obtained by subtracting from the values in figure 4.3, the number of marker pressings at an aircraft equivalent sound level of 0 dB(A). This implies that it are average values over *all 5-min intervals* during sleep, and it does not concern the average noise-induced increase in awakenings during *5-min noise intervals*, as in chapter 3.

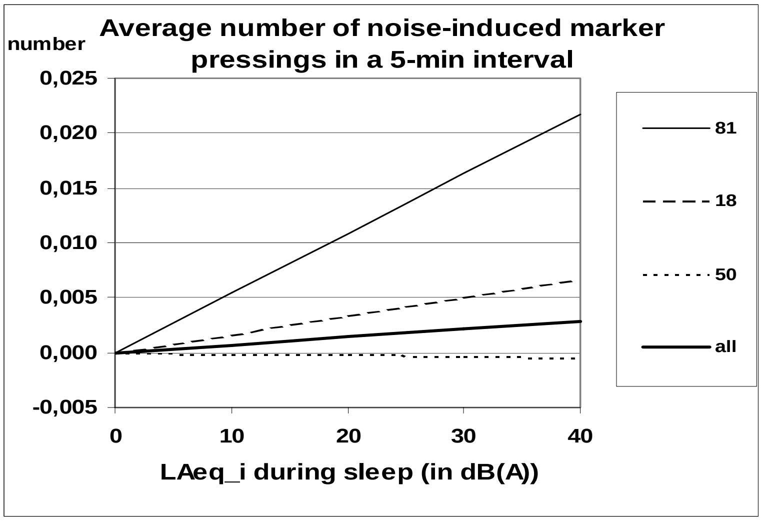

Figure 4.4: Average number of noise-induced marker pressings in a 5-min interval during a sleep period as a function of the equivalent sound level due to aircraft noise during a sleep period in the bedroom of subjects. Age (in years) is effect-modifier. Graphs for male and female subjects are the same. The relationship (all), if age is not taken as effect-modifier, is also given

It is obvious that age is a modifier of the probability of noise-induced awakenings. With increasing age the probability of noise-induced awakenings increases, and the more so if the night-time exposure is higher. Unfortunately, such an effect cannot be estimated from the aggregated data points. It is not unlikely that a part of the variance in the data is the result of differences in mean age of subjects contributing to a data point.

4.4 Model presented by Finegold and Elias (2002)

In contrast with the analysis by Finegold and Elias (2002), the present analysis takes the following factors into account:

- number of noise events in each of the data points;
- differences between probability of awakening on the one hand, and probability of EEG-awakening or of onset of motility on the other hand;
- differences between studies in the length of the time interval around a noise event for which an effect is considered to be related to the event;
- noise source (commercial aircraft, military aircraft, ambient, railway traffic);
- probability of awakening during intervals without noise events.

In Finegold and Elias (2002) the data points from studies 1 to 8 have been used. The result of the regression analysis is given in figure 4.5 by the curve marked F.

The formula of curve F is (Finegold and Elias, 2002):

F: %awakenings = $0.58 + (4.30*10^{-8})*(SEL\_i)^{4.11}$

In curve F-4, the data point of study 4 (Öhrström et al., 1988) has been omitted. The formula of curve F-4 is:

F-4: %awakenings = $0.59 + (4.42*10^{-8})*(SEL\_i)^{4.11}$

If the data points of study 9 are added to the database used by Finegold and Elias (2002), the formula becomes:

F-4+9: %awakenings = $0.66 + (4.35*10^{-8})*(SEL\_i)^{4.11}$

The three curves F, F-4, and F-4+9 are nearly identical.

If the data points are weighted according to the number of cases in each point, the formula becomes:

F-4+9_wght: %awakenings = $1.425 + (2.51*10^{-8})*(SEL\_i)^{4.11}$

The curve F-4+9_wght has a shape different from the former three curves. At the higher *SEL_i* values, the weighted curve has lower values and at the lower *SEL_i* values, the values of the weighted curve are somewhat higher than the values of the former three curves. This is to be expected from the information in Table 2.3: several data points with only a small number of noise events, which implies a low weighting, have a high probability of noise-induced awakening.

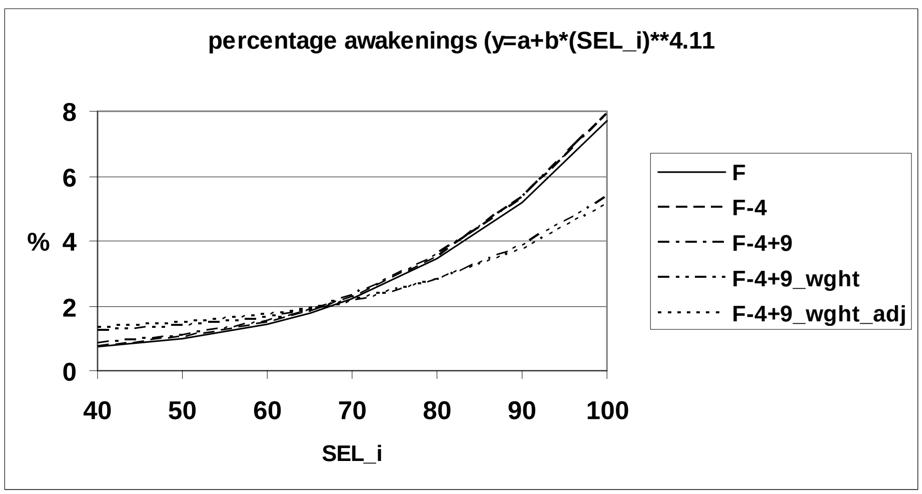

Figure 4.5: Percentage awakenings as a function of *SEL_i* assessed with the database of Finegold and Elias (2002). For explanation of legends, see text

In the analysis of Finegold and Elias (2002), for the studies 1 to 3 percentage behavioural awakenings have been taken equal to percentage EEG-awakenings, and for study 5, percentage behavioural awakenings has been taken equal to 0.4 times percentage onset of motility. If we adjust the data from studies 1, 2, 3, and 5 according to the method in this report, then the adjusted curve has the formula:

F-4+9_wght_adj: %awakenings = $1.26 + (2.33*10^{-8})*(SEL\_i)^{4.11}$

At the higher *SEL_i* values, the adjusted curve is slightly lower than the unadjusted curve. The difference between the adjusted and unadjusted curves is limited.

To obtain an estimate of the percentage noise-induced awakenings, from the data points of percentage awakenings in model F-4+9_wght_adj, percentage awakenings outside 5-min intervals with noise events (1.73%) has been subtracted.

Noise-induced F-4+9_wght_adj: %_n_i_awakenings = $-0.47 + (2.33 \cdot 10^{-8}) \cdot (SEL\_i)^{4.11}$

At *SEL_i* equal to 60 dB(A) the function noise-induced F-4+9_wght_adj is equal to 0, at *SEL_i* of 90 dB(A) equal to 2.0%. In the present analysis, figure 3.1 shows that for the quadratic function, at *SEL_i* equal to also 60 dB(A) percentage noise-induced awakenings is equal to 0, at *SEL_i* of 90 dB(A) equal to 1.1%. The difference at higher *SEL_i* values is due to the power of *SEL_i* in the model of Finegold and Elias. If the noise source is taken into account in the analyses, linear and quadratic functions fit better (higher values of R and F) than the function with power 4.11 of *SEL_i* used by Finegold and Elias.

4.5 Worst case for situations with night-time commercial aircraft

L_{night}_i (the indoor equivalent sound level caused by commercial aircraft during the night with an 8-hours duration) is obtained by the following exponential averaging of the individual *SEL_i* values:

$$L_{night}\_i = 10\lg\left(\Sigma_i\, 10^{SEL\_i/10} / 28800\right) \quad \text{dB(A)} \qquad [1]$$

where 28800 is the number of seconds in an 8-hours period. This can also be written as:

$$L_{night}\_i = 10\lg \Sigma_i\, 10^{SEL\_i/10} - 44.6 \quad \text{dB(A)} \qquad [2]$$

If the *SEL_i* values of the overflights during a night are known, L_{night}_i can be calculated from equation [2].
If all *N* events have equal *SEL_i*, then this equation can be simplified as follows:

$$L_{night}\_i = SEL\_i + 10\lg N - 44.6 \quad \text{dB(A)} \qquad [3]$$

The final model of probability of noise-induced awakening (prob_n-i_awakening) as a function of *SEL_i* for commercial aircraft with $54 < SEL\_i < 90$ dB(A) is given by:

$$\text{prob\_n-i\_awakening}(SEL\_i) = f(SEL\_i) = -0.564 \cdot 10^{-2} + 1.909 \cdot 10^{-6} \cdot SEL\_i^2 \qquad [4]$$

If the *SEL_i* values of the overflights during a sleep period of 8 hours are known, the sum of the probabilities of noise-induced awakening during that period can be calculated from equation [4]. The sum of the probabilities of noise-induced awakening during a night is equal to the number (*n*) of noise-induced awakening during that night, if the noise-induced awakenings due to the individual noise events are independent.

For a given L_{night}_i there is a configuration of *SEL_i* values of the overflights for which *n* is maximal. It has been shown that for this configuration all *SEL_i* values during a night are equal and have the same value irrespective of L_{night}_i (Passchier-Vermeer, 1994; Miedema, Passchier-Vermeer, Vos, 2003). The value of *SEL_i* (*sel_i*) for which this is applicable, is the solution of the following equation:

$$f'(sel\_i) = 0.23*f\,(sel\_i) \qquad [5]$$

with f'(*sel_i*) the derivative of f(*sel_i*)

The maximum of the number of awakenings (n_{max}) for a given L_{night} is:

$$n_{max} \;=\; 10^{(Lnight\_i\,-\,sel\_i\,+\,44.6)/10} * f(sel\_i) \qquad [6]$$

For commercial aircraft *n* is maximal if *SEL_i* is equal to 58.8 dB(A). If *SEL_i* is equal to 58.8 dB(A), f(*sel_i*) = $0.960*10^{-3}$. By substituting 58.8 dB(A) in equation [3] and [4], the following equations are found:

$$L_{night}\_i = 14.2 + 10\ \mathrm{lg}N \quad (\mathrm{dB(A)}) \qquad [7]$$

$$\text{number of noise-induced awakenings per night} = N*0.96*10^{-3} \qquad [8]$$

For N = 10 (10 aircraft noise events with *SEL_i* equal to 58.8 dB(A) during an 8 hours night), *Lnight_i* = 24.2 dB(A) and in the worst-case situation the number of noise-induced awakenings per sleep period is equal to 0.0096. For 365 sleep periods (one year) this implies about 3 to 4 noise-induced awakenings per year.

In figure 4.6 the number of noise-induced awakenings *in a year* due to commercial aircraft noise in the worst-case situation is given as a function of L_{night}*_i*: this number is 1 at L_{night}*_i* equal to 20 dB(A), , 13 at L_{night}*_i* equal to 30 dB(A), and 133 at L_{night}*_i* equal to 40 dB(A).

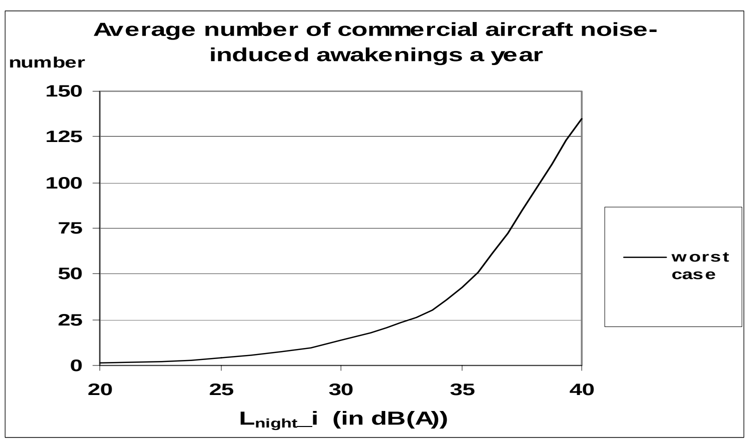

Figure 4.6: Average number of noise-induced awakenings in a year for the worst case situation in which each commercial aircraft overflight has a SEL_i value equal to 58.8 dB(A)

4.6 Awakening and self-reported sleep disturbance in situations with commercial aircraft noise

The percentage awakenings in a 5-min interval without noise events obtained from the studies is on average 1.73%. For an 8-hour sleep period without noise events, the average number of awakenings is equal to 1.66. Over a year the average number of awakenings in a situation without noise events is equal to 606. The number of awakenings during sleep period is, however, dependent on age and gender. Unfortunately, the analyses could not take any individual factors into account. Therefore, the following concerns the average population. Since in section 4.3 it was shown that especially in older people number of awakenings and number of noise-induced awakenings is larger than on average, the following result most probably underestimates effects on older people.

In section 4.5, the *number of noise-induced awakenings* in a year due to commercial aircraft noise in the worst-case situation is 1 at L_{night}_i equal to 20 dB(A), 13 at L_{night}_i equal to 30 dB(A), and 133 at L_{night}_i equal to 40 dB(A). This implies that the *number of awakenings* in a year in the worst-case situation is 607 at L_{night}_i equal to 20 dB(A), 619 at L_{night}_i equal to 30 dB(A), and 739 at L_{night}_i equal to 40 dB(A). In figure 4.7, for situations with commercial aircraft and for an average person, the number of awakenings in a year in the worst-case situation is given as a function of L_{night}_i.

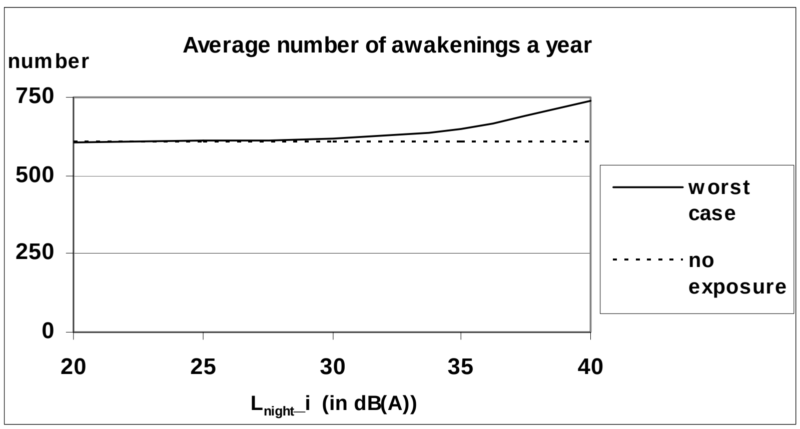

Figure 4.7: For situations with commercial aircraft and for an average person, the number of awakenings in a year in the worst-case situation and the number of awakenings without exposure to noise events, as a function of L_{night}_i

Apparently, only at the higher commercial aircraft noise exposures at night, there is a substantial effect of noise on number of awakenings in a year. This seems to be in contrast with results from socio-acoustic surveys. E.g. in the Netherlands, percentage persons highly sleep disturbed by commercial aircraft noise in the vicinity of Schiphol has been related to L_{night}_i (TNO-PG en RIVM, 1998). The result of this survey, with selective non-response taken into account (table 53 of TNO-PG en RIVM, 1998), is given in figure 4.8. Percentage highly sleep disturbed persons increases from 9 to 32% if L_{night}_i increases from 21.5 to 31.5 dB(A). The number of awakenings in the worst-case situation increases from 608 to 625 (2.8%) if L_{night}_i increases from 21.5 to 31.5 dB(A). This discrepancy may in part be explained as follows.
It is obvious that with increasing number and duration of overflights, the probability of being awake during the overflight, although not necessarily being awoken by aircraft noise, increases. At L_{night}_i = 31.5 dB(A) there is on average every 9 minutes an overflight, and at L_{night}_i = 21.5 dB(A) there is on average every 89 minutes an overflight (a factor 10 less than at 31.5 dB(A)). It is therefore likely that periods during which people are awake, coincide by somewhat more than a factor 10 (if the 2.8% increase in awakening is also taken into account) with the presence of an overflight in the situation with

L_{night}_i = 31.5 dB(A) than in the situation with L_{night}_i = 21.5 dB(A). This coincidence of being awake and perceiving an aircraft overflight, may result in attributing the awakening to aircraft noise, while in fact awakening occurred for other reasons.
Moreover, sleep disturbance also includes assumed effects from aircraft noise before the sleep period, such as difficulty to fall asleep, and effects at the end of the sleep period, such as tiredness.

5 CONCLUSION

In this report a secondary analysis is presented to obtain relationships between behavioural awakening due to noise events and indoor SEL of these noise events.

For *commercial aircraft noise events*, an exposure-effect relationship has been assessed. It has the following equation if $54 < SEL\_i < 90$ dB(A):

$$\text{percentage noise-induced awakenings} = -0.564 + 1.909 \cdot 10^{-4} \cdot SEL\_i^2$$

It has been made plausible that this relationship is applicable to the general population exposed to commercial aircraft noise events during night-time. Since age is an important effect-modifier, it is quite likely that in populations consisting of older people awakening is more frequent than should be expected from the formula given above.

The result for *military aircraft noise events* is of limited applicability: the data pertain to only one study and one situation, in which subjects lived near the end of the main runway of a military airfield.

The few observations on *railway noise* showed no effect of noise exposure on probability of awakening in the range of *SEL_i* considered (up to 80 dB(A)). Also *ambient noise events* showed no effect on probability of awakening. Although it is not unlikely that a substantial part of the ambient noise events was road traffic noise, the uncertainties in the ambient noise data do not allow any conclusion about *road traffic noise*.

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A NETHERLANDS SLEEP DISTURBANCE STUDY

A.1 Introduction

In section A.2 of this Appendix information is given about the assessment of the 10 data points of study 9 that have been included in the present database.
The data points in the present database are aggregated values. The original values in each study consisted of binary values: if a subject pressed a marker in a specified time interval, the value 1 and if the marker was not pressed the value 0 has been given to the test result. With such a set of data, usually a logistic regression analysis is performed to assess the probability of an action or a result (in this case marker pressing) as a function of an exposure metric (in this case *SEL_i*). In the present database, mean probability of marker pressing has been used and linear or curvilinear regression analyses according to the method of least squares performed. In section A.3 of this Appendix, a comparison has been made between the model based on the logistic regression analysis of the original data with binary test outcomes of study 9 and the model of a curvilinear regression analysis of aggregated test results of study 9.
In section A.4 information obtained from study 9 is given about the time of marker pressings within the 5-min intervals with aircraft noise events.
To assess *noise-induced* probability of marker pressing, from the probability of marker pressing during a 5-min interval with at least one noise event the probability of marker pressing in 5-min intervals without noise events has been subtracted. In principle, the probability of marker pressing in 5-min intervals without noise events may be affected by longer-term noise exposure during sleep. E.g., highly aircraft noise-exposed people may awake more frequently during the ‘quiet’ periods in their bedroom than people with a low exposure, or vice versa. In section A.5 the possible effect of longer-term aircraft noise exposure on the probability of marker pressing during the intervals *outside* 5-min aircraft noise windows will be considered.
Section A.6 gives 95%-confidence limits of the relationship between probability of awakening and *SEL_i*.
Section A.7 summarizes the conclusions of this Appendix.

A.2 Data points from study 9 (Passchier-Vermeer et al., 2002)

The number of indoor aircraft noise events in study 9 during 11 sleep periods of each of the 418 subjects for which information about marker pressings is available is 63378. For each of these events indoor SEL (*SEL_i*) is known. Marker pressings have been assessed for 5-min intervals around an aircraft noise event. In the study, the results of the indoor noise measurements have been stored every second, and motility has been recorded in 15-s intervals. The 5-min interval around an aircraft noise event consists of 5 15-s intervals (e1, e2, e3, e4, e5) before the 15-s central interval with L_{max}_i, the central 15-s interval (e6) and 14 15-s intervals after the central interval (e7 to e20). The total number of 15-s intervals within the 63378 aircraft noise windows is 1267560. Due to the overlap in time of the 5-min aircraft windows, a part of the 15-s intervals belong to more than one aircraft window. The total number of different 15-s intervals in the aircraft noise windows is equal to 945949.
Subjects have been requested to press the marker on the actimeter, whenever they woke intermittently during a sleep period. By comparing the times of the marker pressings with the times of the 5-min aircraft noise event intervals, it has been assessed whether a

marker pressing occurred during such an interval or not, and how many marker pressings occurred outside the 5-min aircraft noise intervals.
The 63378 aircraft noise events have been divided in 10 classes according to their *SEL_i* values such that each class contains about the same number of events. The midpoints of the *SEL_i* classes, the number of 5-min intervals (n_5min) and the mean probability of awakening (marker pressing in the 5-min interval) for each *SEL_i* class are given in table A1.
In figure A1 the mean probability of awakening has been plotted as a function of the midpoints of the *SEL_i*-classes.
The 10 data points have been included in the present database.

Table A1: Information about the 10 data points from study 9 included in the present database: *SEL_i*, the number of 5-min intervals with indoor aircraft noise (n_5min) and probability of awakening

Midpoint SEL_i (in dB(A))	Number of 5-min intervals in the class	Mean probability of awakening (marker pressing)
45.2	6877	0.015
48.4	5935	0.012
50.4	6617	0.013
52.4	7967	0.013
54.5	6569	0.012
55.9	4125	0.021
57.5	6212	0.016
59.5	5947	0.021
62.3	7381	0.017
68.1	5748	0.022

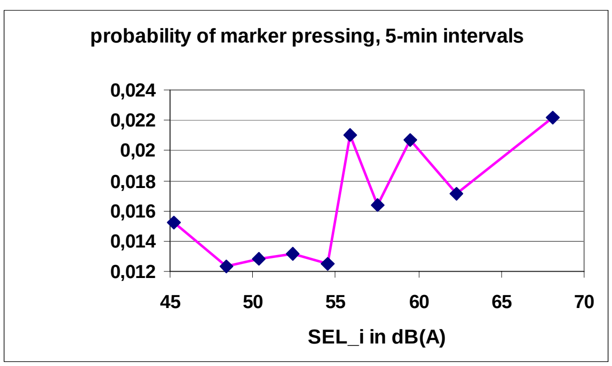

Figure A1: Mean probability of awakening (marker pressing) in a 5-min interval with aircraft noise as a function of *SEL_i* values of the aircraft noise events in study 9

A.3 Comparison of models based on individual data and on aggregated data

Three regression analyses according to the method of least squares have been performed, with probability of awakening as dependent variable, *SEL_i*, SEL_i^2 and a combination of *SEL_i* and SEL_i^2 as independent variables. In the analyses, the data points have been weighted by the number of noise events in the data point. The combination of *SEL_i* and SEL_i^2 did not provide for statistically significant coefficients. The regression model with probability of awakening as a function of SEL_i^2 (R = 0.744; F= 9.89) provides a slightly better fit than the model with *SEL_i* as independent variable (R = 0.730; F= 9.15).

The regression equation is:
$f(SEL\_i) = 0.0051 + 0.00000353 * SEL\_i^2$
with f(*SEL_i*) the probability of awakening.
The relationship is shown by the curve in figure A2.

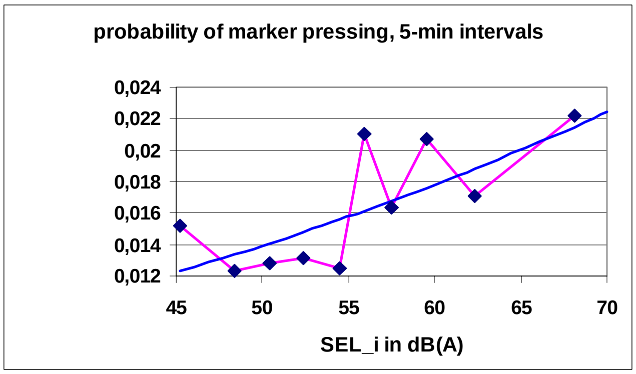

Figure A2: Probability of awakening (marker pressing) in a 5-min interval with aircraft noise for the 10 data points and the quadratic regression curve as a function of *SEL_i*

On the 63378 individual observations (*SEL_i* and awakening or not) a logistic regression analysis has been performed. The resulting equation is:

$$p(SEL\_i)/(1-p(SEL\_i)) = 1.025452*(SEL\_i)^{0.002624}$$

with p(*SEL_i*) the probability of a marker pressing.
The result of the regression model with aggregated data in classes and the result of the logistic regression model on the individual data are given in figure A3.

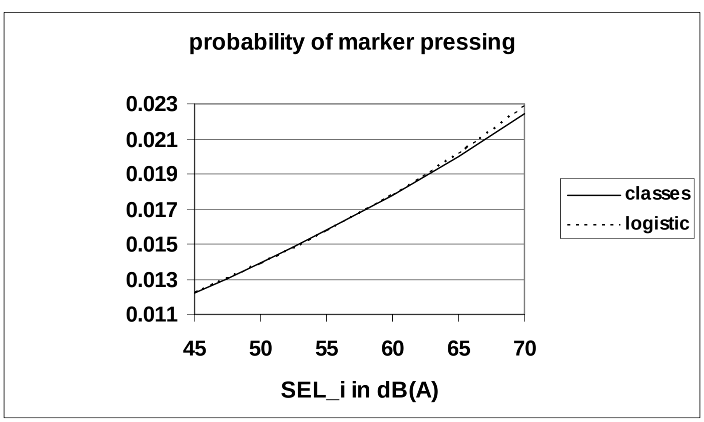

Figure A3: Probability of awakening (marker pressing) in a 5-min interval with aircraft noise as a function of *SEL_i* of the aircraft noise events, according to the logistic regression model and a regression model according to the method of least squares for data in classes

Figure A3 shows that both models result in about the same relationship.

From the information on marker pressings in the 5-min intervals without aircraft noise events, the probability of awakening in those intervals has been estimated. This probability is in study 9 equal to 0.01523. To obtain the probability of *noise-induced awakening* in the 5-min intervals with aircraft noise events, 0.01523 has been subtracted from the probability of awakening in these 5-min intervals. The result has been given in figure A4. According to the data from study 9 noise-induced probability of awakening is equal to 0 at *SEL_i* equal to 53.5 dB(A).

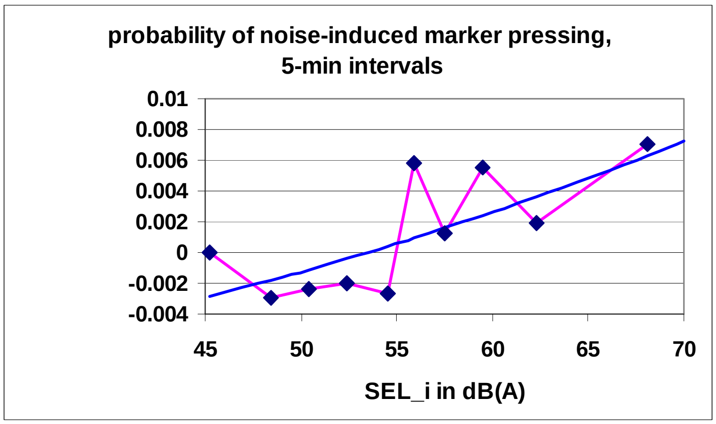

Figure A4: Probability of noise-induced awakening (marker pressing) in a 5-min interval with aircraft noise as a function of *SEL_i* of the aircraft noise events

A.4 Time of marker pressing in the 5-min intervals with aircraft noise events

In Passchier-Vermeer et al. (2002a) the probability of awakening has been given for two different time intervals: a 5-min interval (with the 20 15-s intervals e1 to e20) and a 105-s interval (with the 7 15-s intervals e4 to e10). The result has been reproduced in table A2. The probability of awakening during the 15-s intervals e1 to e3 and e11 to e20 (406 awakenings in 507315 15-s intervals: mean probability 0.0800, 95%-confidence intervals from 0.0725 to 0.0883) is somewhat higher, but not statistically significant different from the probability in 15-s intervals outside the aircraft noise windows (5188 awakenings in 6918960 15-s intervals: mean probability 0.0750, 95%-confidence interval from 0.0730 to 0.0771). The fact that the probability of awakening during the 15-s intervals e1 to e3 and e11 to e20 is somewhat higher than outside aircraft noise windows may be partly due to the effect of another aircraft in overlapping 15-s intervals. About one out of 8 15-s intervals e1 to e3 and e11 to e20 also belongs to another aircraft noise window.
For the present purpose, the calculations have also been carried out for a 1-min interval (for aircraft noise intervals consisting of e5 to e8). The result is given in the last rows of table A2. It turns out that the probability of awakening during the 15-s intervals e1 to e4 and e9 to e20 (554 awakenings in 695296 15-s intervals: mean probability of awakening equal to 0.0797, 95% confidence interval from 0.0732 to 0.0867) is not statistically sig-

nificant different from the probability in the 15-s intervals outside the 5-min aircraft noise intervals.

This implies that the probability of awakening in the period around an aircraft noise event is increased to a large extent only during a one-minute interval (e5 to e8) around the 15-s interval with L_{max}_i.

Table A2: Information about marker pressings of subjects during sleep to indicate intermittent awakening (Passchier-Vermeer et al., 2002a)

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
aircraft noise window e5 to e8			
total	7864899	5951	0.0757
outside window	7614256	5742	0.0754
inside window	250643	209	0.0834

A.5 Probability of marker pressings outside 5-min aircraft noise intervals

In this section the possible effect of longer-term aircraft noise exposure on the probability of marker pressings during the intervals outside 5-min aircraft noise windows will be considered. In study 9 the individual exposure to aircraft noise during sleep (*Li*) has been assessed by calculating from all aircraft *SEL_i* value during the 11 sleep periods of a subject the aircraft equivalent sound level for all sleep periods, taking into account the durations of these periods. By using the 6918960 15-s intervals without aircraft noise events, a logistic regression analysis has been performed to assess the probability of marker pressings as a function of *Li*. Since age and gender have an effect on the probability of marker pressings, these variables have been included as independent variables in the analysis. The analysis showed a small negative (b=-0.005, exp_b =0.99), but not statistically significant, coefficient of *Li*. This implies that the analysis is not able to show that the probability of a marker pressing during intervals without aircraft noise in the bedroom depends on the longer-term aircraft noise exposure of a subject, i.e. highly exposed subjects do not awake more or less frequent during quiet intervals than less exposed subjects.

A.6 95%-confidence limits

In this section the 95%-confidence limits of probability of awakening are given as a function of *SEL_i*. The results are given in figure A5. The 95%-confidence limits have been based on the original data and the logistic model.

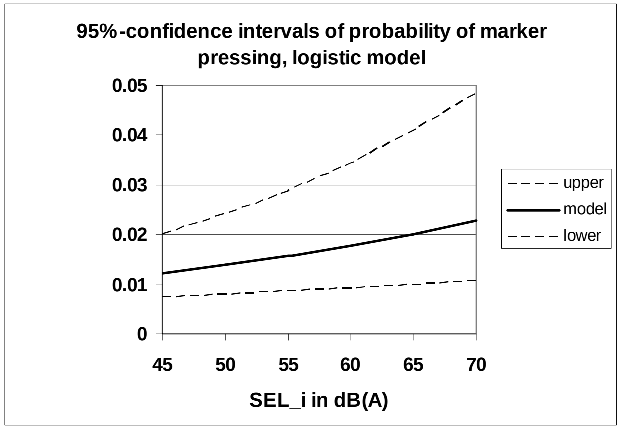

Figure A5: Probability and 95%-confidence intervals of noise-induced awakening (marker pressing) in a 5-min interval with aircraft noise as a function of *SEL_i* of the aircraft noise events

A.7 Conclusions

The following conclusions that are of importance for the main text can be deduced from the analyses in this Appendix:

- From the data in study 9 10 data points have been derived, which have been included in the present database.
- For the present purpose, differences between a model based on curvilinear regression analyses by the method of least squares of aggregated data points and a model based on a logistic regression analysis with original binominal data is negligible
- Aircraft noise-induced awakening (assessed by marker pressings) mainly occurs. during a 1-min interval (consisting of the 15-s interval with L_{max}_i, the 15-s interval preceding and the two 15-s intervals following this interval).
- The probability of awakening during intervals without aircraft noise does not depend on the longer-term aircraft noise exposure of a subject. Therefore, *noise-induced* probability of awakening can be taken as the difference between probability of awakening during noise intervals and probability of awakening in a time interval without noise events.

B PREPARATION OF THE DATABASE

B.1 Introduction

The database presented by Fidell et al. (1998), and used by Finegold and Elias (2002) with only a slight adjustment, has been adjusted in various respects. To the database the 10 data points from study 9 have been added. The data point of study 4 in the database of Finegold and Elias has been omitted, since it concerns self-reported awakening.
For some studies the number of cases in the study is known, but not the distribution of these cases over the data points in the database. This is considered in section B.2.
In section B.3 the probability of noise-induced awakening in a data point is estimated. Section B3.1 concerns studies with marker pressings as effect measure and section B.3.2 studies with onset of motility or EEG-awakenings as indicators of 'awakening'.
Only in one study (Ollerhead et al., 1992) noise measurements have not been performed indoors. In each of the other studies noise measurements have been performed in the bedrooms of subjects. In section B.4 the method used to estimate *SEL_i* from *outdoor SEL* is given. Section B.5 lists conclusions of this Appendix.

B.2 Estimation of number of cases in each SEL_i class

In *study 1, 2, and 3* the total number of noise events is known, but not the distribution of the number of events over the *SEL_i* classes. This distribution is estimated from the distributions in the studies 5, 6, 7, and 8. In each of the studies 5, 6, 7, and 8 the widths of the classes was nearly equal, like in the studies 1, 2, and 3.

The following procedure has been used to estimate the number of noise events in each class in studies 1, 2, and 3, and for each source within a study separately. First for each of the studies 5, 6, 7, and 8 the differences (*SEL_i_0*) between the midpoints of the *SEL_i* classes and the midpoint of the lowest *SEL_i* class have been calculated.
The relationship between number of cases in a *SEL_i* class (n_5min) and *SEL_i_0* has been determined by considering two regression models: one with *SEL_i_0* as independent variable and one with $(SEL\_i\_0)^2$ as independent variable. The model with $(SEL\_i\_0)^2$ as independent variable fits better than with *SEL_i_0* as independent variable (in the first case R = 0.352, F = 11.19; in the second case R = 0.322, F = 9.15). In figure B1 the relative relationships are given, with at *SEL_i_0* = 0 the function taken equal to 100.
For each of the studies 1, 2, and 3 the relative value of n_5min for each data point has been calculated by using the quadratic relative relationship from figure B1.
The absolute number of cases in each SEL_i class has been estimated by multiplying the relative values with the total number of n_5min values in the study divided by the sum of the relative values. The absolute values have been included in the database.

For the data points from *study 5* the number of 5-min intervals have been taken equal to the number of events in a data point.

In the *studies 6, 7, and 8* the number of 5-min intervals of each data point have been published.

The numbers of 5-min intervals of the data points of study 9 are given in Appendix A.

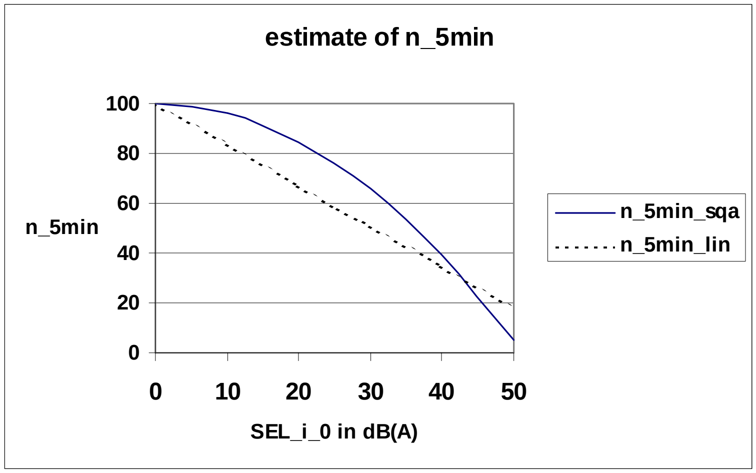

Figure B1: The relative relationship between number of cases (n_5min) in a *SEL_i* class and *SEL_i_0*, for *SEL_i_0* and $(SEL\_i\_0)^2$ as independent variables in the regression models. At *SEL_i_0* = 0 the functions have been given the value 100

B.3 Estimation of probability of noise-induced awakening

B.3.1 Studies with marker pressing as indicator of awakening

In the studies 6, 7, 8, and 9 subjects pressed a marker to indicate intermittent awakening. From these observations the probability of awakening in a 5-min interval with noise has been calculated. To assess the probability of *noise-induced* awakening in 5-min intervals with noise events, from the observed probability of awakening during such an interval, the probability of awakening in a 5-min interval without noise events has to be subtracted.

In table B1 information obtained from the various studies to estimate the probability of awakening in 5-min intervals without noise events has been given. The first column gives the study, the next column the number of sleep period times in the study for which data is available. On the basis of the average sleep period time in each of the studies, the total number of 5-minutes intervals in each study has been calculated. The result has been presented in column 3.

The next two columns give the total number of 5-min intervals with at least one noise event and without noise events. There may be some overlap in time of 5-min aircraft noise intervals. With respect to study 9 12.8% of the 15-s intervals in the 5-min aircraft noise intervals belong to more than one aircraft noise window. This percentage is assumed to be valid also for study 7. This reduces the total number of 5-min intervals with aircraft noise in that study from 26654 to 19892. Since there are relatively much less aircraft noise intervals in study 6 and 8 (during respectively 5.7 and 2.5% of the time) it is assumed that overlap of aircraft noise intervals did not occur in those studies.

The following two columns present the number of awakenings during the 5-min intervals with at least one and without noise events. The last two columns present the probability of awakenings during 5-min intervals with at least one and without noise events.

The last row of the table gives the result for the four studies together.

Table B1: Information to estimate the probability of awakening during 5-min intervals with at least one and without noise events

Study	Number of sleep periods	n_5min during sleep	n_5min during sleep		Number of awakenings during 5-min intervals		Probability of awakening during 5-min intervals	
			with noise events	without noise events	with noise events	without noise events	with noise events	without noise events
6:Fidell '95a	1887	177000	10120	166880	318	3906	0.0314	0.0234
7:Fidell '95b	2717	254854	19892	234962	322	3806	0.0162	0.0162
8:Fidell '98	686	58996	1472	57524	29	979	0.0197	0.0170
9:Passchier-Vermeer '02	4511	387946	47297	340649	763	5188	0.0161	0.0152
Four studies			78781	800015	1432	13879	0.0182	0.0173

The probability of awakening during 5-min intervals without noise events is 0.0173 in the four studies together. Table B1 also shows that the probability of awakening during 5-min intervals without noise events varies substantially between studies. Differences between studies may be due to differences in factors related to subjects, such as age, and instruction of subjects. Another factor with a possible impact may be the definition of a 5-min interval without noise events. In the studies 6, 7, and 8 a noise event was assumed to occur if the sound level in the bedroom exceeded 60 dB(A) for at least 2 s. The aircraft noise events in study 9 have been identified as such at much lower sound levels, i.e. with maximal sound levels from 30 to 40 dB(A), dependent on the background noise level in the bedroom of subjects. The large differences between studies in the probability of awakening in 5-min intervals without noise events implies that probability of noise-induced awakening should be calculated by subtracting from the observed probability of awakening for each study separately the probability of awakening in 5-min intervals without noise events, and not by subtracting for each study the value of 0.0173 calculated for the four studies together.

For the combined studies, the probability of awakening increases from 0.0173 during 5-min intervals without noise events to 0.0182 during 5-min intervals with noise events. The difference (0.0009) implies a percentage noise-induced awakenings of 0.09%: on average once in about 1100 'noise events' a noise-induced awakening occurs.

In the database for each data point of study 6, 7, 8, and 9, noise-induced probability of awakening has been estimated by subtracting from the observed probability of awakening the value given for each of the studies in the last column of table B1.

B.3.2 *Studies with onset of motility or EEG-awakening as indicators*

Study 5 gives the mean probability of onset of motility in 30-s intervals with and without commercial aircraft in classes of *outdoor SEL*. From the *outdoor SEL* values, indoor values have been estimated (see section B.4).

In an iterative process the relationship between probability of noise-induced onset of motility and probability of noise-induced awakening has been assessed.

First with the data points for commercial aircraft obtained from the studies 6, 7, 8, and 9 a regression analysis has been carried out to assess the probability of noise-induced awakening as a function of *SEL_i* (SEL_i^2 has been taken as independent variable, probability of noise-induced awakening as dependent variable, and the data points have been weighted according to their number of 5-min intervals). The exposure-effect-relationship has been compared with the relationship between probability of noise-induced onset of motility and *SEL_i* obtained from Passchier-Vermeer et al. (2002a). In column 3 of table B2 values of probability of noise-induced onset of motility have been given for several values of *SEL_i*. It concerns the increase in onset of motility during the 5 15-s intervals to which noise-induced increase of onset of motility is limited.

By using the relation obtained between both probabilities, from the probability of noise-induced onset of motility in a data point of study 5 the probability of awakening has been estimated and with these estimates added to the database a second regression analysis has been performed. In this process it has also been taken into account that in study 5 onset of motility has been measured in 30-s intervals. In Passchier-Vermeer et al. (2002a) it was shown that the probability of aircraft noise-induced increase in onset of motility during the five 15-s intervals e5 to e9 of an overflight is about 2.05 times the increase in probability of aircraft noise-induced onset of motility in the 30-s interval with L_{max}_i. With this information, from the probability of onset of motility (assessed in 30-s intervals) given in the data points obtained from study 5, the probability of noise-induced awakening has been estimated for those data points.

The second regression equation has then been used to estimate again the relation between both probabilities. After several iterations, the final model of probability of noise-induced awakening has been obtained. This final model is given in column 2 of table B2. In figure B2, for commercial aircraft, the probability of aircraft noise-induced onset of motility and the final model of probability of noise-induced awakening, obtained after some iterations, has been plotted as a function of *SEL_i*.

Table B2: Probability of commercial aircraft noise-induced awakening and onset of motility as a function of SEL_i and relationships between both probabilities

SEL_i in dB(A)	Probability of commercial aircraft noise-induced awakening	Probability of commercial aircraft noise-induced onset of motility	Probability of noise-induced onset of motility minus 0.0149 (probability at 54.4 dB(A))	Quotient of value in column 4 and in column 2 for SEL_i > 60 dB(A)
40		0		
50		0.010		
54.4	0	0.0149	0	
60	0.00123	0.0220	0.0071	5.80
65	0.00242	0.0290	0.0141	5.81
70	0.00371	0.0365	0.0216	5.81
75	0.00510	0.0446	0.0297	5.82
80	0.00658	0.0532	0.0383	5.83
85	0.00815	0.0625	0.0476	5.83
90	0.00982	0.0722	0.0573	5.84

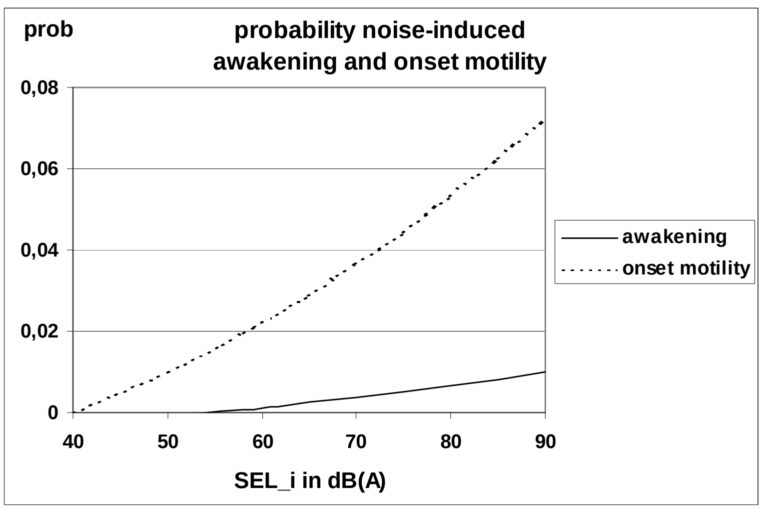

Figure B2: Probability of noise-induced awakening during a 5-min interval with commercial aircraft and probability of noise-induced onset of motility for commercial aircraft as a function of *SEL_i*

In the final model noise-induced awakening starts from *SEL_i* equal to 54.4 dB(A). At that *SEL_i* value the probability of onset of motility is equal to 0.0149. If we subtract from the probabilities of onset of motility above 54.4 dB(A) the value of 0.0149, the result obtained is given in column 4 of table B2. The quotient of the values in column 4 and the values in column 2 (for values of *SEL_i* over 60 dB(A)) appears to be nearly constant, and equal to 5.8 (see column 5 of table B2). Therefore in first approximation:
for *SEL_i* > 54.4 dB(A):
prob noise-induced awakening = (prob noise-induced onset of motility – 0.0149)/5.8

for *SEL_i* <= 54.4 dB(A): prob noise-induced awakening = 0.

with probability of noise-induced awakening assessed over a 5-min interval and probability of noise-induced onset of motility assessed over the time interval around an aircraft noise event during which probability of noise-induced onset of motility is present (i.e. the 5 15-s intervals e5 to e9). In the derivation of the data points, not this equation, but the (somewhat *SEL_i* dependent) quotients in column 4 of table B2 have been used.

The studies 1, 2, and 3 have EEG-awakenings in 1-min intervals as indicator of awakening. Study 5 shows that 2.5 times the probability of EEG-awakening in a 30-s interval corresponds to probability of onset of motility in a 30-s interval. This is assumed to be correct for *noise-induced* EEG-awakenings too. Then, probability of noise-induced onset of motility in a 30-s interval is equal to 2.5 times the probability of noise-induced onset of EEG-awakening in a 30-s interval. By inserting this equality in the equation given above, and by taking the observation time of EEG-awakenings of 1-min in the studies into account, from the probability of EEG-awakening the probability of noise-induced awakening in a 5-min interval has been estimated. Taking into account the uncertainties in the method to estimate noise-induced awakening from noise-induced EEG-awakening, I do not consider such a procedure general applicable.

B.4 Estimate of SEL_i from outdoor SEL for study 5

In Fidell et al. (1998) *SEL_i* is assumed to be 20.3 dB(A) lower than *outdoor SEL*. Horne et al. (1994) suggest that the difference between outdoor L_{max} and L_{max}*_i* (which is about equal to the difference between *outdoor SEL* and *SEL_i*) at the study locations is on average about 20 dB(A). However most probably the difference between outdoor L_{max} and L_{max}*_i* is dependent on outdoor L_{max} and on location, since at the two locations with the highest outdoor night-time aircraft noise exposure (equivalent sound levels during the night 66.5 and 61.5 dB(A)) 90% of the dwellings had bedroom windows with double or triple glazing, and at the locations with lower exposure (equivalent sound levels during the night between 43 and 55 dB(A)) the percentages of double-glazed bedroom windows varied from 10 to 90%, with an average of 50%. Since it is reasonable to assume that the overflights with the highest L_{max} and *SEL_i* values mainly occur at the highest exposed locations, 25 dB(A) instead of 20 dB(A) has been subtracted from the *outdoor SEL* values to obtain *SEL_i*.

B.5 Conclusion

The following results have been obtained:

- A method has been developed to estimate the number of noise events in a data point from the total number in a study. This seems more realistic than dividing the total number of cases by the number of data points and attributing to each data point in a study the same number of noise events.
- Probability of awakening during 5-min intervals without noise events is on average 0.0173, and varies between studies from 0.0152 to 0.0234.
- Probability of noise-induced awakening (prob n-i_w) during a 5-min interval has been related to probability of noise-induced onset of motility (prob n-i_om) during a 5-min interval. Preliminary relationships are:
  for *SEL_i* > 54.4 dB(A): prob n-i_w = (prob n-i_om – 0.0149)/5.8
  for *SEL_i* <= 54.4 dB(A): prob n-i_w = 0.

- For the purpose of the estimation of probability of noise-induced awakening from probability of EEG-awakening in this report, a conversion rule has been derived. Taking into account the uncertainties in the derivation of this relationship, it should not be used for purposes other than the estimations used in the present analysis. In this respect it is important to take into account the minor contribution of the data points based on EEG-awakenings to the model, since the data points only concern 1869 (1%) of the 5-min intervals in the database.

C INFORMATION ABOUT THE DATA POINTS IN THE DATABASE

Table C1: Information about data points in the database

Study	*SEL_i* value of data point (in dB(A))	Source	Number of events in data point (n_5min)	Percent-age response	Effect measure
1	65.3	1	18	0	EEG-awakening
1	75.3	1	17	6	EEG-awakening
1	85.3	1	15	0	EEG-awakening
1	95.3	1	12	12	EEG-awakening
1	100.3	1	7	6	EEG-awakening
2	47.8	4	133	0	EEG-awakening
2	55.8	4	130	0	EEG-awakening
2	59.8	4	126	0	EEG-awakening
2	63.8	4	120	2	EEG-awakening
2	67.8	4	113	2	EEG-awakening
2	71.8	4	104	3	EEG-awakening
2	76.8	4	91	2	EEG-awakening
2	80.8	4	78	5	EEG-awakening
3	46.3	1	460	1	EEG-awakening
3	56.3	1	442	2	EEG-awakening
3	66.3	1	390	3	EEG-awakening
3	76.3	1	303	4	EEG-awakening
3	86.3	1	181	5	EEG-awakening
3	96.3	1	24	6	EEG-awakening
5	46.5	1	3509	5.3	Onset motility
5	51.5	1	9650	5.4	Onset motility
5	56.5	1	13159	5.2	Onset motility
5	61.5	1	21933	5.6	Onset motility
5	61.5	1	13159	6.1	Onset motility
5	66.5	1	14914	7.2	Onset motility
5	71.5	1	8733	8.0	Onset motility
5	76.5	1	1754	9.2	Onset motility
5	81.5	1	877	12.7	Onset motility
6	58	3	3	0.0	Behav awakening
6	61	3	108	0.9	Behav awakening
6	64	3	210	2.4	Behav awakening
6	67	3	281	2.1	Behav awakening
6	70	3	178	4.5	Behav awakening
6	73	3	124	6.5	Behav awakening
6	76	3	60	8.3	Behav awakening
6	79	3	34	11.8	Behav awakening
6	64	2	197	2.5	Behav awakening
6	67	2	184	1.1	Behav awakening
6	70	2	331	1.8	Behav awakening
6	73	2	332	3.0	Behav awakening

6	76	2	583	1.9	Behav awakening
6	79	2	610	4.6	Behav awakening
6	82	2	447	3.6	Behav awakening
6	85	2	317	3.2	Behav awakening
6	88	2	343	4.7	Behav awakening
6	91	2	291	2.7	Behav awakening
6	94	2	233	9.0	Behav awakening
6	97	2	157	16.6	Behav awakening
6	100	2	79	24.1	Behav awakening
6	61	1	67	1.5	Behav awakening
6	64	1	1150	1.2	Behav awakening
6	67	1	1507	1.4	Behav awakening
6	70	1	998	2.2	Behav awakening
6	73	1	616	2.8	Behav awakening
6	76	1	354	3.7	Behav awakening
6	79	1	212	1.9	Behav awakening
6	82	1	85	4.7	Behav awakening
6	85	1	29	20.7	Behav awakening
7	52	1	444	0.5	Behav awakening
7	55	1	2137	0.9	Behav awakening
7	58	1	1829	0.7	Behav awakening
7	61	1	1124	1.1	Behav awakening
7	64	1	1183	0.8	Behav awakening
7	67	1	888	1.2	Behav awakening
7	70	1	638	1.9	Behav awakening
7	73	1	1047	1.8	Behav awakening
7	76	1	1175	0.6	Behav awakening
7	79	1	933	1.7	Behav awakening
7	82	1	969	0.9	Behav awakening
7	85	1	904	2.0	Behav awakening
7	88	1	622	1.3	Behav awakening
7	91	1	536	1.5	Behav awakening
7	94	1	230	1.3	Behav awakening
7	97	1	109	0	Behav awakening
7	100	1	67	1.5	Behav awakening
7	103	1	24	8.3	Behav awakening
7	52	3	540	0.9	Behav awakening
7	55	3	2121	0.9	Behav awakening
7	58	3	1904	1.0	Behav awakening
7	61	3	1135	1.8	Behav awakening
7	64	3	1262	2.1	Behav awakening
7	67	3	1009	1.5	Behav awakening
7	70	3	790	1.9	Behav awakening
7	73	3	605	1.7	Behav awakening
7	76	3	490	0.8	Behav awakening
7	79	3	827	0.7	Behav awakening
7	82	3	568	0.9	Behav awakening
7	85	3	304	1.0	Behav awakening
7	88	3	143	2.8	Behav awakening
7	91	3	63	0.0	Behav awakening
7	94	3	34	0.0	Behav awakening

8	61	1	67	1.5	Behav awakening
8	64	1	82	1.2	Behav awakening
8	67	1	63	6.3	Behav awakening
8	70	1	276	2.5	Behav awakening
8	73	1	484	1.0	Behav awakening
8	76	1	258	1.2	Behav awakening
8	79	1	106	1.9	Behav awakening
8	82	1	82	4.9	Behav awakening
8	85	1	54	3.7	Behav awakening
9	45.2	1	6877	1.5	Behav awakening
9	48.4	1	5935	1.2	Behav awakening
9	50.4	1	6617	1.3	Behav awakening
9	52.4	1	7967	1.3	Behav awakening
9	54.5	1	6569	1.2	Behav awakening
9	55.9	1	4125	2.1	Behav awakening
9	57.5	1	6212	1.6	Behav awakening
9	59.5	1	5947	2.1	Behav awakening
9	62.3	1	7381	1.7	Behav awakening
9	68.1	1	5748	2.2	Behav awakening