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# Motility and road and railway traffic noise

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# EXECUTIVE SUMMARY

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# 1 INTRODUCTION

This report presents a secondary analysis of the data of a German study on the effects of road and railway noise during sleep [1-3]. The study was performed to examine the difference between road and rail traffic noise with regard to physiological, subjective, and behavioural responses. At 8 locations where either rail or road noise prevailed, a total of 1 600 persons were interviewed; a subgroup of 376 persons (18 to 66 years of age) was examined during 2 times 5 nights (Sunday through Thursday night). In this sleep observation period noise and motility (by actimeters carried on the wrist) was recorded (semi-)continuously during each night. Every morning the subjects stated the position of the windows during the night, they evaluated their sleep in a diary and performed a 4-choice reaction time test. Only the behaviour to sleep with open or closed windows was significantly associated with the rating level of road and railway noise. Also, the windows of subjects primarily exposed to road noise were significantly more often closed. None of the other aggregated effect data revealed any difference between the two types of noise.

In this report the main focus is not on *differences* between effects measures in road or railway traffic noise exposed subjects, but on the *relationships* between noise-induced effects and noise exposure metrics for each of the two noise sources.

The German researchers made available all recorded data for the secondary analysis presented in this report. The analyses are limited to the effects of noise on motility. In the analyses only for a few demographic variables it has been considered whether they have an effect on the relationships or the effect measures.

Most of the terms and definitions used in this report are equal to those used in the reports on the Netherlands aircraft noise sleep disturbance study [4-7]. An overview of terms and definitions is given in chapter 6 of this report.

This chapter shortly reviews the characteristics of the subjects, the noise measurements, and the motility measures. In the next three chapters the results are presented of analyses of motility data on three time scales:

- Instantaneous motility effects based on observations during short term (30-s) intervals
- Mean motility effects over one sleep period time
- Mean motility effects aggregated over 10 sleep period times.

All results relate to sleep period times of subjects. These sleep period times were assessed by Griefahn in the original analysis[1].

*Subjects*
In the study 376 subjects participated: 188 subjects primarily exposed to road traffic noise, the other 188 subjects primarily exposed to railway traffic noise (from trains). Of the 376 subjects 185 were male, 187 were female, and from 4 subjects gender was not classified. Table 1.1 and figure 1.1 give the cumulative distribution of age of subjects, for road and railway noise separately.

Table 1.1 Cumulative distribution of age of subjects exposed to road or railway traffic noise. Age in years.

| Percentage | Road traffic | Railway traffic |
|---|---|---|
| Missing number | 11 | 11 |
| | Age | Age |
| 0 | 18 | 18 |
| 10 | 24 | 24 |
| 20 | 28 | 27 |
| 30 | 30 | 32 |
| 40 | 34 | 35 |
| 50 | 38 | 37 |
| 60 | 42 | 39 |
| 70 | 47 | 42 |
| 80 | 52 | 46 |
| 90 | 56 | 54 |
| 100 | 66 | 66 |

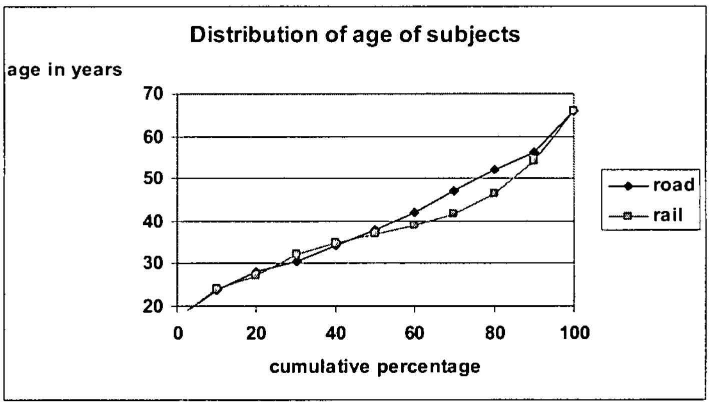

Figure 1.1 Cumulative distribution of age of subjects exposed to road or railway traffic noise

The table and figure shows that a smaller percentage of subjects exposed to railway traffic than exposed to road traffic are 50 years and over.

The total number of subject nights with information about motility and noise exposure is 1581 (84% of all possible subject nights) for railway traffic noise, and 1710 (91%) for road traffic noise.

*Actimetry*

Motility has been recorded in 30-s intervals. In the analyses two binary motility measures will be used: motility (m) and onset of motility (k). If motility is above threshold in a 30-s interval: m = 1, otherwise m=0. If motility above threshold starts to occur during a 30-s interval: k = 1, otherwise k = 0.

*Noise measurements and noise metrics used in the analyses*

Noise measurements were performed outside in the vicinity of a noise source during each of the 10 study nights at a location, and indoors in the bedrooms of subjects during one of these 10 study nights. The noise measurements consisted of 1-s or 2-s equivalent

sound levels. From a comparison of the outdoor 1-s and 2-s equivalent sound levels and the corresponding indoor equivalent sound levels, Möhler assessed a relationship between out- and indoor 1-s and 2-s equivalent sound levels, for 12 combinations of position and type of bedroom window(s). In the model, the differences between outdoor and indoor 1-s or 2-s values range from 8 dB(A) (windows wide open) to 35 dB(A) (double windows fully closed). For the initial analyses, Möhler estimated all indoor equivalent 1-s and 2-s sound levels from the outdoor equivalent sound levels by using the relationship and the position and type of bedroom window during the night.
For the present analyses, the equivalent sound levels over 1 or 2 s have been grouped in 30-s intervals and from the equivalent sound levels over 1 or 2 s, equivalent sound levels over 30-s intervals have been calculated. The outdoor equivalent sound level during a 30-s interval is indicated by Leq_o, the indoor equivalent sound level by Leq_i.
Outdoor noise levels have been measured from 35 dB(A). The calculated lowest Leq_o values are therefore 35 dB(A), but a fraction of these 35 dB(A) values would in reality have been lower.
For each 1 or 2 s interval Möhler indicated whether the noise source was present outside at the location or not. From these observations we determined whether during a 30-s interval the noise was present for at least one interval of 1 or 2 s or not. If so, the 30-s interval was marked by bron=1, if not by bron=0.

A noise event starts in a 30-s interval if bron=1 for that interval and bron=0 for the preceding 30-s interval. The 30-s interval during which a noise event starts is marked by start_br=1. The first interval after a noise event has ended is specified by bron=0 for that interval and bron=1 for the preceding interval. The duration of a noise event is defined as the difference in time (in s) between the start of the first interval after a noise event has ended and the start of the 30-s interval with start_br=1.

Table 1.2 gives information about the number and duration of road traffic noise events and table 1.3 about railway traffic noise events. The number of 30-s intervals without road or railway noise (marked by bron=0) is also included.

The tables show that the total number of 30-s intervals during sleep of the 188 subjects exposed to road traffic noise is about 9% larger than those of the 188 subjects exposed to railway traffic noise. The railway traffic data concern 1581 subject nights, and the road traffic data 1710 subject nights, the average number of 30-s intervals during sleep of the railway traffic noise exposed subjects is therefore 787, and of the road traffic noise exposed subjects 791. The average duration of the sleep periods is therefore about the same.
For road traffic noise, the percentage of 30-s intervals with road traffic noise is 53%, for railway traffic noise 17%.
A substantial fraction of the road traffic noise events are more than one hour long: the total number of 30-s intervals within these long duration events is 125 653 (18% of all 30-s intervals with road traffic noise). Only 46 railway noise events are longer than 6 minutes (more than 12 30-s intervals).

Table 1.2 Number and duration of road traffic noise events, and number of 30-s intervals without road traffic noise

| number of 30-s intervals in an event | number of events | total number of 30-s intervals |
|---|---|---|
| 1 | 48115 | 48115 |
| 2 | 62577 | 125154 |
| 3 | 23599 | 70797 |
| 4 | 15298 | 61192 |
| 5 | 8064 | 40320 |
| 6 | 5531 | 33186 |
| 7 | 3504 | 24528 |
| 8 | 2219 | 17752 |
| 9 | 1813 | 16317 |
| 10 | 1270 | 12700 |
| 11 | 978 | 10758 |
| 12 | 688 | 8256 |
| 13 | 640 | 8320 |
| 14 | 506 | 7084 |
| 15 | 376 | 5640 |
| 16 - 30 (0.25 - 0.5 hours) | 2295 | 47282 |
| 31 – 60 (0.5 - 1 hour) | 1135 | 46537 |
| 61 – 90 (1 - 1.5 hours) | 391 | 29287 |
| 91 – 120 (1.5 - 2 hours) | 218 | 22734 |
| 121 – 180 (2 - 3 hours) | 196 | 28538 |
| 181 – 240 (3 - 4 hours) | 109 | 22387 |
| > 240 (> 4 hours) | 79 | 22707 |
| All events | 179601 | 709591 |
| Number of 30-s intervals without noise | | 643056 |
| Total number of 30-s intervals | | 1352647 |

Table 1.3 Number and duration of railway traffic noise events, and number of 30-s intervals without railway traffic noise

| number of 30-s intervals in an event | number of events | total number of 30-s intervals |
|---|---|---|
| 1 | 2818 | 2818 |
| 2 | 22447 | 44894 |
| 3 | 24497 | 73491 |
| 4 | 11953 | 47812 |
| 5 | 3294 | 16470 |
| 6 | 1903 | 11418 |
| 7 | 1183 | 8281 |
| 8 | 315 | 2520 |
| 9 | 192 | 1728 |
| 10 | 38 | 380 |
| 11 | 26 | 286 |
| 12 | 0 | 0 |
| 13 | 5 | 65 |
| 14 | 16 | 224 |
| 15 | 23 | 345 |
| 16 | 2 | 32 |
| All events | 68712 | 210764 |
| Number of 30-s intervals without noise | | 1032837 |
| Total number of 30-s intervals | | 1243601 |

# 2 INSTANTANEOUS EFFECTS

## 2.1 Introduction

The first chapter showed that there is a substantial difference between the road and railway traffic noise data with respect to number and duration of events. None of the railway noise events in the study is longer than 8 minutes, and a large part of the road noise events are substantial longer. Therefore, the analysis of the road traffic noise data is different from the analysis of the railway traffic data. In section 2.2 the data on railway traffic noise are analysed and in section 2.3 the data on road traffic noise.

## 2.2 Railway noise

### 2.2.1 *General analysis*

In this analysis railway noise is considered to consist of separate noise events.

For each event, the number of 30-s intervals with k=1 and the number of 30-s intervals with m=1 was calculated. Table 2.1 shows the number of events with a specified number of 30-s intervals with onset of motility (k=1) and motility (m=1) during the event. The table shows that during 59205 events motility does not start to occur, during 9056 events onset of motility occurs once, and during 451 events two or more times. With respect to motility, during 2821 events motility occurs during two or more 30-s intervals.

Table 2.1 Information about the number of 30-s intervals with onset of motility (k=1) and with motility (m=1) during railway traffic noise events.

| | k | | | m | | |
|---|---|---|---|---|---|---|
| Number of 30-s intervals with k=1 or m=1 | Number of events | Percentage of events | Cumulative percentage of events | Number of events | Percentage of events | Cumulative percentage of events |
| 0 | 59205 | 86.2 | 86.2 | 57862 | 84 | 84 |
| 1 | 9056 | 13.2 | 99.3 | 8029 | 12 | 96 |
| 2 | 436 | 0.63 | 99.98 | 2270 | 3 | 99 |
| 3 | 14 | 0.02 | 100.00 | 421 | 0.61 | 99.81 |
| 4 | | | | 93 | 0.14 | 99.95 |
| 5 | | | | 19 | 0.03 | 99.97 |
| 6 | 1 | 0.00 | 100.00 | 9 | 0.01 | 99.99 |
| 7 | | | | 7 | 0.01 | 100.00 |
| 8 | | | | 1 | 0.00 | 100.00 |
| 9 | | | | 1 | 0.00 | 100.00 |
| Total | 68712 | 100 | | 68712 | 100 | |

To be able to perform a logistic regression analysis, we defined two binary effect measures (k_bin and m_bin) during an event, based on the number of 30-s intervals during an event with (onset of) motility: k_bin=1 if the number of 30-s intervals with k= 1 is at least 1, and k_bin=0 if the number of 30-s intervals with k=1 is 0; m_bin=1 if the number of 30-s intervals with m= 1 is at least 1, and m_bin=0 if the number of 30-s intervals with m=1 is 0.

In the final models k_bin and m_bin are dependent variables, and SEL_o (outdoor SEL value of an event), x (number of the 30-s interval after sleep onset during which an event started), n_30s (number of 30-s intervals in an event), and a dummy for each subject. The logistic regression analyses with SEL_I, Lmax_I or Lmax_o as one of the independent variables instead of SEL_o did not produce a statistical significant coefficients of the noise metrics. The final formula of the model used is as follows:
Probit (z_bin) = constant + b1*SEL_o + b2*x + b3*n_30s + b4*d1 + .... + b191*d188
with:

- z equal to k or m
- probit (z_bin) = lg [prob z_bin/(1-prob z_bin)] with prob z: probability of z
- sum b4 to b191 equal to 0.

The coefficients b1 to b3 are statistically significant for k and m ($P < 0.05$).

A logistic regression analysis has also been performed with k and m of the 30-s intervals without railway noise. The final formula of the model used is as follows:
Probit (z) = constant + b1*x + b2*d1 + .... + b189*d188
with:

- z equal to k or m
- probit (z) = lg [prob z/(1-prob z)] with prob z: probability of z
- sum b2 to b189 equal to 0.

The coefficient b1 is statistically significant for k and m ($P < 0.05$).
The results of the logistic regression analyses with k_bin as dependent variable are given in figure 2.1 for noise events occurring within one or two 30-s intervals and in figure 2.2 for noise events lasting 90 or 120 s. Details about the figures are given in the section after figure 2.1.

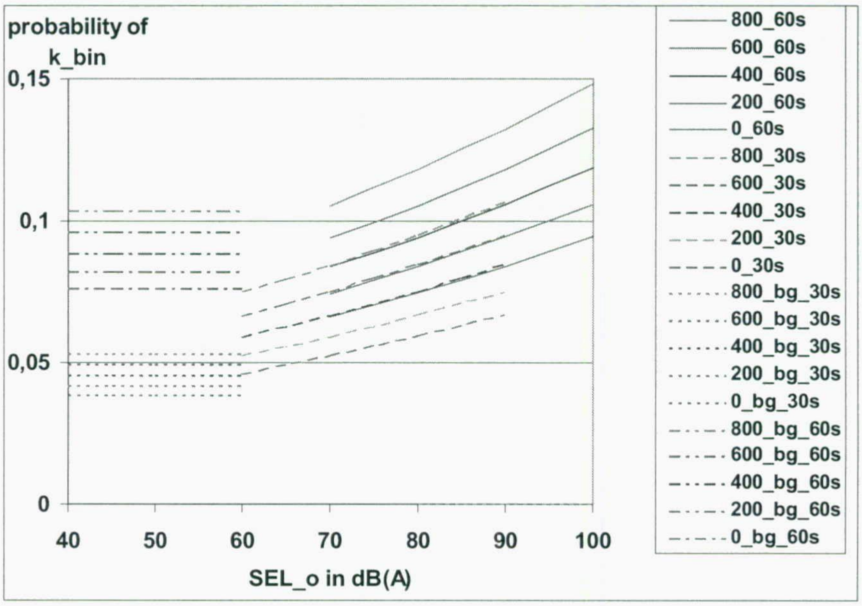

Figure 2.1 Probability of onset of motility (k_bin=1) as a function of SEL_o of railway noise events. The number of the 30-s interval during sleep at which the event starts varies from 0 to 800. The figure relates to event durations of 30 and 60 s. Also included probability of onset of motility in the absence of railway noise during 30-s and 60-s intervals.

Additional information about figure 2.1 and 2.2:

- For 30-s intervals without railway noise, Leq_o varies from 35 dB(A) (lowest measuring value) to 45 dB(A). For an interval of 30-s SEL_o is 14.8 dB(A) higher than Leq_o. Therefore the calculated SEL_o values in the absence of railway noise vary from 50 to 60 dB(A), but in practice it is reasonable to assume that also SEL_o values lower than 50 dB(A) have occurred. Therefore the range of SEL_o values in 30-s intervals without railway noise has been taken as from 40 to 60 dB(A). The data in the figure are indicated by x_bg_30s, with x 0 to 800. x=0 is the start of sleep period, x=800 is 400 minutes after sleep onset (6.7 hours after sleep onset)
- From the probability of onset of motility during 30-s intervals without railway noise, the probability of onset of motility during 60-s, 90-s and 120-s intervals without railway noise have been calculated. The data in the figures are indicated by x_bg_60s, x_bg_90s, and x_bg_120s
- The curves for events with a duration of 30 s have been obtained by substituting n_30s=1 in the logistic regression equation, for events of 60, 90, or 120 s n_30s has been taken as 2, 3, or 4
- The values of SEL_o for railway noise events with a duration of one 30-s interval range from 60 to 90 dB(A) (range from 10 to 90% of the values), and for longer events from 70 to 100 dB(A)
- For an event with duration of 30 or 60 s, the number of 30-s intervals with k= 1 is by definition equal to 0 or 1. By using the formula for probability of onset of motility for 90-s and 120-s intervals, this probability is underestimated since at these intervals the number of 30-s intervals with onset of motility may be 2 in-

stead of 1 or 0, which is assumed when k is taken as a binary outcome. The frequency of the number of 30-s intervals with onset of motility for 90-s duration events is given in table 2.2.

Table 2.2 Information about the sum of k during railway traffic noise events of 90-s duration.

| Number of 30-s intervals with onset of motility | Frequency |
|---|---|
| 0 | 21471 |
| 1 | 2672 |
| 2 | 354 |
| Total | 24497 |

This implies that probability of onset of motility for 90-s intervals is a factor 1.12 (equal to (2672+2*354)/(2672+354)) times higher than obtained from the logistic regression analysis. This factor has been taken into account in the construction of figure 2.3 for onset of probability of motility at 90-s event intervals. For events with 120-s durations the factor is 1.25.

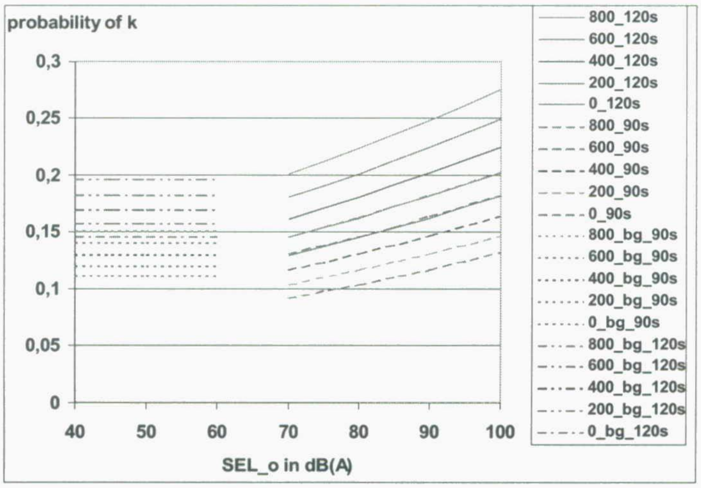

Figure 2.2 Probability of onset of motility (k_bin=1) as a function of SEL_o of railway noise events. The number of the 30-s interval during sleep at which the event starts varies from 0 to 800. The figure relates to event durations of 90 and 120 s.

The results of the logistic regression analyses with m_bin as dependent variable are given in figures 2.3 and 2.4. The information about figures 2.1 and 2.2 also pertain to figures 2.3 and 2.4.

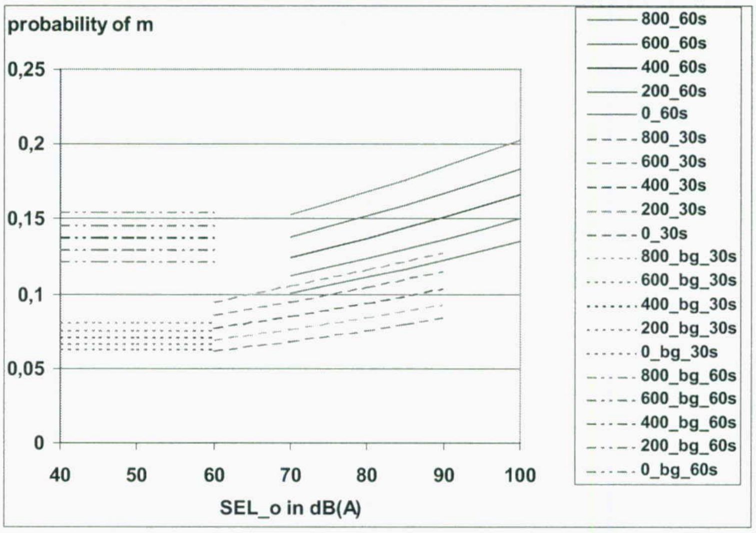

Figure 2.3 Probability of motility as a function of SEL_o of railway noise events. The number of the 30-s interval during sleep at which the event starts varies from 0 to 800. The figure relates to event durations of 30 and 60 s. Also included probability of motility in the absence of railway noise during 30-s and 60-s intervals.

By using the formula for probability of motility for 60-s, 90-s or 120-s intervals, this probability is underestimated since at these intervals during noise events the number of 30-s intervals with motility may be 2, 3 or 4 instead of 1 or 0, which is assumed when m is taken as a binary outcome. The frequency of the number of 30-s intervals with motility for 60-s duration events is given in table 2.3.

Table 2.3 Information about the sum of m during railway traffic noise events of 60-s duration.

| Number of 30-s intervals with motility | Frequency |
|---|---|
| 0 | 19849 |
| 1 | 2133 |
| 2 | 465 |
| Total | 22447 |

This implies that probability of motility for 60-s intervals is a factor 1.18 (equal to (2133+2*465)/(2133+465)) times higher than obtained from the logistic regression analysis. This factor has been taken into account in the construction of figure 2.3 for probability of m at 60-s event intervals. For 90-s and 120-s event durations the factors are equal to 1.54 and 1.81 respectively.

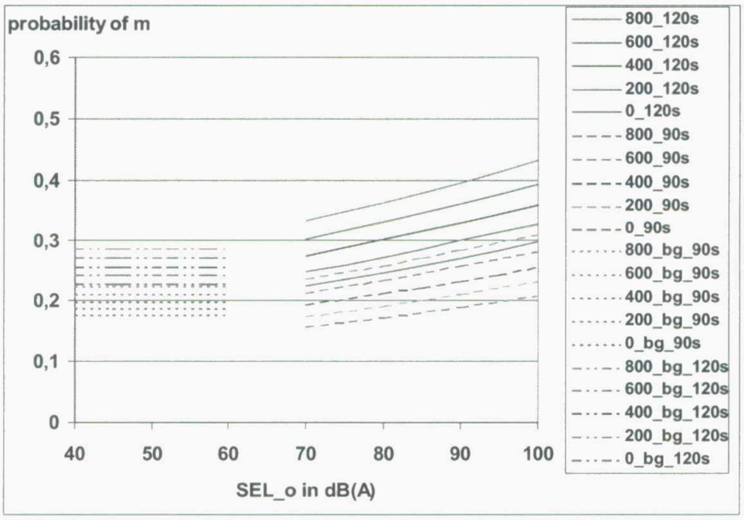

Figure 2.4 Probability of motility as a function of SEL_o of railway noise events. The number of the 30-s interval during sleep at which the event starts varies from 0 to 800. The figure relates to event durations of 90 and 120 s. Also included probability of motility in the absence of railway noise during 90-s and 120-s intervals.

### 2.2.2 *Individual differences in effect measures of motility*

For each of the four models (k_bin and m_bin during railway noise events and in the periods without railway noise) presented in section 2.2, the value of the coefficient of the dummy of each of the 188 subjects is available. These coefficients are here considered as new variables. They are indicated by

- k_noise: the coefficient of a subject dummy variable in the logistic regression analysis based on events, with k_bin as dependent variable
- m_noise: the coefficient of a subject dummy variable in the logistic regression analysis based on events, with m_bin as dependent variable
- k_bg: the coefficient of a subject dummy variable in the logistic regression analysis based on 30-s intervals without railway noise, with k_bin as dependent variable
- m_bg: the coefficient of a subject dummy variable in the logistic regression analysis based on 30-s intervals without railway noise, with m_bin as dependent variable

Each of the four variables has been constructed such that the average of the 188 individual values is 0. The values of the variables can be interpreted as follows. A value of a variable of a subject (e.g. k_noise) is proportional to the relative value of an effect measure of the subject, since 10 to the force of this value is the factor with which the general function prob_x/(1-prob_x) has to be multiplied to obtain prob_x/(1-prob_x) of the subject. If the value is 0, the probability of (onset of) motility is about equal to average (onset of) motility of the subjects. If the value is negative, the probability of (onset of) motility is smaller, and if the value is positive larger than average (onset of) motility of the subjects. Therefore, the lower the coefficient, the smaller are on average the values of the effect measure of a subject. E.g. if the value is +0.5 or –0.5, the effect measure is 1.52, respectively 0.48 times as large as the average values of the effect measure of all subjects.

The correlation between the four variables, based on the 188 individual values, is given in table 2.4.

Table 2.4 Correlation coefficients for the coefficients of the subject dummies obtained from logistic regression analysis with k_bin and m_bin during railway traffic noise events (k_noise and m_noise) and in the absence of railway noise (k_bg and m_bg) as dependent variables.

| | k_noise | k_bg | m_noise | m_bg |
|---|---|---|---|---|
| k_noise | | 0.77 | 0.98 | 0.73 |
| k_bg | 0.77 | | 0.80 | 0.93 |
| m_noise | 0.98 | 0.80 | | 0.80 |
| m_bg | 0.73 | 0.93 | 0.80 | |

There is apparently a very high correlation between k_noise and m_noise (correlation coefficient of 0.98), and a somewhat less but still high correlation between k_bg and m_bg (correlation coefficient 0.93). This is not surprising, since probability of k=1 and probability of m=1 at 30-s intervals are closely related. The correlation coefficients between k_noise and k_bg and between m_noise and m_bg are 0.77 and 0.80 respectively. This implies that subjects with higher (onset of) motility during railway noise events also show higher (onset of) motility in the absence of railway noise.

In each of the graphs in figure 2.5 two variables have been plotted against each other.

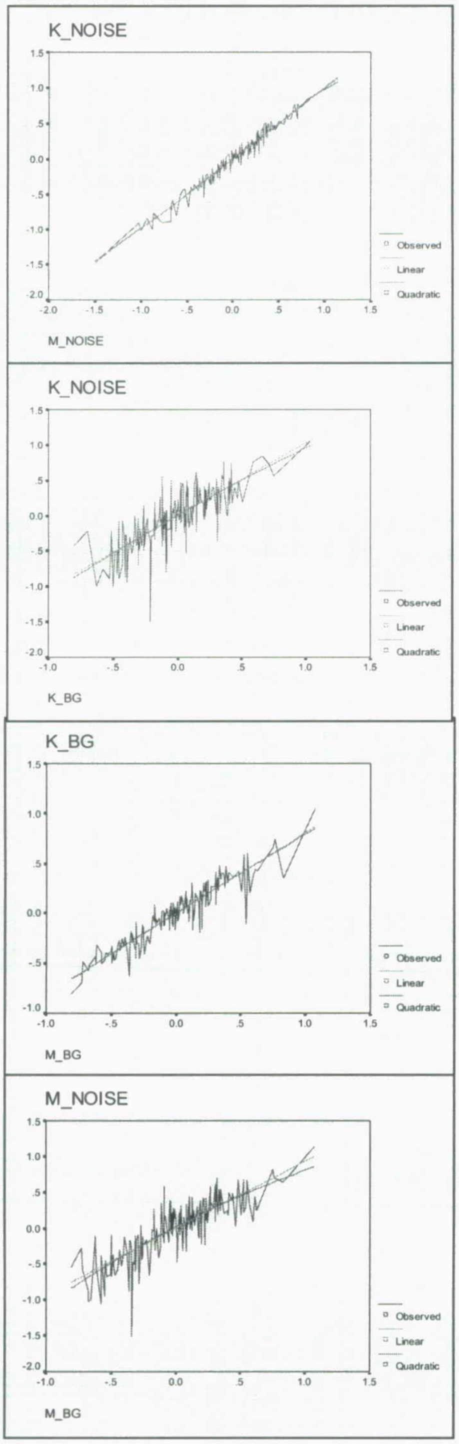

Figure 2.5 Four graphs with the individual values of k_noise, m_noise, k_bg, and m_bg plotted against another individual value.

Whether k_noise, m_noise, k_bg, and m_bg depend upon age (and/or age*age) and gender has been considered in linear regression analyses, with each of these variables as dependent variable and age (and age*age) and in separate analyses gender as independent variables. None of the four variables is statistical significant related to age (or age*age, or a combination of age and age*age). Gender has an important effect upon k_noise and m_noise, as will be shown hereafter.
Regression analyses with Lo or Li, and gender as independent variables, and k_noise and m_noise as dependent variables, showed that k_noise and m_noise are both related to Lo (outdoor equivalent sound level during sleep due to railway noise) and k_noise also to Li. In the cases of k_noise and Lo and of m_noise and Lo, gender is an effect-modifier. The results are given in figure 2.6.

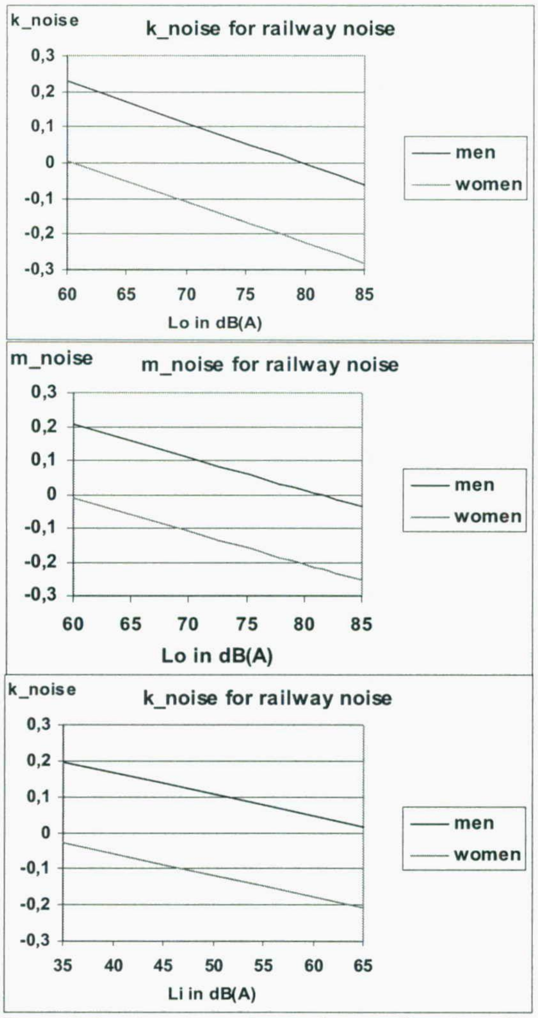

Figure 2.6 k_noise and m_noise as a function of Lo (upper two figures) and k_noise as a function of Li (lowest figure), for male and female subjects.

The figure shows that k_noise and m_noise are larger for men than for women, and decrease with increasing Lo (and in one case with Li). This is in line with the observations on aircraft noise.
Regression analyses with Lo or Li, and gender as independent variables, and k_bg and m_bg as dependent variables, showed no statistical significant relationships with Lo or Li. Also with respect to k_bg and m_bg, the coefficients of female subjects are on average smaller than those of male subjects

### 2.2.3 *Instantaneous probability of (onset of) motility and average values during sleep*

The total number of 30-s intervals with onset of motility due to railway noise exposure has been estimated from the results underlying figure 2.2. This number is about 830 for all subject nights. The number of 30-s intervals with onset of motility of all subjects nights is equal to 59294 during 1243601 30-s intervals, which implies an average probability of onset of motility during a 30-s interval of 0.0477. The contribution of railway noise to this average value is 0.0007, i.e a change in the last digit.
The total number of 30-s intervals with motility due to railway noise exposure has been estimated as 885 for all subject nights. The number of 30-s intervals with onset of motility of all subjects nights is equal to 86060 during 1243601 30-s intervals, which implies an average probability of motility of 0 .0692. The contribution of railway noise to this average value is 0.0007, i.e a change in the last digit.
Therefore, the instantaneous increase in (onset of) motility due to railway noise exposure contributes only slightly, and statistically not significant, to the average (onset of) motility during sleep.

## 2.3 Road traffic noise

### 2.3.1 *General analyses*

For each road noise event the number of 30-s intervals with (onset of) motility was calculated. Table 2.5 gives the number of events having a specified number of 30-s intervals with (onset of) motility. The table shows that during 155656 events motility does not start to occur and that during 23945 events onset of motility occurs at least once. For motility these numbers are 152314 and 27287 respectively. In about 200 and 400 events onset of motility and motility occurs ten times or more. Taking into account that for a considerable number of events (onset of) motility does occur more than once, it does not seem to be appropriate to define binary values of k and of m during an event, as we did with railway noise events.

Table 2.5 Information about the number of 30-s intervals with (onset of) motility during road traffic noise events.

| | k | | | m | | |
|---|---|---|---|---|---|---|
| Number of 30-s intervals with (onset of) motility | Number of events | Percentage of events | Cumulative percentage of events | Number of events | Percentage of events | Cumulative percentage of events |
| 0 | 155656 | 86,67 | 86,67 | 152314 | 84,81 | 84,81 |
| 1 | 20566 | 11,45 | 98,12 | 18991 | 10,57 | 95,38 |
| 2 | 1909 | 1,06 | 99,18 | 5175 | 2,88 | 98,26 |
| 3 | 514 | 0,29 | 99,47 | 1362 | 0,76 | 99,02 |
| 4 | 273 | 0,15 | 99,62 | 605 | 0,34 | 99,36 |
| 5 | 157 | 0,09 | 99,71 | 315 | 0,18 | 99,53 |
| 6 | 113 | 0,06 | 99,77 | 171 | 0,10 | 99,63 |
| 7 | 88 | 0,05 | 99,82 | 112 | 0,06 | 99,69 |
| 8 | 64 | 0,04 | 99,85 | 85 | 0,05 | 99,74 |
| 9 | 59 | 0,03 | 99,89 | 79 | 0,04 | 99,78 |
| 10 through 19 | 169 | 0,09 | 99,98 | 295 | 0,16 | 99,95 |
| 20 through 29 | 28 | 0,02 | 100,00 | 63 | 0,04 | 99,98 |
| 30 through 49 | 5 | 0,00 | 100,00 | 28 | 0,02 | 100,00 |
| 50 and over | | | | 6 | 0,00 | 100,00 |
| Total | 179601 | | | 179601 | | |

Other methods than logistic regression analysis to analyse the road traffic data are:

- By considering road traffic noise as noise events, by considering the 30-s adjacent 30-s intervals during which road traffic noise occurs as an entity. Aggregated effect measures for these events could be the number of 30-s intervals with (onset of) motility, and the average probability of (onset of) motility for a 30-s interval of an event. The statistical method to specify exposure-effect relationships would be a regression analysis by using the method of least squares
- By considering the 30-s intervals during which road traffic noise occurs as separate data. The statistical method to be used would be a logistic regression analysis.

Only the second type of analysis showed one statistical significant meaningful result. This result relates to the probability of motility as a function of Leq_o. Other models (probability of motility as a function of Leq_i, probability of onset of motility as a function of Leq_o and Leq_i) did not show that these probabilities increase statistical significant with the equivalent sound level during a 30-s interval. The result of the analysis is given in figure 2.7. In the logistic regression model, probability of motility has been taken as dependent variable, and Leq_o, x (number of 30-s interval after sleep onset), and start_br (a dummy with value equal to 1 if the 30-s interval is the first 30-s interval of a noise event) as independent variables. Also for each subject a dummy variable has been included in the model.

A logistic regression analysis has also been performed on the basis of the 30-s intervals without road traffic noise, with x as independent variable, and in addition the number of the 30-s interval of the consecutive 30-s intervals during which road traffic noise was absent (n_bg). Also for each subject a dummy variable has been included in the model. n_bg has been included in the model because it was assumed that the longer the duration of absence of road traffic noise, i.e. the longer the 'quiet period', the lower the probability of motility. The analysis showed the reverse. The longer the duration of 'quiet' between road traffic noise events, the higher the probability of motility, provided x (time since onset of sleep) and subject was taken into account. Results of the analysis are given in figure 2.8. Additional information about the periods without road traffic noise is given in table 2.6.

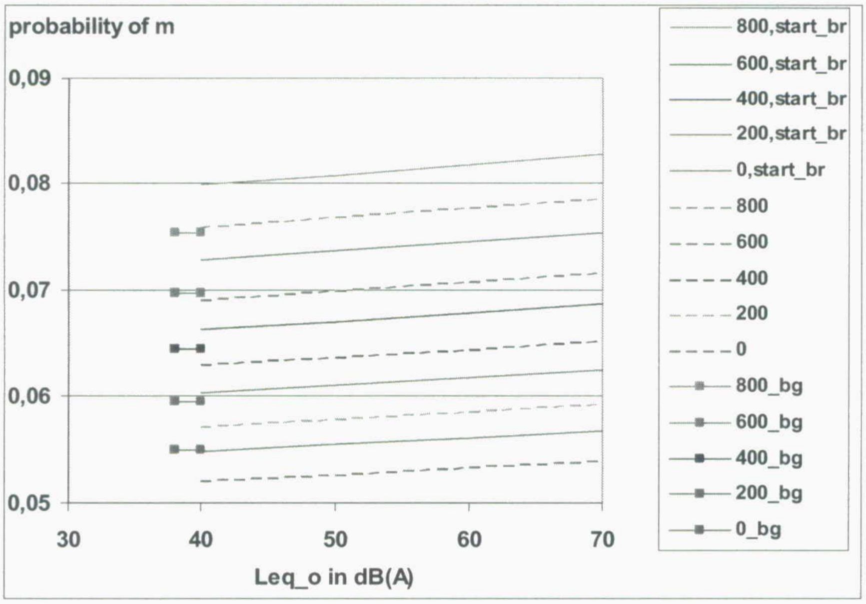

Figure 2.7 Probability of motility as a function of Leq_o of 30-s intervals with road traffic noise. The number of the 30-s interval (x) during sleep varies from 0 to 800. Curves indicated by start_br relate to the first 30-s interval of a road traffic noise event. The figure also includes probability of motility in a 30-s interval without road traffic noise for the mean duration of the periods without road traffic noise of 1.8 minutes; these values are indicated by x_bg.

Additional information about figure 2.7:

- For 30-s intervals without road traffic noise, Leq_o varies from 38 dB(A) to 40 dB(A) (10 to 90% values). For 30-s intervals with road traffic noise, Leq_o varies from 41 to 63 (10 to 90% values), with a minimum of 38 dB(A) and a maximum of 91 dB(A).

Table 2.6 Frequency and (cumulative) percentage of number of consecutive 30-s intervals without road traffic noise (left side of the table) and the frequency and (cumulative) distribution of the number of 30-s intervals included in the intervals without road traffic noise

| | intervals without road traffic noise | | | 30-s intervals without road traffic noise | | |
|---|---|---|---|---|---|---|
| Number of consecutive 30-s intervals without road traffic | number | percentage | cumulative percentage | number | cumulative number | cumulative percentage |
| 1 | 62723 | 35,12 | 35,12 | 62723 | 62723 | 9,75 |
| 2 | 35394 | 19,82 | 54,94 | 70788 | 133511 | 20,76 |
| 3 | 22163 | 12,41 | 67,35 | 66489 | 200000 | 31,10 |
| 4 | 15504 | 8,68 | 76,03 | 62016 | 262016 | 40,75 |
| 5 | 10437 | 5,84 | 81,87 | 52185 | 314201 | 48,86 |
| 6 | 6898 | 3,86 | 85,73 | 41388 | 355589 | 55,30 |
| 7 | 5326 | 2,98 | 88,72 | 37282 | 392871 | 61,09 |
| 8 | 4353 | 2,44 | 91,15 | 34824 | 427695 | 66,51 |
| 9 | 3305 | 1,85 | 93,00 | 29745 | 457440 | 71,14 |
| 10 | 2918 | 1,63 | 94,64 | 29180 | 486620 | 75,67 |
| 11 through 20 | 8243 | 4,62 | 99,25 | 112985 | 599605 | 93,24 |
| 21 through 40 | 1228 | 0,69 | 99,94 | 32300 | 631905 | 98,27 |
| 41 through 80 | 62 | 0,03 | 99,98 | 3130 | 635035 | 98,75 |
| 81 through 160 | 17 | 0,01 | 99,99 | 1997 | 637032 | 99,06 |
| over 160 | 25 | 0,01 | 100,00 | 6024 | 643056 | 100,00 |

Table 2.6 shows that 94.6% of the intervals without road traffic noise last at most 300 s. These intervals include 75.7% of all 30-s intervals. The mean duration of intervals without road traffic noise is 3.6 30-s intervals (1.8 minutes).

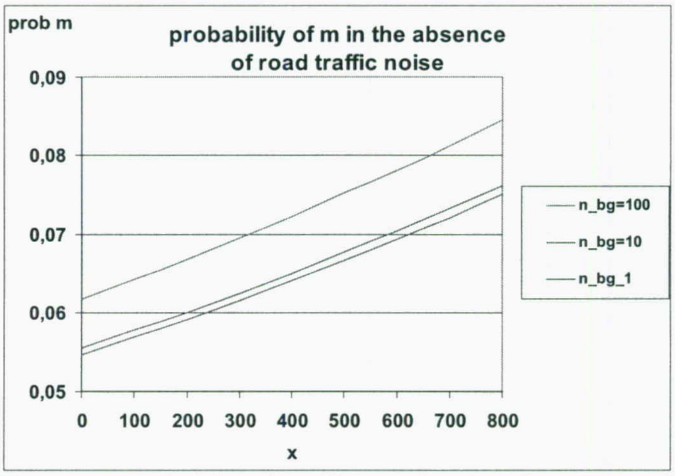

Figure 2.8 Probability of motility as a function of x (number of 30-s after sleep onset) for 30-s intervals without road traffic noise for three numbers of adjacent 30-s intervals without road traffic noise: 1, 10 and 100 30-s intervals.

### 2.3.2 *Individual differences in motility*

The analysis in section 2.3.1 provides for two sets of coefficients of dummies of the 188 subjects. These two variables are indicated by:

- m_noise: the coefficient of a subject dummy variable in the regression analysis based on 30-s intervals with road traffic noise
- m_bg: the coefficient of a subject dummy variable in the regression analysis based on 30-s intervals without road traffic noise.

The two variables have been constructed such that the sum of the 188 individual values is 0. It has been explained in section 2.2.2 that the lower the value of m_noise or m_bg of a subject, the smaller the probability of motility of that subject is.

The correlation between the two coefficients is 0.97. In figure 2.9 the two values of the 188 subjects have been plotted against each other.

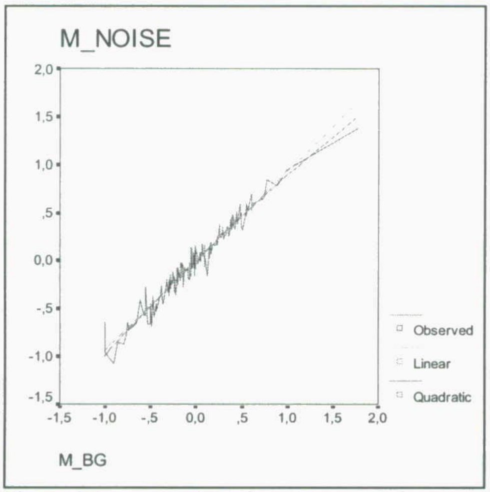

Figure 2.9 m_noise of a subject as a function of m_bg of the subject.

Whether m_noise and m_bg are dependent upon age (and age*age) and gender has been considered in a linear regression analysis, with m_noise and m_bg separately as dependent variable, and age (and age*age) and in separate analyses gender as independent variables. The coefficients are related to gender and age (and age*age). Regression analyses with Lo or Li, and the coefficients of the dummies as dependent variables, showed that the coefficients are both related to Lo (outdoor equivalent sound level during sleep due to road traffic noise). The final result, in which Lo, age (and age*age), and gender are independent variables, is given in figure 2.10.

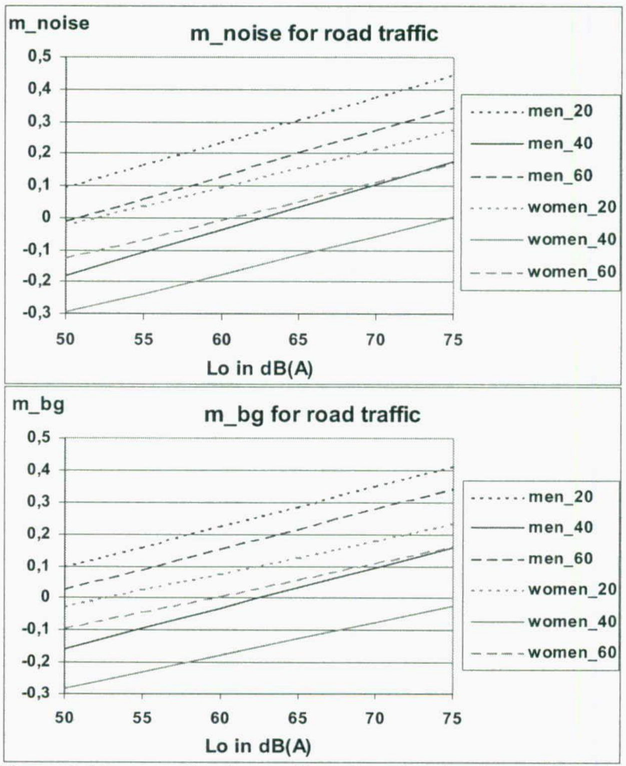

Figure 2.10 m_noise (upper figure) and m_bg (lower figure) for road traffic noise as a function of Lo, for male and female subjects, aged 20, 60, and 40 years (the age at which m_noise and m_bg are smallest).

m_noise and m_bg are larger for men than for women. This is in agreement with the results about railway noise in this report and the results from the aircraft noise study. Also, m_noise and m_bg are functions of age (and age*age) and minimal at an age of 40 years. For railway noise there appeared to be no dependency on age of the probability of (onset of) motility. In the aircraft noise study, noise-induced increase in probability of (onset of) motility and probability of (onset of) probability showed the same dependency of age and age*age as the present observations about road traffic noise.

Apparently, m_noise and m_bg increase with Lo. For railway noise it turned out that m_noise decreases with Lo (in line with the observations for aircraft noise) and that m_bg is independent of Lo. For aircraft noise it has been shown that m_bg is an increasing function of Li.

## 2.4 Discussion

# 3 MOTILITY DURING A SLEEP PERIOD TIME

## 3.1 Introduction

In this chapter the results of the analyses based on the average values of (onset of) motility over a sleep period time are presented. In section 3.2 the results for road traffic noise and in section 3.3 the results for railway traffic noise are given.
Multi-variate linear regression analyses according to the method of least squares have been carried out. The following road and railway noise exposure variables have been considered:

- Lispt: indoor equivalent sound level during sleep period time of a subject
- Lospt; outdoor equivalent sound level during sleep period time of a subject.

The following effect variables have been used in the analyses:

- mspt: average value of probability of motility in a 30-s interval during a sleep period time
- kspt: average value of probability of onset of motility during a sleep period time.

It has been considered whether age (and age*age) and gender have an effect on the relationships.

The equation of the relationship between an effect variable y (mspt or kspt), a road or railway noise exposure metric L (Lispt or Lospt) and age, age*age, and dummy for gender is given by:

$$y = \text{constant} + b1*L + b2*\text{age} + b3*\text{age}*\text{age} + b4*\text{dummy\_gender}$$

If b3 is negative, the function b2*age + b3*age*age has a maximum, if b3 is positive, this function has a minimum.
The analyses consisted of the following steps:

1. Each of the effect variables mspt or kspt, has been used in a linear regression analysis with Lispt and Lospt as independent variables. For the relationship obtained it has been considered whether the coefficient of the effect variable was statistical significant ($P < 0.05$) and in accordance with the model in which mspt or kspt increase with increasing noise exposure
2. For statistical significant relationships age, age*age and gender have been added as independent variables. The final results include age, age*age and gender if they have a statistical significant coefficient.

## 3.2 Road traffic noise

The results are given in the figures 3.1 to 3.4. For each of the four relationships, age, age*age, and gender have statistical significant coefficients.

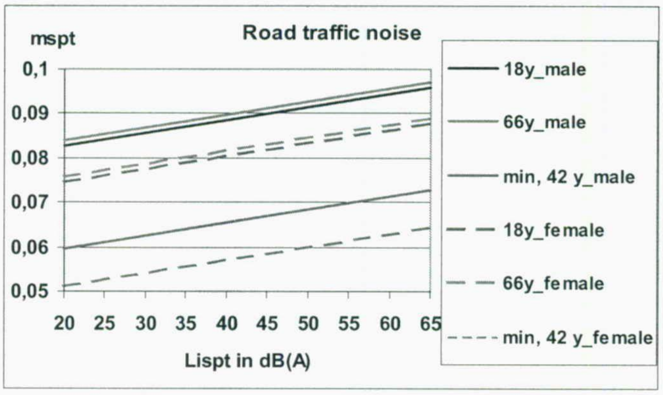

Figure 3.1 mspt as a function of Lispt of road traffic noise, for male and female subjects, aged 18, 66, and 42 years (the age at which mspt is smallest).

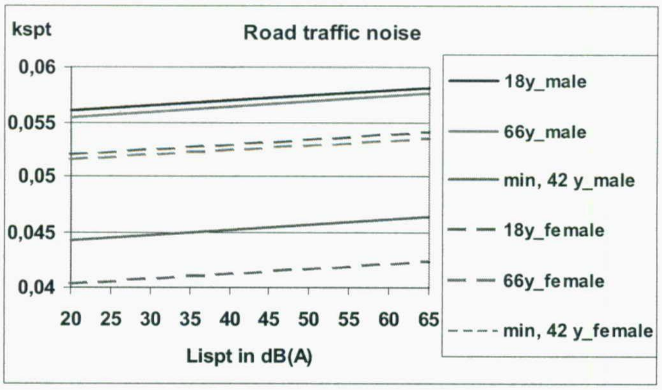

Figure 3.2 kspt as a function of Lispt of road traffic noise, for male and female subjects, aged 18, 66, and 42 years (the age at which kspt is smallest).

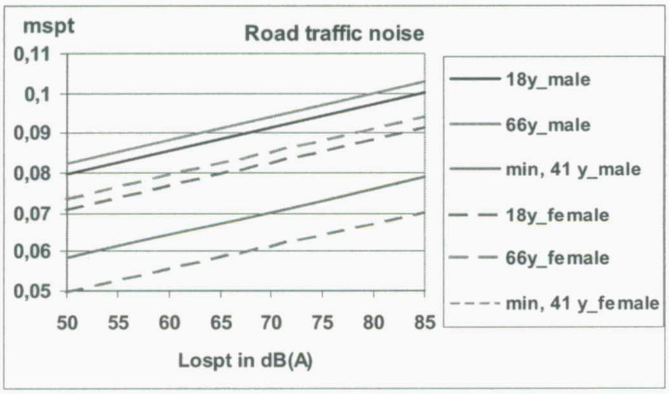

Figure 3.3 mspt as a function of Lospt of road traffic noise, for male and female subjects, aged 18, 66, and 41 years (the age at which mspt is smallest).

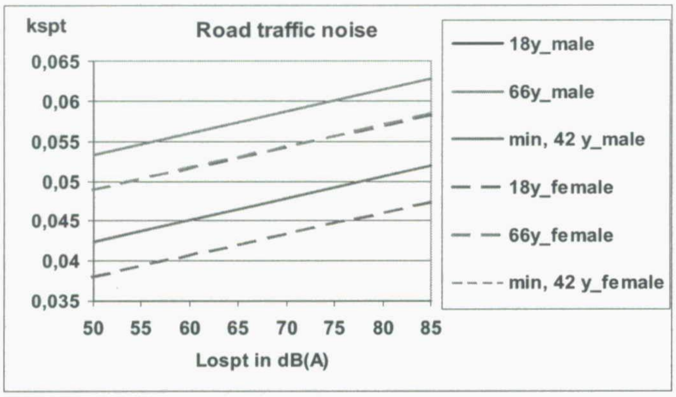

Figure 3.4 kspt as a function of Lospt of road traffic noise, for male and female subjects, aged 18, 66, and 42 years (the age at which kspt is smallest).

## 3.3 Railway traffic noise

For none of the four relationships the coefficient of the railway noise metric is statistically significant.

## 3.4 Comparison with aircraft noise

In the figures 3.5 and 3.6 the average values of the probability of (onset of) motility in a 30-s interval (mspt and kspt) obtained for aircraft noise exposure during sleep are given.

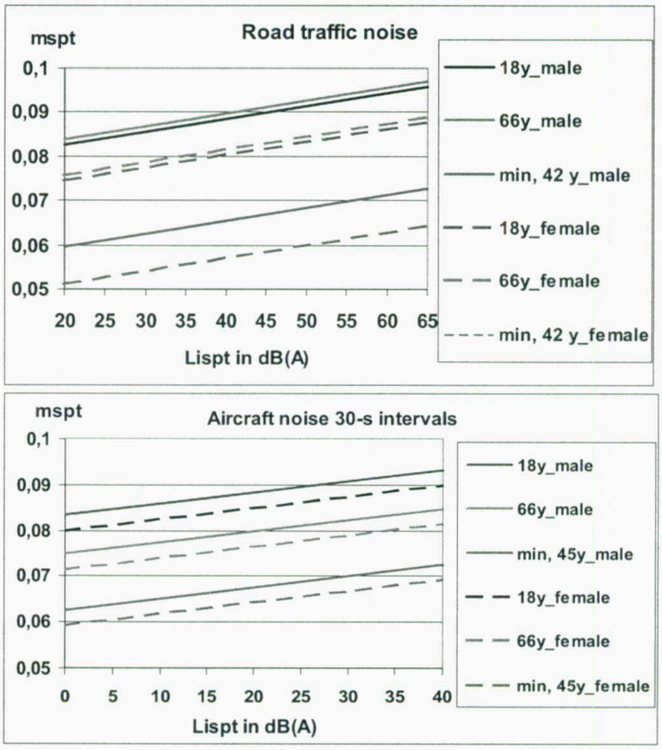

Figure 3.5 Average probability of motility (m) during 30-s intervals of a sleep period time as a function of Lispt of road traffic noise (upper figure) and Lispt of aircraft noise (lower figure) for 18 and 66 years, and the age at which prob_m is minimal.

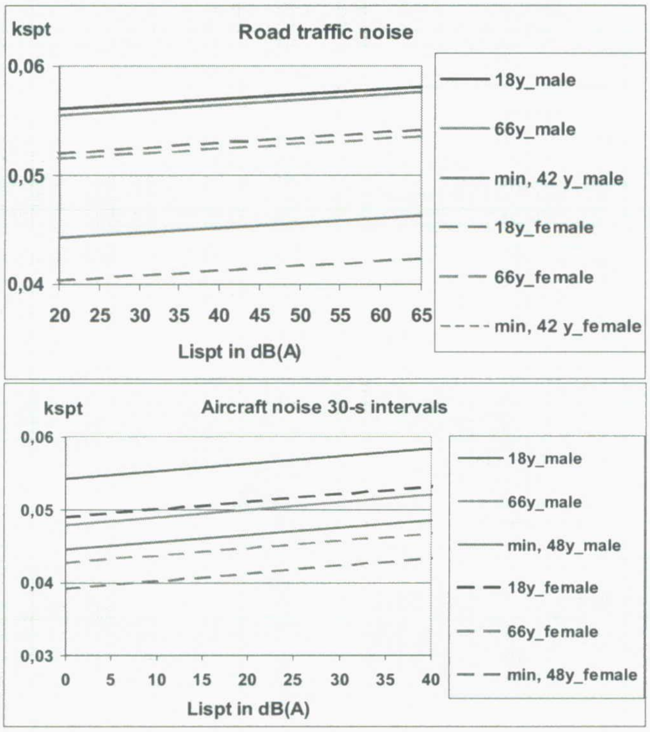

Figure 3.6 Average probability of motility (m) during 30-s intervals of a sleep period time as a function of Lispt of road traffic noise (upper figure) and Lispt of aircraft noise (lower figure) for 18 and 66 years, and the age at which m is minimal.

## 3.5 Discussion and conclusion

The results will be discussed in chapter 5.

# 4 EFFECTS AGGREGATED OVER ALL STUDY NIGHTS

## 4.1 Introduction

In this chapter the results of the analyses based on the average values of (onset of) motility over all sleep period times are presented. In section 4.2 the results for road traffic noise and in section 4.3 the results for railway traffic noise are given. In section 4.4 the results for road traffic noise and rail traffic noise are compared and a comparison is given with the results for aircraft noise.

Multi-variate linear regression analyses according to the method of least squares have been carried out.
The following road and railway noise exposure variables have been considered:
- Li: indoor equivalent sound level during all sleep period times of a subject
- Lo: outdoor equivalent sound level during all sleep period times of a subject.

The following effect variables have been used in the analyses:
- prob_m during spt: average probability of motility in a 30-s interval during all sleep period times
- prob_k during spt: average probability of onset of motility in a 30-s interval during all sleep period times
- prob_m during noise: average probability of motility in the 30-s intervals with road traffic (or railway) noise during all sleep period times
- prob_k during noise: average probability of onset of motility in the 30-s intervals with road traffic (or railway) noise during all sleep period times
- prob_m during background: average probability of motility in the 30-s intervals without road traffic (or railway) noise during all sleep period times
- prob_k during background: average probability of onset of motility in the 30-s intervals without road traffic (or railway) noise during all sleep period times.

For age (and age*age) and gender it has been considered whether they have an effect on the relationships.

The equation of the relationship between an effect variable y, a road or railway noise exposure metric L (Li or Lo) and the possible determinants age, age*age, and dummy for gender is given by:

$$y = \text{constant} + b1*L + b2*\text{age} + b3*\text{age}*\text{age} + b4*\text{dummy\_gender}$$

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

The analyses consisted of the following steps:
1. Each of the six effect variables has been used as dependent variable in a linear regression analysis with Li and Lo as independent variables. For the relationship obtained it has been considered whether the coefficient of the effect vari-

able was statistical significant ($P < 0.05$) and in accordance with the model in which prob_m or prob_k increase with increasing noise exposure

2. For statistical significant relationships age, age*age and gender have been added as independent variables. The final results include age, age*age and gender if they have a statistical significant coefficient.

## 4.2 Road traffic noise

The three dependent variables based on motility are statistically significant related to Li and Lo. Age, age*age, and gender have an effect on the relationships. The three dependent variables based on onset of motility are statistically significant related to Lo, but not to Li. Age, age*age, and gender have an effect on the relationships with Lo. The results are given in table 4.1 and illustrated in the figures 4.1 to 4.8. In figure 4.9 and 4.10 the results with Lo as independent variable and prob_m or prob_k for 30-s intervals during spt, noise, and background are given. It turns out that prob_m and prob_k during the 30-s intervals without road traffic noise are larger than during the 30-s intervals with road traffic noise.

Table 4.1 Coefficients of the independent variables in the regression models with the average value of m and k during all 30-s intervals during sleep, during the 30-s intervals with road traffic noise, and during the 30-s intervals without road traffic noise. Only the 9 equations (out of 12) with statistical significant coefficients of Li or Lo are shown.

| | coefficient | | coefficient | | |
|---|---|---|---|---|---|
| m during sleep | | m during 30-s intervals with noise | | m during 30-s intervals without noise | |
| Constant | 0.09234 | Constant | 0.101 | Constant | 0.07611 |
| Lo | 0.000651 | Lo | 0.000544 | Lo | 0.000886 |
| age | -0.00327 | age | -0.0034 | age | -0.00316 |
| age*age | 0.0000396 | age*age | 0.0000406 | age*age | 0.0000394 |
| gender | -0.00876 | gender | -0.00834 | gender | -0.00985 |
| m during sleep | | m during 30-s intervals with noise | | m during 30-s intervals without noise | |
| Constant | 0.121 | Constant | 0.132 | Constant | 0.11 |
| Li | 0.000379 | Li | 0.000812 | Li | 0.000633 |
| age | -0.00341 | age | -0.00343 | age | -0.00332 |
| age*age | 0.0000408 | age*age | 0.000410 | age*age | 0.0000407 |
| gender | -0.00818 | gender | -0.00792 | gender | -0.0093 |
| k during sleep | | k during 30-s with noise | | k during 30-s intervals without noise | |
| Constant | 0.06014 | Constant | 0.06391 | Constant | 0.05385 |
| Lo | 0.000298 | Lo | 0.000277 | Lo | 0.000349 |
| age | -0.00158 | age | -0.00172 | age | -0.00142 |
| age*age | 0.0000188 | age*age | 0.0000203 | age*age | 0.0000171 |
| gender | -0.00428 | gender | -0.00405 | gender | -0.00451 |

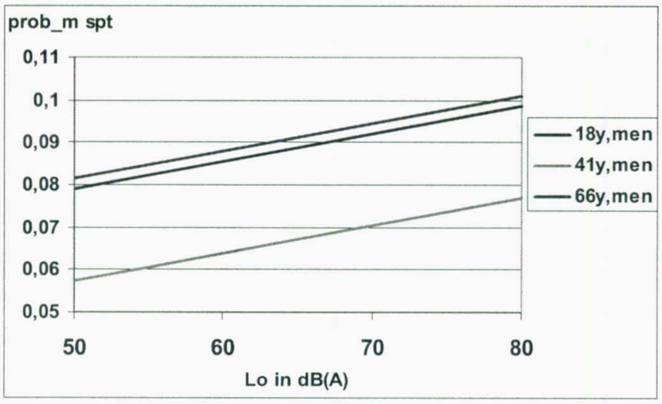

Figure 4.1 Average probability of motility (m) during sleep period times as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which m is minimal. The figure refers to male subjects. For female subjects straight lines are somewhat lower (see table 4.1 and figure 4.2 for an example).

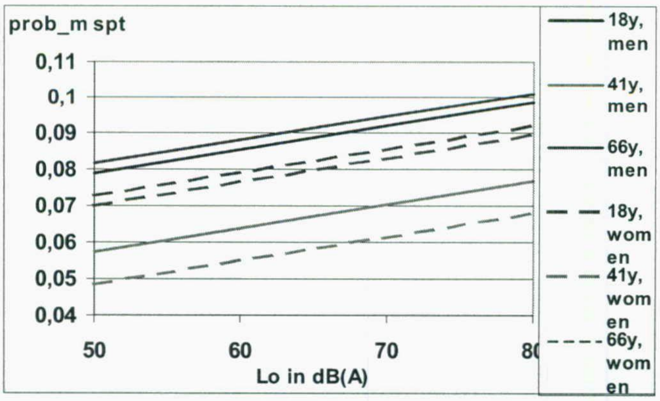

Figure 4.2 Average probability of motility (m) during sleep period times as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which m is minimal. Uninterrupted straight lines refer to male subjects, broken lines to female subjects.

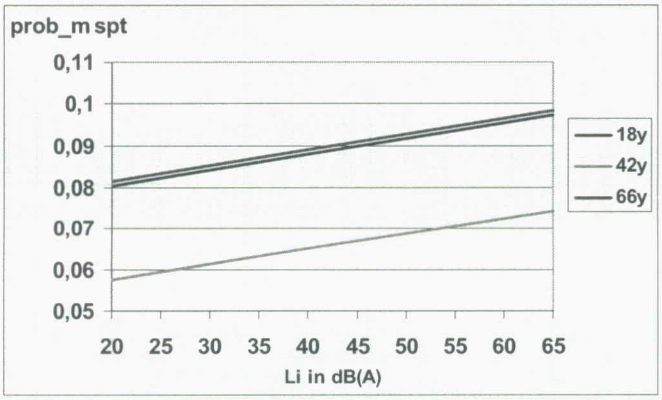

Figure 4.3 Average probability of motility (m) during sleep period times as a function of indoor equivalent sound level of road traffic noise during sleep period times (Li) for 18 and 66 years, and the age at which m is minimal. Figure refers to male subjects. For female subjects straight lines are somewhat lower (see table 4.1 and figure 4.2 for an example).

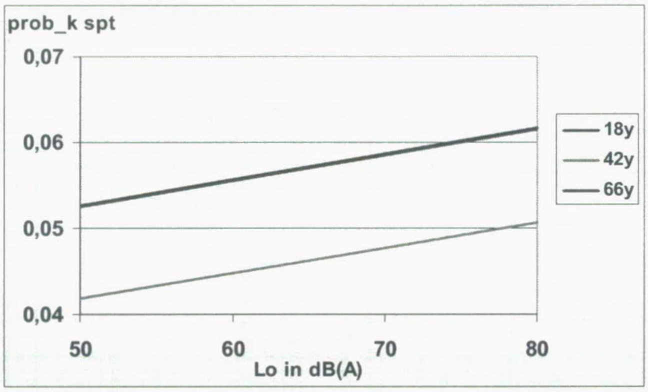

Figure 4.4 Average probability of onset of motility during 30-s intervals of sleep period time as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which prob_k is minimal. Figure refers to male subjects. For female subjects straight lines are somewhat lower (see table 4.1 and figure 4.2 for an example).

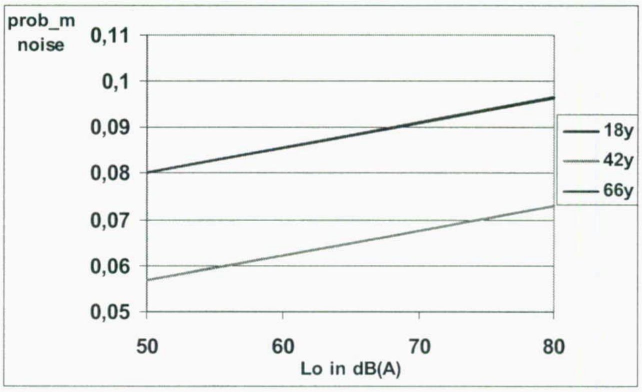

Figure 4.5 Average probability of motility (m) during 30-s intervals with road traffic noise during sleep period times as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which m is minimal. Figure refers to male subjects. For female subjects straight lines are somewhat lower (see table 4.1 and figure 4.2 for an example).

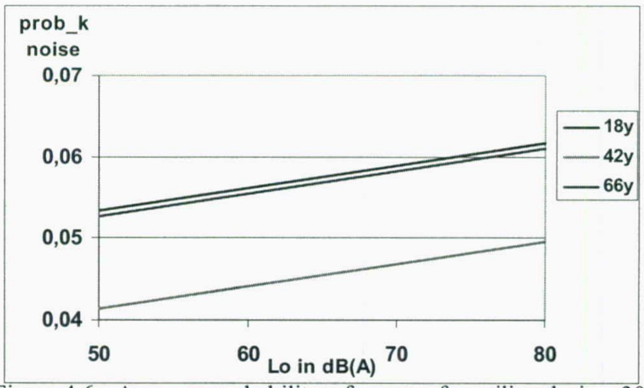

Figure 4.6 Average probability of onset of motility during 30-s intervals with road traffic noise during sleep period times as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which k is minimal. Figure refers to male subjects. For female subjects straight lines are somewhat lower (see table 4.1 and figure 4.2 for an example).

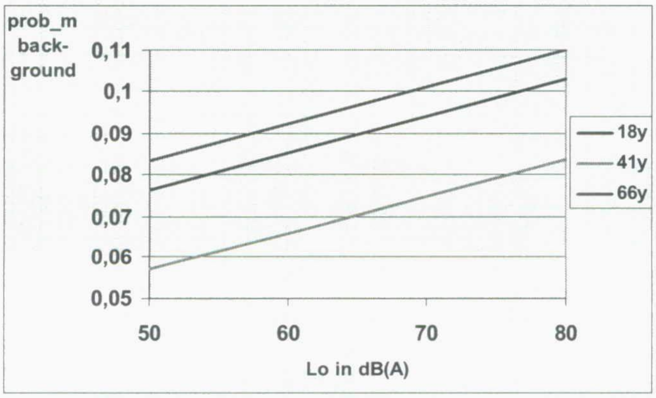

Figure 4.7 Average probability of motility (m) during 30-s intervals without road traffic noise during sleep period times as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which m is minimal. Figure refers to male subjects. For female subjects straight lines are somewhat lower (see table 4.1 and figure 4.2 for an example).

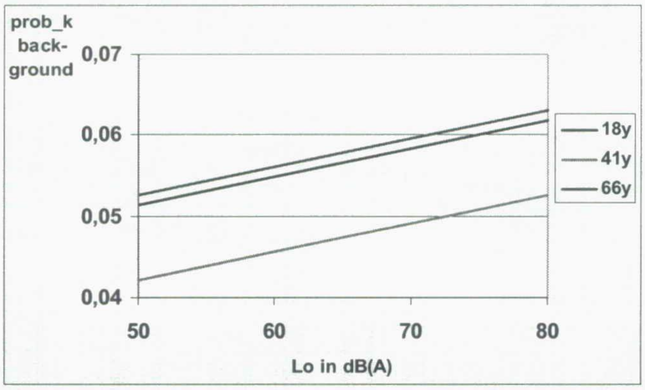

Figure 4.8 Average probability of onset of motilty during 30-s intervals without road traffic noise during sleep period times as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which k is minimal. Figure refers to male subjects. For female subjects straight lines are somewhat lower (see table 4.1 and figure 4.2 for an example).

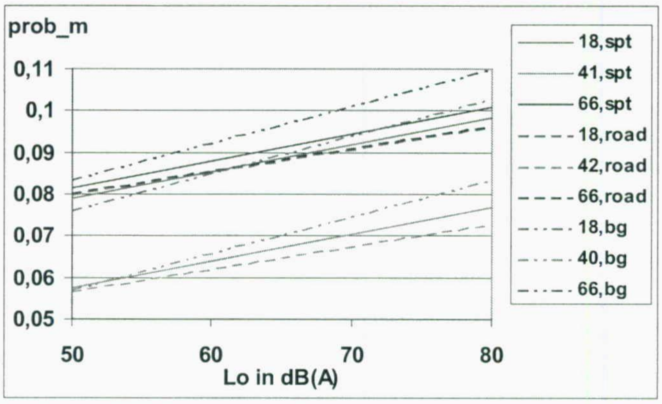

Figure 4.9 Average probability of motility (m) during 30-s intervals during sleep period times (spt), during 30-s intervals with road traffic noise (road), and during 30-s intervals without road traffic noise (bg) as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which m is minimal. Figure refers to male subjects. For female subjects straight lines are somewhat lower (see table 4.1 and figure 4.2 for an example).

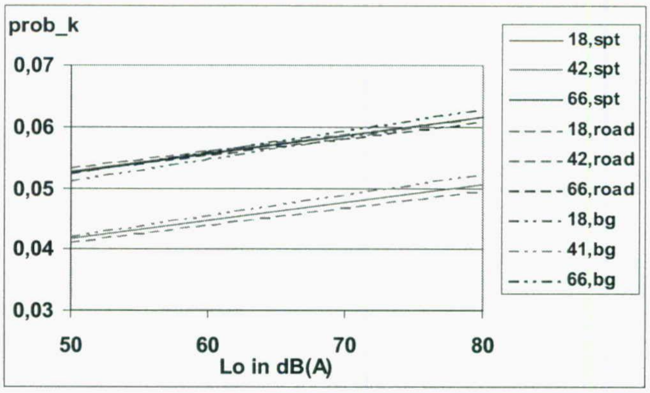

Figure 4.10 Average probability of onset of motility (k) during 30-s intervals during sleep period times (spt), during 30-s intervals with road traffic noise (road), and during 30-s intervals without road traffic noise (bg) as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which m is minimal. Figure refers to male subjects. For female subjects straight lines are somewhat lower (see table 4.1 and figure 4.2 for an example).

## 4.3 Railway traffic noise

None of the relationships between the dependent and independent variables given in section 4.1 have statistical significant coefficients of the railway noise variables. Also, prob_m and prob_k are independent of age. They are, however, dependent on gender.

## 4.4 Comparison road traffic noise and railway traffic noise

In the figures 4.11 and 4.12 prob_m and prob_k during all sleep period times for road traffic noise and railway traffic noise are given.

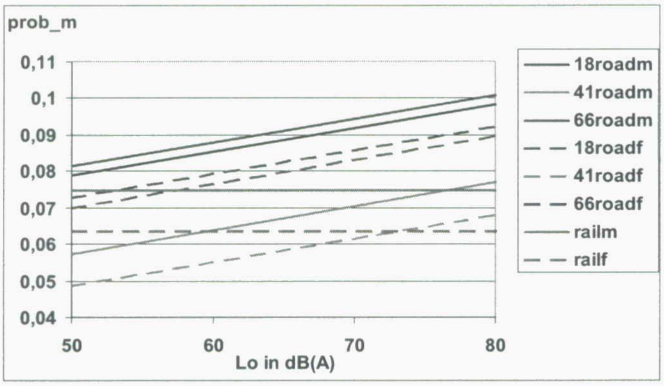

Figure 4.11 Probability of motility during 30-s intervals during sleep period times for male and female subjects as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which probability of motility is minimal. Also given probability of motility for the subjects exposed to railway noise.

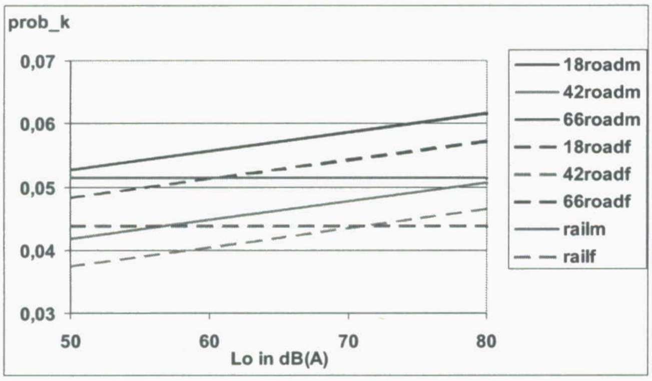

Figure 4.12 Probability of onset of motility during 30-s intervals during all sleep period times for male and female subjects as a function of outdoor equivalent sound level of road traffic noise during sleep period times (Lo) for 18 and 66 years, and the age at which probability of motility is minimal. Also given probability of onset of motility for the subjects exposed to railway noise (m = male, f= female).

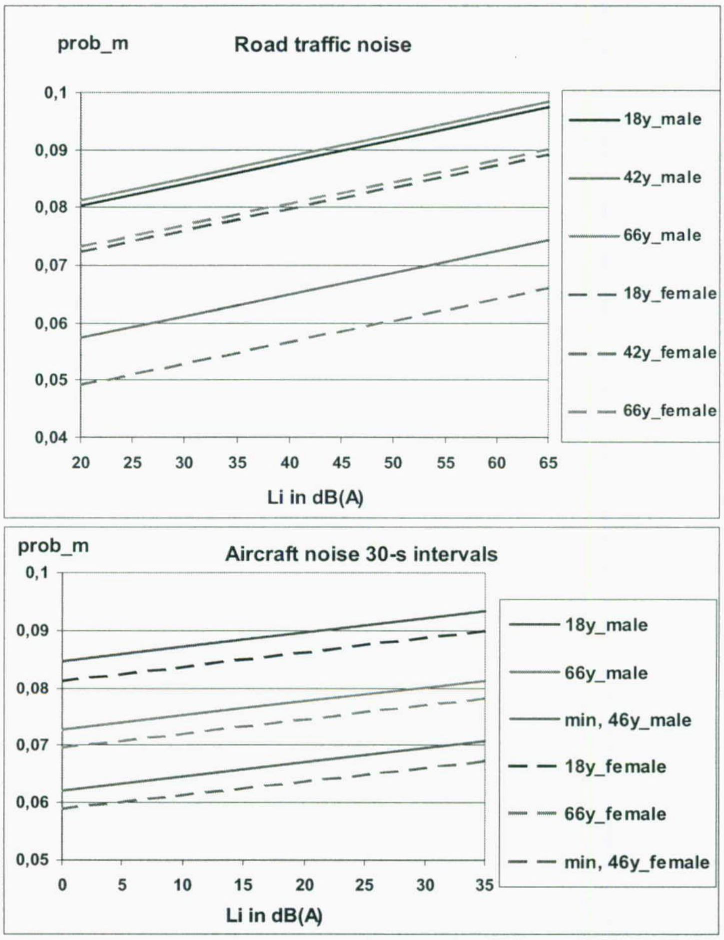

Figure 4.13 Average probability of motility (m) during 30-s intervals of all sleep period times as a function of Li of road traffic noise (upper figure) and Li of aircraft noise (lower figure) for 18 and 66 years, and the age at which prob_m is minimal.

# 5 DISCUSSION AND CONCLUSION

Ergens:
In figure 4.9 and 4.10 the results with Lo as independent variable and prob_m or prob_k for 30-s intervals during spt, noise, and background are given. It turns out that prob_m and prob_k during the 30-s intervals without road traffic noise are larger than during the 30-s intervals with road traffic noise. Since prob_m and prob_k are highly dependent on the time after sleep onset, this result can be explained if the 30-s intervals without noise are on average later after sleep onset than the 30-s intervals with road traffic noise.

# 6 VARIABLES USED IN THE ANALYSES

Table 5.1

| | Label of variable | Description variable |
|---|---|---|
| General | respnr | Number of subject |
| General | ort | Location |
| General | night | Number of night of participation (1 – 10) |
| General | spt | Sleep period time (in s) |
| General | sleep_start | Time at which a subject falls asleep |
| General | source | Source=1 railway traffic, source=0 road traffic |
| Instantaneous | x | Number of 30-s interval after sleep onset time |
| Instantaneous | m | Motility (dichotomy: m=1 motility, m=0 no motility) |
| Instantaneous | k | Onset motility (dichotomy k=1 if m=1 and m=0 in preceding interval; k=0 otherwise) |
| sleep period time | mspt | Mean value of m during sleep period time |
| sleep period time | kspt | Mean value of k during sleep period time |
| sleep period time | fenster | Position of bedroom window during sleep period time |
| questionnaire | gender | Gender (0 male, 1 female) |
| questionnaire | age | Age in years |
| instantaneous | Leq2s_i | Indoor equivalent sound level over a 2-s interval (in dB(A)) |
| instantaneous | Leq2s_o | Outdoor equivalent sound level over a 2s interval (in dB(A)) |
| instantaneous | Leq_i | Indoor equivalent sound level over a 30-s interval (in dB(A)) |
| instantaneous | Leq_o | outdoor equivalent sound level over a 30-s interval (in dB(A)) |
| instantaneous | Lmax_i | Maximum value of Leq2s_i of a 30-s interval, assessed indoors (in dB(A)) |
| instantaneous | Lmax_o | Maximum value of Leq2s of a 30-s interval, assessed outdoors (in dB(A)) |
| | SEL | Equivalent sound level over a time period, normalised to 1 s (in dB(A)) |
| instantaneous | SEL_i | SEL of a 30-s interval, assessed indoors (in dB(A)) |
| instantaneous | SEL_o | SEL of a 30-s interval, assessed outdoors (in dB(A)) |
| | x | Nmber of 30-s interval after sleep onset |
| instantaneous | bron_2s | Dichotome for a 2-s interval: value=0 if source is not present, value=1 if source is present |
| instantaneous | bron | Fraction of 2-s intervals within a 30-s interval with bron_2s=1 |
| instantaneous | Start_br | Dichotome for a 30-s interval: value=1 if bron=0 in preceding 30-s interval and bron=1 in 30-s interval, value=0 for all other 30-s intervals |
| sleep period time | Lispt | Indoor equivalent sound level during a sleep period time calculated from all Leq_i values of 30-s intervals with bron>0 and duration of sleep period time (in dB(A)) |
| sleep period time | Lospt | Outdoor equivalent sound level during a sleep period time calculated from all Leq_o values of 30-s intervals with bron>0 and duration of sleep period time (in dB(A)) |
| location interval period | Li | Indoor equivalent sound level due to a noise source calculated from all Lispt values obtained for a subject, taking into account the durations of sleep period times of the subject (in dB(A)) |
| location interval period | Lo | Outdoor equivalent sound level due to a noise source calculated from all Lospt values obtained for a subject, taking into account the durations of sleep period times of the subject (in dB(A)) |

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