AIRCRAFT NOISE AND SLEEP: STUDY IN THE NETHERLANDS

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Abstract In this paper relationships between aircraft noise-induced increase in probability of motility and indoor Lmax and indoor SEL of aircraft noise events are given. The relationships are based on actimetry with 418 subjects, each participating in the study for 11 nights, and on 63242 aircraft noise events. The following variables modify the relationships: age, time after sleep onset, clock time, and indoor equivalent aircraft sound level during sleep of the subject. Attitude towards aircraft and aircraft noise do not have an impact on the relationships.

Introduction Sleep is an active physiological process, and not only the absence of waking. It has a restorative function that cannot be fullfilled by food, drink, or drug.
Sound is a carrier of information, also with respect to possible danger in the surroundings of a person. When sound reaches a person, a signal is transmitted from the hearing organ to the cortex and then interpreted. Besides this signal to the cortex, a signal is also transferred to lower parts of the central nervous system, which results, in anticipation to a physical response to a dangerous situation, in instantaneous changes in autonomous functions. Changes are for example increase in stress hormones and cortisol levels in blood, increase in heart rate and blood pressure, increase in muscular tone which induces small movements. When the situation has been interpreted as safe, the autonomous functions return to their earlier equilibrium. This process also occurs during sleep.
The small movements (motility) can be measured with an actimeter, in research usually worn on a wrist. A measure of the accelerations during movements is stored in the memory of the actimeter in successive time intervals (usually chosen between 2 and 60 s). Motility occurs if the accelerations during an interval exceed a threshold. The threshold is such, that motility of active people occurs in nearly all intervals: the probability of motility in e.g. a 15-s interval during time awake is over 0.90. During sleep, motility is strongly reduced. For example, in the present sleep disturbance study, motility of subjects while asleep occurs in 3.66% of the measurement intervals of 15-s, i.e., the probability of motility during sleep was 0.0366 (Passchier-Vermeer et al., 2002). The number of 15-s intervals in the average sleep period (430 minutes) in our study population is 1720. Thus, the number of 15-s intervals with motility during the average sleep period is 63, and the number without motility is 1657. Another measure frequently used is the probability of *onset* of motility above threshold. The number of 15-s intervals during sleep with onset of motility is equal to 40 (probability is equal to 0.0234) in our study.

Relationships between night-time aircraft noise exposure and adverse effects have been investigated on an instantaneous time scale, on a 24 hours level (including one sleep period time), and on a long-term basis. This paper is restricted to the results on an instantaneous time scale: measures of *instantaneous motility* have been related to measures of *aircraft noise events*.

Method In the study 418 adult subjects participated, exposed during their participation in the study to night-time aircraft noise as it usually occurs in their bedroom. Ages of subjects varied between 18 and 81 years, 50% of the subjects was male, and 50% female; 6% lived less than 1 year in the present environment, 44% more than 15 years and the remaining 50% between 1 and 15 years.
The study has been carried out at 15 locations within a distance of 20 km from Schiphol Airport. The locations have been selected mainly on the basis of night-time aircraft noise exposure, from relatively few aircraft at night up to the highest exposure in residential areas close to Schiphol.
To assess night-time (aircraft) noise exposure of subjects, from 22 – 9 hours indoor noise measurements have been performed in the bedroom of each subject and at each location one outdoor noise monitor has been in operation. Identification of aircraft noise events occurred by comparing the noise and time data stored in the indoor and outdoor noise monitors with information obtained from FANOMOS, the flight track monitoring system of the Ministry of Transport.
Subjects participated from a Monday evening starting at 22 hours until a Friday morning 11 days later. After a subject agreed to participate in the study, he/she filled out an extensive questionnaire. Participants in the study carried out the following tasks during each of the 11 participation days: filling out a morning- and evening diary, performing a reaction time test just before going to bed, filling out a sleepiness strip five times during time awake, and wearing an actimeter (weight about 50 grammes) on the non-dominant wrist. The actimeter is equipped with an event marker, which subjects pressed once when they awoke during sleep, and twice to indicate that they were going to sleep and that they woke up at the end of their sleep time.

The following two aircraft noise event metrics have been considered:

- *Lmax_i* maximal *indoor* equivalent sound level in a 1-s interval during an aircraft noise event (in dB(A));
- *SEL10_i* *indoor* equivalent sound level of an aircraft noise event, normalised to one second, assessed over the time the sound level of aircraft is larger than *Lmax_i* – 10 (in dB(A)).

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

The probability of (onset of) motility has been considered at the 15-s interval at which *Lmax_i* occurs (the central aircraft noise event interval) and at five intervals before and 14 intervals after the central aircraft noise event interval.

First, relationships have been assessed without taking into account other variables which also may have an impact on the effects. Then, the role of additional factors is investigated. Relationships have been obtained by using random effects logistic regression models with a random subject factor. With these models, the probability of motility (p_m) and of onset of motility (p_k) at a 15-s interval is specified as a function of *Lmax_i* and of *SEL10_i*. To obtain the *aircraft-noise induced* increase in probability of motility (*m*), the estimate of the *probability of motility that would have occurred if there would have been no aircraft noise event*, has been subtracted from p_m. The procedure to obtain these estimates is outlined in

Passchier-Vermeer et al., 2002. The *aircraft-noise induced* increase in onset of probability of motility (*k*) has been obtained analogously to *m*.

Whether subject-, location- or situation-related variables are effect-modifiers has been tested with *m* at the central aircraft noise event interval as the dependent variable and *Lmax_i* as a predictor. Many variables have been entered in the multi-level logistic equations, such as *demographic* variables, variables from the *questionnaire* (such as attitude towards aircraft noise and towards the expansion of Schiphol, sleep quality, number of complaints about aircraft noise at night), *type of aircraft noise events (*aircraft descending or ascending), *individual indoor aircraft noise exposure during sleep (Li)*, median sound level in the bedroom during sleep outside aircraft noise event periods (*L50*), *type of glazing of bedroom window(s)* (double- or single-glazing), *time of aircraft noise event after sleep onset*, and *clock-time of aircraft noise event*.

Results

Relationships without effect-modifying factors

In figure 1 an example of an exposure-effect relationship is given: *m* at the central aircraft noise event interval has been plotted as a function of *Lmax_i*. *m* in our study starts to increase on average from *Lmax_i* of 32 dB(A). The effect increases with increasing *Lmax_i* values: at *Lmax_i* of 68 dB(A) *m* is on average about 0.07, which implies that probability of motility is about 3 times the probability of motility in the absence of aircraft noise. The figure also includes the 95%-confidence intervals.

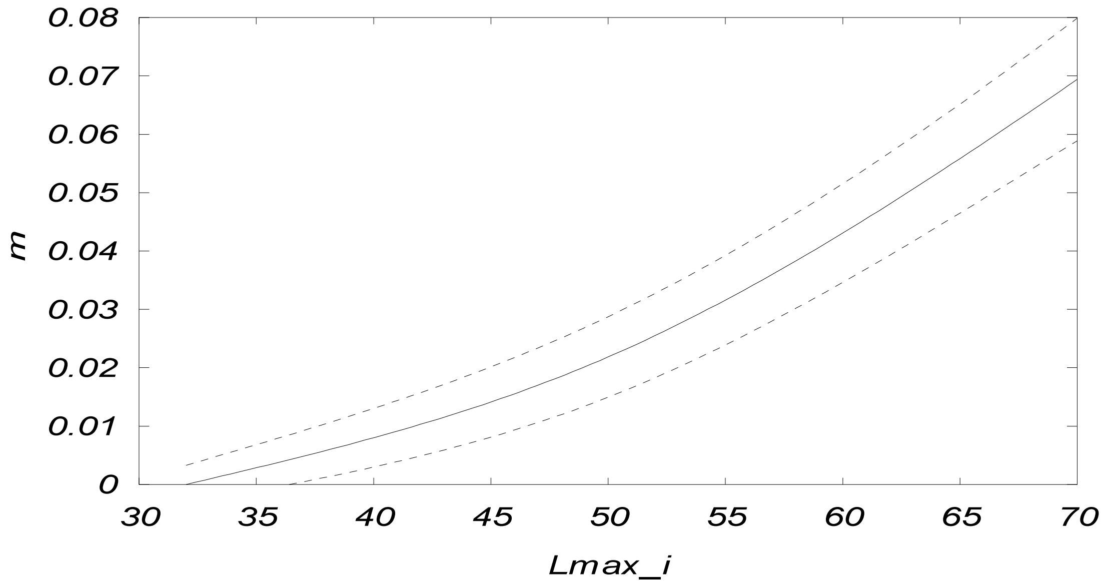

Figure 1 *Aircraft noise-induced probability of motility (m) at the central aircraft noise event interval as a function of Lmax_i. Broken lines represent 95%-confidence intervals.*

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

The relationships between *m* or *k* and *Lmax_i* and *SEL10_i* have been approximated by quadratic functions with the following format for *m* and *Lmax_i* (similar equations apply for the other combinations):

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

The coefficients a, b and c are given in table 1. The value of 'a' is the value at which *m* or *k* is zero. These curves represent the average effects, without taking effect-modifying factors into account.

Table 1 *Coefficients of the quadratic equation of m andof k as a function of Lmax_i and SEL10_i for the central aircraft noise event interval. The equations are applicable to the range of Lmax_i or SEL10_i from at least the value 'a' up to SEL10_i equal to 80 dB(A) or Lmax_i equal to 70 dB(A). At values below 'a', m, and k are zero.*

	m	*k*
aircraft noise event metric *Lmax_I*		
A	32	32
B	0.000633	0.000415
C	$3.14*10^{-5}$	$8.84*10^{-6}$
aircraft noise event metric *SEL10_I*		
A	38	40
B	0.000532	0.000273
C	$2.68*10^{-5}$	$3.57*10^{-6}$

Effect-modiying factors

Four effect-modifiers of the relationship between aircraft noise-induced increase of probability of motility at the central aircraft noise event interval *m* and *Lmax_i* have been identified: time after sleep onset, clock time, age, and *Li*. *m* increases with time after sleep onset: *m* after seven hours of sleep is a factor of about 1.3 higher than at the start of sleep. *m* in the period from 6 to 7 hours is about a factor 1.2 larger than in the period from 23 to 6 hours. *Age* of subjects has a small effect on *m*: *m* is maximal at an age of 40 to 50 years, and somewhat smaller in younger and older subjects. Figure 2 shows that *Li* has a substantial impact on *m*. For subjects with a low value of *Li* (say 5 dB(A)), *m* is about a factor 3 larger than for subjects with high values of *Li* (say 35 dB(A)).

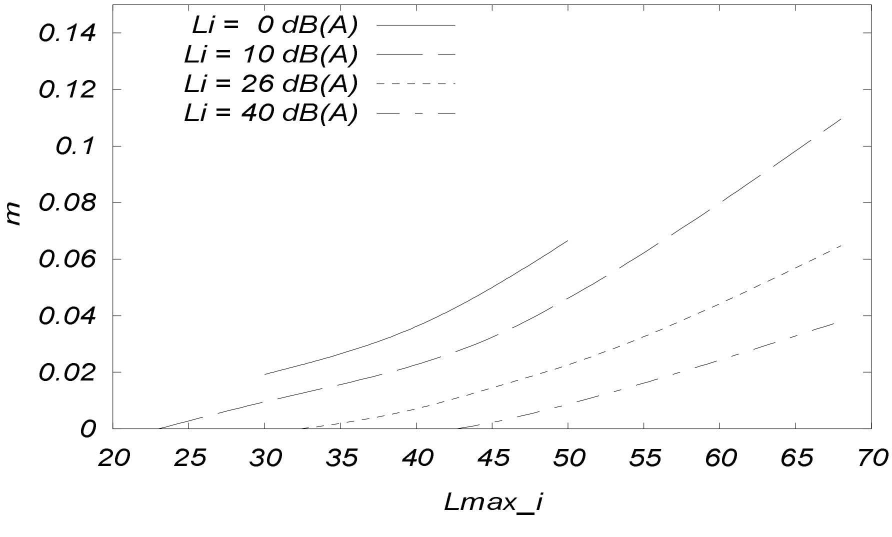

Figure 2 Aircraft noise-induced probability of motility (m) at the central aircraft noise event interval as a function of Lmax_i for four values of Li.

Comparison with previous findings on night-time aircraft noise The results of the present study have been be compared with the results of two other large field studies on the relationship between aircraft noise and aircraft noise-induced increase in (onset of) motility (Ollerhead et al., 1992, see also Horne et al., 1994; Fidell et al., 1995).

UK sleep disturbance study

In the UK, the first large scale field study on sleep disturbance assessed the effects of night-time aircraft noise on onset of motility during sleep in 400 subjects (for 15 nights), 20-70 years of age, living at one of eight locations in the vicinity of four UK airports, with different levels of night flying (Ollerhead et al., 1992). A 30-s interval was used as measurement time interval of the actimeters in that study. Noise measurements have been performed outdoors only. Ollerhead et al. state that instantaneous aircraft noise-induced increase of onset of motility is statistical significant larger than 0 for data points with outdoor *Lmax* values of at least 82 dB(A). If the difference between outdoor and indoor *Lmax* is taken as about 25 dB(A), then the difference between the present study and the Ollerhead et al. study between the threshold where effects start to occur is at least 20 dB(A). Also, the differences at high values of Lmax are substantial: Ollerhead et al. found about a factor 3 smaller values of *k* than the present study. The following factors are likely to have contributed to an underestimation of the effect of aircraft noise on onset of motility in the UK study.

- No indoor noise measurements have been performed. Other studies showed that indoor noise event measures have a much stronger relationship with (onset of) motility than outdoors measures (Fidell et al, 1995; Passchier-Vermeer et al., 2002).
- Conclusions are based on data points, and not on a model which incorporates all information at the same time.
- The 'threshold' for an aircraft noise event in the UK study was 60 dB(A) outdoors. This implies that all 30-s intervals with (aircraft) noise events below 60 dB(A) are considered as quiet. Effects on onset of motility of these lower (aircraft) noise events increase the probability of onset of motility during quiet.
- Especially when *Lmax_i* is high, noise-induced motility may start before the 30-s interval with *Lmax_i* of the aircraft noise event (Passchier-Vermeer et al., 2002). In those cases *onset* of motility is absent in the 30-s interval with *Lmax_i*.
- Due to limitations of computer facilities in 1992, only aircraft noise events that occurred between 23.30 and 5.30 hours have been considered. However, probability of aircraft noise-induced motility increases with time of the night, which implies an underestimation of the overall effect of noise exposure if events after 5.30 h are not taken into account.

USA sleep disturbance study

A large field study in the USA on aircraft noise-induced disturbance was conducted in the vicinity of Stapleton International Airport (DEN) and of Denver International Airport (DIA) during the period of transition in flight operations from the closing of DEN to the opening of DIA (Fidel et al., 1995). The 77 subjects participated for in total 2717 subject nights. Subjects were selected from locations as close as feasible to the runway ends. Fidell et al. state that because no effort was made to obtain a representative sample of any population, conclusions drawn from the study strictly apply to the test participants only. Noise measurements have been performed outdoors and inside bedrooms. The results of the study with respect to indoor relationships give a reasonable correspondence with the results in the Netherlands study for subjects with an Li of 35 to 40 dB(A).

By using the data of 27 subjects, Fidell et al. (1995) could not assess a statistical significant relationship between aircraft noise-induced increase in probability of onset of motility and *outdoor* aircraft noise event metrics.

Conclusion This paper presents recently established exposure-effect relationships. A new finding of the present study is that subjects with a *long-term high exposure* to aircraft noise during sleep show a *smaller instantaneous* motility response to an aircraft noise event than subjects with *a long-term relatively low* aircraft noise exposure during sleep. However, the reader of the reports of the present study will realize that *average* motility during intervals without aircraft noise of subjects *highly* exposed to aircraft noise during sleep is substantially *higher* than of subjects with *minor* aircraft noise exposure during sleep.

Keywords: Aircraft noise, sleep disturbance, field study, actimetry, motility

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