Self-reported sleep disturbance caused by aircraft noise

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1 INTRODUCTION

In our work reported earlier to WG HSEA (TNO Inro report 2002-59 “Elements for a position paper on night-time transportation noise and sleep disturbance”), we could not establish a relationships between $L_{\text{night}}$ and self-reported sleep disturbance for aircraft. The estimated coefficient of $L_{\text{night}}$ for aircraft was negative. Moreover, the estimated variance of the normal distribution of the sleep disturbance scores (scale 0-100) was very (unusually) high (5690) for aircraft. Because of these outcomes for self-reported sleep disturbance caused by aircraft noise, no exposure–response relationships were presented for aircraft.

In a follow-up project, commissioned by the Netherlands’ Ministry of Environment, we looked deeper into this matter. More specifically, the objective was to investigate whether there are reasons not to include particular datasets used in the earlier analysis, and to explore whether additional data could be obtained so that a more extensive overall dataset could be used for deriving the relationships. The studies considered previously are listed in table 5.2 of the above mentioned report.

This note is not self-contained but an addendum to the above mentioned report. It describes and discusses the composition of the new aircraft noise and self-reported sleep disturbance dataset, and the results from the exposure-response analyses conducted with this new dataset.
2 STUDIES INCLUDED IN THE PREVIOUS ANALYSES

When we explored the relationships between $L_{night}$ and self-reported sleep disturbance (average score per 2 dB $L_{night}$ class) for the individual studies that were included in the previous analyses, two points were remarkable. The curve of the study FRA-239, which was one of the three studies in an European project (the others being NET-240 and UKD-238), was over the whole exposure range below the curves for the other studies and did hardly show any relation of sleep disturbance with $L_{night}$, even though the range was sufficiently large to expect such a relation. The other point was that the curve for NET-522 was far above all other curves. In the included exposure range of the NET-522 curve (about 45-55 dB), the sleep disturbance value was between ca 40 and 60, while for the other studies this value was between ca 15 and 30.

When considering not including certain studies, in general the best approach is to be very conservative in the sense that studies are included unless there are very clear reasons to do otherwise. With respect to FRA-239 we consulted Jacques Lambert, from Inrets in France which conducted this study, with the question whether there had been very specific circumstances that could explain the position of the curve of FRA-239. Jacques Lambert forwarded this matter to Michel Vallet, one of the authors of the study, who informed us that "… at Orly in 1985 there are very few aircraft at night, due to a curfew between 11h30pm and 6h30 am. Indeed there was and this is still true for 2000ies, that the period before the beginning of the curfew is very busy…". Thus, it appears that only the first and the last half hour of the period from 23 to 7h contributed substantially to the $L_{night}$ levels. A comparison of the levels between 7 and 19h and between 23 and 7h in this study revealed that the differences between the daytime level and the nighttime level were large (minimum: 12.7 dB(A), maximum: 29.6 dB(A); average: 19.2 dB(A)). We believe that this case illustrates a cause of the large variation found in self-reported sleep disturbance at a given $L_{night}$. More than for road traffic and for railways, the traffic in the night at airports have been regulated. Because this is not always the case, and because regulations are different at different airports, the time pattern of the flights that together cause the $L_{night}$ is expected to be very different at different airports. We do not consider the specific time pattern around Orly in 1985 to be a proper cause for excluding FRA-239 from the analyses.

We excluded NET-522 from the analyses that must produce curves of which the absolute height is important, because it clearly is an outlier. However, this point requires further attention because it appears that the deviant position of the curve of NET-522 is not due to rare random coincidence or methodological artefacts. We compared the results from NET-522 with the results from a study conducted earlier around Schiphol (NET-371), with 3961 cases with a valid sleep disturbance score in the $L_{night}$ 45-65dB(A) range. This study has been not included in the analyses, because the percentage highly annoyed persons found in this study was known to be in the order of four times higher than the percentage highly annoyed found for a combination of other aircraft studies (cf TNO and RIVM, 1997; Miedema and Oudshoorn, 2001). We found that in the common exposure range self-reported sleep disturbance found in both studies matched rather closely, which means that the self-reported sleep disturbance found in both studies was in the order of a factor 2 higher than in the other studies. This indicates that the self-reported sleep disturbance is truly elevated around Schiphol as compared to the other studies that were included in the analyses. One of the other studies in the analyses is NET-240, which was also conducted around Schiphol, but earlier (in 1985 compared to NET-522 in 2001, and NET-371 in 1996). Thus, around Schiphol airport
between 1985 and 1996 the level of self-reported sleep disturbance at a given $L_{night}$ appears to have risen considerably. Because the other studies outside the Netherlands were conducted before 1990, these data do not give information as to whether only around Schiphol and possibly in the Netherlands, the self-reported sleep disturbance from aircraft noise has consistently increased to a higher level over the last one or two decades, or whether this trend is more general and not confined to the area around Schiphol and possibly the Netherlands. Below some indication is found that around Kloten airport (Zürich) the self-reported sleep disturbance may be somewhat elevated (also see Wirth et al., 2004) but by far not to the extent found around Schiphol.
3 STUDIES NOT INCLUDED IN THE PREVIOUS ANALYSES

3.1 Studies previously excluded for technical reasons

Two available studies (UKD-024 and USA-022) were not used in the earlier analyses, because for these studies $L_{night}$ was estimated on the basis of data for periods other than 23-07h. We further studied the definition of $L_{night}$ in the two studies, and found that in both studies the available estimate of $L_{night}$ could be regarded as an upper limit to the true $L_{night}$, while it was possible to also derive a lower limit. The available estimate was regarded as an upper limit, because it was the $L_{Aeq}$ for a period that also encompassed one hour (UKD-024: $L_{Aeq}(22-7h)$) or two hours (USA-022: $L_{Aeq}(21-6h)$) of the evening period that presumably was busier than the nighttime period. For the latter study it was assumed that one evening hour compensated for the relatively busy early morning hour 6-7h not being included. We used the available evening or daytime $L_{Aeq}$ for these studies to obtain the lower estimate in the following way. For UKD-024 it was assumed that the level in the evening hour included in the nighttime level (22-23h) was equal to the available level for the evening period $L_{Aeq}(7-22h)$. For USA-022 it was assumed that the level in the morning hour 6-7h was equal to the level of an the evening hour included in the nighttime level (21-22h or 22-23h), and that the level in the evening hours included in the nighttime level (21-23h) was equal to the available level for the daytime period $L_{Aeq}(6-21h))$. Then the contribution from one evening hour was subtracted from the nighttime level, giving a low estimate of the nighttime level because the subtracted average evening or daytime level presumably is higher than the specific evening hour actually included in the nighttime level. We considered the cases with a $L_{night}$ (available – high- estimate) that comes in the exposure 45 – 65 dB(A). For UKD-024 the average difference between the high and low estimate of $L_{night}$ turned out to be on the average 3.4 dB with a maximum of 6 dB(A), and for USA-022 for most cases the differences also was limited but not for all cases. For USA-022 the 197 cases with the largest difference ($\geq$ 7 dB(A)) were excluded and the average difference for the remaining cases was 1.8 dB(A). Both studies (excluding the 197 cases from USA-022) were included in the new analyses with the high estimate assigned to (a randomly chosen) half of the respondent, and the low estimate to the other half of the respondents, so that the uncertainty regarding $L_{night}$ contributes to the variance but does not systematically bias the results.
3.2 New studies

Two studies with data on $L_{\text{night}}$ and self-reported sleep disturbance became available, namely, UKD-182, with a face to face survey and a postal survey, and SWI-xxx (Wirth et al., 2004), to which we referred above. The sleep disturbance questions are presented in table 1.

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Sleep disturbance question</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWI-xxx</td>
<td>308</td>
<td>How strongly during the past 12 months were you annoyed by the following noise types: &lt; noise type = aircraft noise while maintaining sleep&gt; Not, very weakly, weakly, clearly, strongly very strongly, unbearably strongly.</td>
<td>Wirth et al, 2004</td>
</tr>
<tr>
<td>UKD-182</td>
<td>2274+613</td>
<td>Q13a: Still thinking of the past three months or so, have you ever been woken up while asleep. No, less than one night a month, one or two nights a month, about one night a week, about two or three nights a week, or almost every night. Q14a: What caused you to wake once you were asleep (Administered survey: probe, Postal survey, chooses from a list where Aircraft is among the alternatives).</td>
<td>DORA, 1980</td>
</tr>
</tbody>
</table>

For SWI-xxx, $L_{\text{night}}$ and the sleep disturbance question that could be directly used were available in the dataset. While in UKD-182 $L_{\text{night}}$ was was directly usable, sleep disturbance due to aircraft was assessed in a specific way, by first asking about sleep disturbance and then in follow-up questions asking about the causes of sleep disturbance. The procedure was somewhat different for the postal and the face-to-face surveys. As an illustration, the procedure for the face-to-face will be discussed. In the follow-up question, 3 causes of the sleep disturbance could be mentioned as cause 1, cause 2, and cause 3, respectively. A high estimate of sleep disturbance caused by aircraft noise was obtained by counting all sleep disturbed persons (Q13a: see table 1) who mentioned aircraft as cause 1, 2, or 3 (Q14a: see table 1) as sleep disturbed by aircraft noise; a low estimate was obtained by counting only those who mentioned aircraft as the first cause. Then by a similar split half procedure as described above, half of the respondents was assigned their high estimate of sleep disturbance caused by aircraft and the other half their low estimate.
4 ANALYSES AND RESULTS

An overview of the studies that are used in the present analyses is given in table 2.

Table 2: Overview of aircraft noise studies: bold= new in the analyses; italics= now excluded; normal = was and is in analysis.

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRA-239</td>
<td>264</td>
<td>Diamond,1986</td>
</tr>
<tr>
<td>NET-240</td>
<td>474</td>
<td>Diamond,1986</td>
</tr>
<tr>
<td>NET-522</td>
<td>572</td>
<td>Passchier-Vermeer, 2002</td>
</tr>
<tr>
<td>SWI-xxx</td>
<td>308</td>
<td>Wirth et al., 2004</td>
</tr>
<tr>
<td>UKD-024</td>
<td>2158</td>
<td>DORA, 1967</td>
</tr>
<tr>
<td>UKD-182</td>
<td>2274</td>
<td>DORA, 1980</td>
</tr>
<tr>
<td>UKD-238</td>
<td>598</td>
<td>Diamond, 1986</td>
</tr>
<tr>
<td>UKD-242</td>
<td>1294</td>
<td>Brooker,1983</td>
</tr>
<tr>
<td>USA-022</td>
<td>1751</td>
<td>Hazard, 1971</td>
</tr>
<tr>
<td>Total</td>
<td>9734</td>
<td></td>
</tr>
</tbody>
</table>

The same type of analyses as described in section 5.2 of the above mentioned report were conducted, here for aircraft, with $L_{night}$ as the predictor of self-reported sleep disturbance. Table 3 gives the results.

Table 3: Coefficients (b) of Equation 5.2 in the above mentioned report and their standard errors (s.e.), estimated on the basis of the aircraft data in table 2. The only predictor is $L_{night}$. The dependent variable is self-reported sleep disturbance. Significance at the 5 % level is indicated with *, significance at the 1 % level with **.

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>with study effect</th>
<th>without study effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b</td>
<td>s.e.</td>
</tr>
<tr>
<td>$s^2$</td>
<td>5407.2**</td>
<td>236.3</td>
</tr>
<tr>
<td>$\sigma_0$</td>
<td>912.1</td>
<td>427.4</td>
</tr>
<tr>
<td>$b_0$</td>
<td>-188.49**</td>
<td>16.02</td>
</tr>
<tr>
<td>$L_{night}$</td>
<td>2.92**</td>
<td>0.22</td>
</tr>
<tr>
<td>$-2L$</td>
<td>16925</td>
<td>-</td>
</tr>
<tr>
<td>N</td>
<td>9734</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1 shows the curves for three sleep disturbance measures ($\%HSD$, $\%SD$, and $\%LSD$) and their 95% confidence intervals, together with the polynomial approximations of the curves, corresponding to the results with study effect (left-hand side of table 3). The curves are based on data in the $L_{\text{night}}$ range 45-65 dB(A). The polynomial functions are close approximations of the curves in this range and their extrapolations to lower exposure (40-45 dB(A)) and higher exposure (65-70 dB(A)). The formulas of these polynomial approximations are as follows:

$$\%HSD = 18.147 - 0.956L_{\text{night}} + 0.01482L_{\text{night}}^2$$

$$\%SD = 13.714 - 0.807L_{\text{night}} + 0.01555L_{\text{night}}^2$$

$$\%LSD = 4.465 - 0.411L_{\text{night}} + 0.01395L_{\text{night}}^2$$

The parameter estimates of the model with study effect are not fully stable, in particular the estimate of the study variance is not. This is probably caused by the relatively small size of the study variance as compared to the individual variance. Other equally good solutions can be obtained that have a lower estimate of the study variance that is significant at the 5% level (the estimate of the study variance in table 3 is significant at the 10% level). This instability is a highly undesirable situation. In order to get an indication of the uncertainty regarding the best estimate, the model without study variance also has been fitted to the same data. The results are presented in the right-hand side of table 3. The measure of fit (-2L) is higher which means that the fit is somewhat worse. The curves that correspond to the results without study effect (the right-hand side of table 3) are also shown in figure 1. The polynomial approximations of these curves, not shown in the figure, are as follows:

$$\%HSD = 4.428 - 0.168L_{\text{night}} + 0.004873L_{\text{night}}^2$$

$$\%SD = 3.801 - 0.00681L_{\text{night}} + 0.00523L_{\text{night}}^2$$

$$\%LSD = 2.679 + 0.127L_{\text{night}} + 0.004731L_{\text{night}}^2$$

Figure 1 also shows the data points when the sleep disturbance percentages are determined per 3 dB class on the basis of pooled data from the different studies. As expected, the curve corresponding to the model without study effect fits these pooled data points closer than the curve corresponding to the model with study effect. It appears that the curves of the individual studies are steeper than the curves for the model without study effect, but shifted with respect to each other so that neglecting the study effect leads to a flatter curve. We consider the variation between the results of the two models in table 3 and illustrated in figure 1 to be an indication of the range of uncertainty regarding the best estimate of sleep disturbance as a function of $L_{\text{night}}$. 
Figure 1: Self-reported sleep disturbance as a function of $L_{night}$ and the 95% confidence intervals for the model with study effect (left-hand side of table 3). Also shown is the flatter curve for the model without study effect (right-hand side of table 3), and data points when the sleep disturbance percentages are determined per 3 dB class on the basis pooled data from the different studies (see text for discussion).
5 CONCLUSION AND DISCUSSION

Relationships between $L_{\text{night}}$ and self-reported sleep disturbance were established. The variance of the responses at a given exposure level is large compared to the variance found for road traffic and railways. To put it another way, the distribution of the responses at a given exposure level is relatively flat. This means that the uncertainty regarding the relations for nighttime aircraft noise is large, and they can be considered to be indicative only.

It appears that the curves of the individual studies are steeper than the curves for the model without study effect, but shifted with respect to each other so that neglecting the study effect leads to flatter overall curves. When neglecting the study effect, the model fit is somewhat worse. The study effect has also been included in the previous analyses for road traffic and railways. For these reasons, we recommend the use of the curves obtained with the model that incorporates a study effect. Although there is uncertainty regarding the best description of the data, in the studies analyzed the exploration of the results with various models roughly suggest the following relative position of the curves for aircraft (cf. Miedema et al., 2003: fig 5.1) caused by a given $L_{\text{night}}$, is higher for aircraft than for road traffic, the %SD for aircraft is in between the percentages for road (higher) and railways (lower), and the %LSD for aircraft is in the same order of magnitude as the %LSD for railways (but see comment below regarding possible trends in time).

The following factors may have contributed to the large study variance, in addition to factors that also contribute to study-related variance in responses found for other types of transportation sources (road, rail):

- The time pattern of noise exposures around different airports may be very different due to the effect of different regulations on these time patterns, such as regulations prescribing nighttime curfews;
- While there is a large variation in the wording of the sleep disturbance questions in general, the sleep disturbance questions for aircraft noise appear to be even more variable; (see table 1, this report, and table 5.2 in Miedema et al., 2003)
- There may be a trend in time towards higher self-reported sleep disturbance at the same $L_{\text{night}}$. In the most recent study included in the analyses on which the presented curves are based, the self-reported sleep disturbance is highest. Furthermore, a recent aircraft noise effects study conducted in the Netherlands was exclude from the analyses, because its results were so deviant (high) that it was considered to be an outlier.

The following factors may have contributed to the individual variance, in addition to factors that also contribute to the individual variance in responses found for other types of transportation sources (road, rail):

- Uncertainties regarding the nighttime noise exposure, and possible changes in the exposures;
- Individual differences in fear of aircraft accidents and in expectations regarding future developments, which may affect the reactions to noise;

Because of the above reasons, the curves presented can only be considered to give indications of the self-reported sleep disturbance caused by nighttime aircraft noise, and it may be that recent trends lead to higher self-reported sleep disturbance than indicated by these curves.
We therefore recommend that:

- An international study with respect to self-reported sleep disturbance due to aircraft noise is conducted;
- The indications of a trend in time towards higher levels of self-reported sleep disturbance are investigated, and, if such a trend is substantiated, specific attention is given to the possible mechanisms causing such a trend.
REFERENCES


