Noise Annoyance from Urban Roads and Motorways

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ABSTRACT

A socio-acoustic noise annoyance survey with approximately 7,000 respondents has been performed in 2014 along motorways and urban roads in major cities in Denmark. The annoyance questions followed ISO 15 666 and the answers were analysed together with the noise levels (L_{den}) at the most exposed façade.

The results show that persons living near motorways on average are much more annoyed at the same noise exposure than persons living near urban roads. At 20 % Highly Annoyed the difference in L_{den} between the two types of roads is more than 10 dB. The dose-response curves found in this survey for the urban roads are quite close to the EU (Miedema) dose-response curves for road traffic noise and to the curves found in earlier surveys in Denmark. Analyses for moderating factors for the annoyance were also made. The type of residence, existence of a quiet façade, direct view to the traffic, and age were among the moderating factors. The outdoor annoyance was significantly higher for motorways than for urban roads while the indoor annoyance was about the same for the two types of roads. The results indicate a need to consider noise from motorways separately from noise from other roads.

Keywords: Road noise, Annoyance, Dose-response I-INCE Classification of Subjects Number(s): 52.3, 66.2, 68.3

1. INTRODUCTION

Residents living in cities and near motorways experience noise annoyance from road traffic. Two previous reports (1), (2), and (3) indicate that noise from motorways causes more annoyance than noise from urban roads at the same noise level.

The Danish Road Directorate generally wants more knowledge of how road traffic noise affects people. This knowledge can be used in the future work to focus, improve, and optimize efforts against road traffic noise. The Danish Road Directorate therefore carried out a major study of how citizens experience road traffic noise along motorways and urban roads in Denmark.

The primary purpose of this study was to find out whether the noise annoyance experienced by residents along motorways is greater than for residents along urban roads when the residents are exposed to the same average noise level from the road traffic and to make suggestions for the possible reasons for this difference.

In addition, the purpose was to compare the results of this study with the general European dose-response curves (Miedema) (4). The European dose-response curves are normally used to calculate noise annoyance from roads and do not distinguish between noise from motorways and other roads.

2. SURVEY METHODOLOGY

The study was carried out on the basis of a large questionnaire survey with a total of approx. 7,000 respondents, evenly distributed by residents along motorways and along urban roads, and the results were compared with data on the calculated noise level at the home of each individual respondent. The following briefly describes the study method.

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2.1 Calculated noise levels

Results from noise mapping of main roads and local roads have been used for the study. The Danish Road Directorate's noise mapping forms the basis of the study along the motorways, while noise mapping results from the municipalities of Copenhagen, Aarhus, and Odense have been used for the study along the urban roads.

For all the mappings, noise levels have been calculated for the most noise-impacted dwelling facade. Noise is calculated as \( L_{den} \) using the Nord2000 propagation model (5). Nord2000 is a joint Nordic prediction method. The method includes source models for road traffic in third octave bands from 25 Hz to 10 kHz. The propagation model applies for a variety of weather conditions, allowing a precise yearly average to be determined. Buildings and complicated terrain is handled by a concise procedure.

The calculations were completed in 2012. The questionnaire survey was carried out in 2014. On the selected sections of roads included in the study, the traffic conditions etc. are not considered to have changed so significantly during the period from 2012 to 2014 that it would have resulted in changes compared to the calculated noise levels in 2012.

Given the large population studied, the results of the calculated noise levels are generally considered to form a solid and valid basis for estimating noise impact on the respondents.

The calculated noise levels have been linked to each individual respondent by means of address details, and associated information about building and dwelling conditions from the Danish Central Register of Buildings and Dwellings (BBR).

2.2 Questionnaire survey of the experienced annoyance

The survey of the experienced annoyance was carried out based on a questionnaire developed for the purpose.

The basis for the relationship between dose and response is the answer to the question: "Thinking about the last year or so, when you are at home, how much does noise from road traffic bother, disturb, or annoy you?". The respondents answered using a numerical scale from 0 to 10 where 0 corresponds to "Not at all annoyed" and 10 corresponds to "Extremely annoyed". Moreover, the respondents stated their annoyance by ticking one of the options (in Danish, see(6)) "Not at all annoyed", "Slightly annoyed", "Moderately annoyed", "Very annoyed", "Extremely annoyed", or "Don't know". The question is phrased in accordance with the ISO 15 666 standard (7), so that the results are comparable with similar surveys elsewhere, and in other countries. The questionnaire consisted of 30 questions about road traffic noise, personal data, dwelling information, etc.

2.3 Conduction of interviews

Along the selected road sections (see section 3), and on the basis of the noise mapping results, 14,000 postal address points evenly distributed by motorways and urban roads were selected. In the autumn of 2014, the postal addresses received a questionnaire and an explanatory cover letter. A total of 6,761 interviews were conducted in this survey. In order to ensure the representativeness of the survey, the adult person in the household next celebrating his or her birthday was asked to answer the questionnaire.

The respondents completed the questionnaire via a website on the internet. The respondents used an assigned user name and password. It was therefore possible to trace which addresses had not responded to the questionnaire via the internet. These respondents were contacted by phone by the market research company, Epinion, who offered the respondents to complete the questionnaire as a telephone interview.

The completion rate for interviews with residents along urban roads was 59 % and 63 % for residents along motorways. 49 % of all interviews were conducted via the internet and 51 % via telephone interviews.

Interview data for the survey have subsequently been combined with all other data in the study, i.e. data on noise level on facade and other data from the Central Register of Buildings and Dwellings and at postal address level. All interview data are anonymous, and all information from interviews has been treated confidential.

2.4 Calculation of dose-response curves

The calculation of dose-response curves uses data regarding the calculated noise impact, \( L_{den} \), at the most exposed facade of each home and the respondent's related answers to questions about noise
annoyance. Dose-response curves between the self-reported noise annoyance and the noise impact (L_{den}) and 95% confidence intervals have been calculated by using logistic regression, where the answers concerning noise annoyance is divided into 1 dB noise classes which are weighted relative to the number of responses.

The dose-response relationship is described by a logistic function which is calculated by grouping the respondents into level classes of noise impact (L_{den}) corresponding to 1 dB intervals. For each level class, the percentage of ‘Highly Annoyed’, ‘Annoyed’, and ‘Little Annoyed’ has been calculated on a scale for experienced noise annoyance (“... how much does noise from road traffic bother, disturb, or annoy you ...”). Logistic transformation has been performed for these percentages. Linear regression has been performed where the transformed percentages are compared with the noise impact (L_{den}). In the regressions, the level classes have been weighted according to the number of respondents in the relevant group.

The curves shown are limited to the L_{den}-interval, where there is actually a meaningful grouping of observations, i.e. in the range 48 - 75 dB. A numerical response scale from 0 to 10 is used, allowing the respondent to grade answers about the degree of the experienced annoyance. The response scale is in accordance with the ISO 15 666 standard, meaning that results about reported annoyance are comparable with similar surveys elsewhere and in other countries.

The following descriptors for noise annoyance have been used: Highly annoyed (HA): All answers in the categories 8, 9, and 10, Annoyed (A): All answers in the categories 5 to 10, Little annoyed (LA): All answers in the categories 3 to 10.

The dose-response curves are expressed as (8):

\[
A = \frac{u}{1 + e^{-s(E-f)}}
\]

Where:
- A is the percentage of annoyed (HA, A, LA) respondents
- u is the upper limit of A (i.e. u = 100)
- s is the slope
- E is the noise Exposure, L_{den}
- f is the value of E for a fifty percent annoyance response

Thus, the dose-response curves show a relationship between the respondents’ experience of noise annoyance and the noise impact (L_{den}), i.e. the yearly average noise impact over a period of 24 hours. The associated confidence intervals indicate the uncertainty of the calculated dose-response curve. As a rule of thumb: If the confidence intervals for two dose-response curves cross each other, the uncertainty is greater than the difference between the curves, and the difference cannot be regarded as significant.

3. SELECTION OF ROADS AND AREAS FOR THE STUDY

The purpose of the noise annoyance survey was to study the differences in the noise annoyance experienced from motorways and urban roads, respectively. On this basis, it was important that the respondents in the study lived in areas where the primary source of road traffic noise was motorways and urban roads, respectively. Also, it was important that the respondents, and the environments in which they live, roughly are representative of people who live along motorways and urban roads in Denmark. For this reason, the criteria for selection of road sections for the survey were a reasonable distribution between road types, area types, and geography.

The motorways include sections that affect residential areas in large cities (Aalborg, Odense, and Copenhagen), and affect both urban communities and dwellings in rural areas throughout Denmark. Altogether, the sections represent approx. 200 km motorway with speed limits from 110 km/h to 130 km/h. This corresponds to approx. 10% of the total Danish motorway system.

The urban roads include sections in the three largest cities in Denmark (Copenhagen, Aarhus, and Odense). The sections in cities are both urban roads with little traffic, shopping streets and large, busy thoroughfares.

The study has a reasonably balanced distribution of respondents between the regions of Denmark; Jutland (36%), Funen (34%), and Zealand (30%). The distribution of respondents along urban roads is 17% from Aarhus, 15% from Odense, and 17% from Copenhagen.
In the selection of road sections, it was ensured that no conditions have changed the noise significantly within the past year before the questionnaire survey was carried out. For example sections with new asphalt, construction works and roadworks, traffic diversions etc. the past year were excluded. Figure 1 give an overview of motorway sections and cities included in the study.

4. RESPONDENTS, TYPE OF DWELLING, AND NOISE IMPACT

Almost the same number of responses has been received from residents at motorways as from residents at urban roads. The overall proportion of respondents at motorways and urban roads is 51 % and 49 %, respectively. The percentage distribution of the respondents' dwelling type, stated as single-family house or flat either along motorways or urban roads, can be seen in table 1. The table shows that the distribution between dwelling types is nearly inversely proportional. The majority of respondents at motorways live in single-family houses, while the majority of respondents at urban roads live in flats.

Table 1 - Distribution of the respondents' dwelling type, stated as single-family house or flat either along motorways or urban roads

<table>
<thead>
<tr>
<th></th>
<th>Single-family houses</th>
<th>Flats</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>91 %</td>
<td>8 %</td>
<td>1 %</td>
</tr>
<tr>
<td>Urban roads</td>
<td>17 %</td>
<td>81 %</td>
<td>2 %</td>
</tr>
</tbody>
</table>

The distribution of noise levels at the dwelling facade for all respondents, by motorways and urban roads, is shown in table 2. The distribution of the noise impact along road types differs. Along the urban roads, 37 % of the homes have a noise impact of more than 65 dB, whereas "only" 19 % of the homes along the motorways have a noise impact of more than 65 dB. Dwellings in towns and cities are generally exposed to noise levels in the high end compared to dwellings at motorways because many of the dwellings are located close to the source of noise, while along motorways, the distance to the
dwellings is generally greater. However, it should be noted that the areas and the sections have been selected to ensure that the answers represent an impact from both high and low noise levels along motorways and urban roads, respectively.

Table 2 – Noise levels (L_{den}) at the respondent’s dwelling façade displayed in exposure classes of 5 dB

<table>
<thead>
<tr>
<th></th>
<th>Under 50 dB</th>
<th>50-55 dB</th>
<th>55-60 dB</th>
<th>60-65 dB</th>
<th>65-70 dB</th>
<th>Over 70 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>1 %</td>
<td>23 %</td>
<td>30 %</td>
<td>28 %</td>
<td>16 %</td>
<td>3 %</td>
</tr>
<tr>
<td>Urban roads</td>
<td>5 %</td>
<td>20 %</td>
<td>21 %</td>
<td>17 %</td>
<td>22 %</td>
<td>15 %</td>
</tr>
<tr>
<td>Total survey</td>
<td>3 %</td>
<td>21 %</td>
<td>25 %</td>
<td>22 %</td>
<td>19 %</td>
<td>9 %</td>
</tr>
</tbody>
</table>

5. RESULTS

5.1 Dose-response relationships

Figure 1 shows the dose-response relationship for respondents who are exposed to noise from motorways, Highly Annoyed, Annoyed, and Little Annoyed, respectively. The figure shows that approx. 22 % of the respondents are Highly Annoyed when the noise level at the most exposed facade is L_{den} = 58 dB, while 48 % of the respondents feel Annoyed at 58 dB. L_{den} = 58 dB is the recommended noise limit in the Danish guidelines for road traffic noise (9).

Figure 2 shows the dose-response relationship between respondents who are exposed to noise from urban roads, Highly Annoyed, Annoyed, and Little Annoyed, respectively. The figure shows that approx. 8 % of the respondents are Highly Annoyed when the noise level at the most exposed facade is L_{den} = 58 dB, while 28 % of the respondents feel Annoyed at 58 dB.
From the figures above it appears that the difference between the dose-response curves for motorways and urban roads is significant. It is found that all curves (HA, A, and LA) are significantly higher along motorways than along urban roads.

As an example, the proportion of respondents who are Highly Annoyed is shown in Figure 3. At $L_{den} = 65$ dB at the most expose facade 44 % is Highly Annoyed along the motorway compared to 15 % along the urban road. Seen in another way 20 % are Highly Annoyed at a level of $L_{den} = 68$ dB at the urban roads while 20 % is Highly Annoyed at $L_{den} = 57$ dB at the motorways, a difference of more than 10 dB!
In Figure 4 the results from urban roads from this study is compared to an earlier Danish study with 2870 respondents (8). The confidence intervals (not shown) of the two studies are approximately the same (see Figure 2). It appears that the results from these two Danish studies are very similar, considering the confidence intervals.

![Figure 4 - Dose-response curves for urban roads from this study (thin lines) compared to an earlier Danish study (8) for urban roads (2870 respondents).](image)

The Danish dose-response curves shown above are compared to the curves for road traffic noise given in the EU-position paper (4), the so-called Miedema-curves. These curves are based on 19,172 observations in 26 studies from different countries. Figure 5 shows the comparison for the Danish curves for motorways. It is found that all Danish curves (HA, A, and LA) are significantly higher along motorways than the Miedema curves. For the same percentage of Highly Annoyed the difference is 9 -14 dB depending on the level of annoyance.

![Figure 5 - Dose-response curves for motorways compared to “Miedema” (4). The dotted lines indicate the 95 % confidence intervals for the Danish curves.](image)

Figure 6 shows the Danish curves for urban roads compared with the Miedema curves. It appears
that the curves for Highly Annoyed and Little Annoyed are very similar, and the Miedema curve for Annoyed is slightly below the Danish curve for Annoyed.

![Dose-response curves for urban roads compared to “Miedema” (4). The dotted lines indicate the 95 % confidence intervals for the Danish curves.][1]

For further use and comparison of the results, the data given in Table 3 can be used.

<table>
<thead>
<tr>
<th></th>
<th>Motorways</th>
<th>Urban roads</th>
<th>Miedema (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$f$, dB</td>
<td>$s$</td>
<td>$f$, dB</td>
</tr>
<tr>
<td>Little annoyed</td>
<td>66.7</td>
<td>0.147</td>
<td>80</td>
</tr>
<tr>
<td>Annoyed</td>
<td>58.4</td>
<td>0.157</td>
<td>67.9</td>
</tr>
<tr>
<td>Highly annoyed</td>
<td>54.2</td>
<td>0.173</td>
<td>58.9</td>
</tr>
</tbody>
</table>

5.2 Indoor and outdoor annoyance

The dose-response relationship has been studied in three different situations:

1. Overall annoyance when people are at home, by asking: "Thinking about the last year or so, when you are at home, how much does the noise from road traffic bother, disturb, or annoy you?" The results are shown in section 5.1 above.

2. Annoyance indoors in the home, by asking: "Thinking about the last year or so, when you are inside your home, how much does the noise from road traffic bother, disturb, or annoy you?"

3. Annoyance outdoors at the home, by asking: "Thinking about the last year or so, when you are outside in the garden, yard, or on the balcony at your home, how much does the noise from road traffic bother, disturb, or annoy you?"

Figure 7 shows the results for the indoor question and Figure 8 for the outdoor question.
The confidence intervals (not shown) in Figure 7 and Figure 8 are approximately of same size as in Figure 2.

If we compare the dose-response curves for motorways and urban roads with regard to the annoyance inside the home (see Figure 7), the difference across road type is small and insignificant. However, if we look at the annoyance experienced outside the home (see Figure 8), the difference is very pronounced. For motorway respondents the outdoor noise annoyance is significantly higher than for people who live near urban roads.

Regression analyses show that for residents at motorways the outdoor annoyance is relatively more important than the indoor gene when analysing what drives the total annoyance. For residents at urban roads the result is the opposite. Here the indoor annoyance is a much more important factor than the outdoor annoyance.

The models for respectively one-family houses and flats (see Figure 9 and Figure 10) are - not surprisingly - similar to the results for motorways and urban roads respectively, due to the large amount of people living in one-family houses at the motorway and the large amount of people living in flats at the urban roads (see Table 1).
Other results (not shown in this paper) show that the overall annoyance for people who live in single-family houses is mainly determined by the annoyance experienced outdoors, while the overall annoyance experienced by people who live in flats to a large degree is determined by the annoyance experienced indoors at home. The explanation may be that in general outdoor recreational areas for Danish single-family houses are less secluded compared to recreational areas for flats. Many Danish flats have recreational areas in the back yards where the noise levels typically are low, while the outdoor areas at single-family houses typically are not shielded to the same extent.

5.3 Moderators for the annoyance

Figure 9 – Percentage of Highly Annoyed compared for two types of residences, flats and one-family houses. Pooled data from motorways and urban roads. The dotted lines indicate the 95% confidence intervals for the curves.

Figure 10 – Percentage of Highly Annoyed compared for respondents who have access to a silent side of the residence and those who have not. Pooled data from motorways and urban roads. The dotted lines indicate the 95% confidence intervals for the curves.
In the earlier investigation (8) it was found that people living in one-family houses (i.e. detached houses) were more annoyed than people living in flats. This effect is also found in this study however, it is more prominent here, see Figure 9. This may be due to the mentioned correlation between type of housing and road type.

Research shows that access to a quiet side of the dwelling can have an influence on the noise annoyance experience. This is also found in this study, see Figure 10.

It was also found that young people are less annoyed by traffic noise than elderly people - and relatively more young people live along the urban roads and in flats.

It was found that the degree of acceptance of the noise level to which one are exposed, has an influence on the experienced annoyance. Respondents living along motorways generally have a lower degree of acceptance of the noise levels compared to respondents living along urban roads.

More results can be found in the full report (in Danish) (10).

6. CONCLUSIONS

On the basis of the study, it can be concluded that:

- People who live along motorways are significantly more annoyed by road traffic noise compared to people who live along urban roads when they are exposed to the same noise exposure on the most exposed facade. 2-3 times as many people living along motorways feel Highly Annoyed compared to people living along urban roads. Residents living along motorways are Annoyed at approx. 6 - 13 dB lower noise levels compared to residents living along urban roads.

- The annoyance experienced indoors in the home is almost the same for motorways and urban roads, while the annoyance outdoors at the home (in the garden, in the yard, etc.) is significantly higher along motorways than along urban roads.

- People who live along motorways are significantly more annoyed than shown by the European (4) noise annoyance curves, whereas the annoyance for people who live along urban roads is in line with the general European curves.

A number of contexts relate in particular to the dwelling conditions, each of which are factors which indicate that respondents living along urban roads are less annoyed than those who live along motorways, such as:

- People who live in flats are less annoyed than people who live in single-family houses – and significantly more respondents live in flats along the urban roads.

- Young people are less annoyed by traffic noise than elderly people - and relatively more young people live along urban roads/in flats.

- Access to a quiet facade in the home has a positive impact on the perception of annoyance – and significantly more homes in urban areas have a quiet facade.

- That the degree of acceptance of the noise level to which people are exposed has an influence on the experienced annoyance – the lower the acceptance, the greater the annoyance – and the respondents living along motorways generally have a lower degree of acceptance of noise levels compared to the respondents living along urban roads.

- The overall perception of annoyance for people who live in single-family houses is mainly determined by the annoyance experienced outdoors, etc., while the overall annoyance experienced by people who live in flats to a large degree is determined by the annoyance experienced indoors in the home. The outdoor recreational areas are generally less shielded for single-family houses compared to flats.

It was not the purpose of the investigation to specify actions or assess the consequences of the fact that the reported noise annoyance is significantly higher for motorways than for urban roads. However, the results give rise to considerations about how it can be taken into account in the future that road traffic noise from motorways and urban roads is perceived very differently.
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