Noise annoyance from motorways is worse than annoyance from urban roads

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Abstract
A literature survey was made for the Danish EPA on the annoyance felt by people living along urban roads and motorways. A few studies before 1992 show, that noise from motorways is more annoying than noise from other roads. A Danish survey from 2014 with 6761 respondents shows the same. A Schweiz survey from 2014-17 with 5364 respondents show that at motorway like roads (constant noise with no pauses) people are 7dB "more annoyed" than people living by roads with scattered traffic and pauses at the same noise levels. It is thus concluded that:

- Studies, incl. a background article for the WHO report on Environmental Noise Guidelines from 2018, supports the Danish noise limit on L_{den} = 58 dB for ordinary roads for 10 % highly annoyed
- Studies show that motorways are more annoying at the same noise levels than other roads. The Danish investigations point to L_{den} = 52 dB for 10 % highly annoyed. The Swiss study suggests L_{den} = 51 dB for 10% highly annoyed

It is important to note how much more annoying motorway noise is perceived. This should be taken into account when performing socio-economic evaluations of infrastructure projects and when determining guidelines for road noise.

Keywords: Noise from motorways, noise from urban roads, dose-response curves, noise guidelines.

1 Introduction

The Danish guideline for noise from roads is currently set at L_{den} = 58 dB for homes along urban roads and motorways [1]. This should correspond to approx. 10 % of the population being highly annoyed by the noise. The WHO report from 2018 recommends a limit value of L_{den} = 53 dB to keep the highly annoyance below 10 % [2]. A study from the Danish Road Directorate questions whether the limit value is correct in relation to the noise annoyance from motorways [13].

Therefore, the Danish Environmental Protection Agency (EPA) in 2020 has requested that socio-acoustic studies from the literature be found and referenced in order to shed light on whether the Danish EPA's limit values [1] have been set on a professionally correct basis. On this background FORCE Technology has performed the literature search and analysis [4].

Dose-response curves indicate the relationship between the exposure or dose, here usually the noise level, L_{den}, and the effect e.g. the percentage of highly annoyed. The curve can be derived from different mathematical formulas, e.g. second or third-degree polynomials, normal distribution or other formulas. Dose-response curves between noise nuisance and L_{den} as well as 95 % confidence intervals can be calculated, for example, by means of logistic regression, where responses regarding noise nuisance are divided into e.g. 1 dB noise classes which are weighted according to the number of responses. Logistic regression has been used in recent Danish studies [3] [13].

The logistic dose-response curves are expressed as:

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

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

The Dutch researcher Miedema et. al. dose-response curves [5], also called EU reference curves after [6], are often used as a reference for the studies presented. They come from 26 different international studies with a total of 19,172 observations. These curves represent a collection of many different studies, and the proportion of highways, roads, urban roads and city streets are unknown.
Initially, it should be noted that the result of a study of noise annoyance depends on both input data and analysis method. In this context, input data comes partly from population surveys which can be performed in different ways that can affect the result and partly from noise calculations where different noise propagation models have been used which can also affect the result. You can also use different analysis methods to arrive at a connection between noise load (expressed e.g. by L_{den}) and the noise (expressed e.g. by % highly annoyed). For these reasons, it is rarely possible to compare different studies of the noises on a 1:1 basis. It must therefore be made clear that minor differences between different studies may just as well be due to differences in methods as differences in noise nuisance.

2 Kastka´s survey

In 1976 and 1988 Kastka et. al. performed a series of surveys with a total of 525 respondents [7]. It was primarily about the annoyance of highway noise before and after the construction of noise barriers along a number of motorways but also included surveys on urban roads [7]. FORCE has reanalysed the original results [8] and this shows that the noise annoyance from motorways in Kastka’s study is significantly higher than the annoyance from ordinary roads in cities at the same noise level in the range 45-75 dB (se Figure 1).

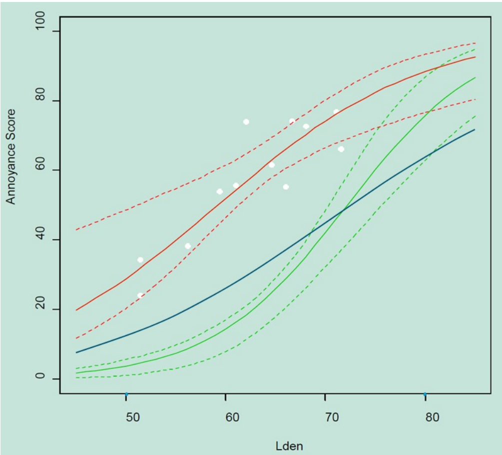

Figure 1 – Reanalysis performed by FORCE [8] of data from Kastka’s et. al. survey in 1976 and 1988. Correlation found by logistic regression between L_{den} and annoyance score for motorways without barriers (red curve) and for roads in cities (green curve) based on data from [7] and Miedema’s curve (blue). The dotted curves indicate 95 % confidence intervals. Figure from [8].

3 Miedema 1992

The purpose of a Miedema study from 1993 [9] was to shed light on differences in annoyance from the different types of noise sources, and in the analysis of noise from roads, a distinction is made between motorways and other roads. A series of studies conducted before 1992 with a total of 5144 respondents were included.
The results for "other roads" are broadly similar to the later EU reference curve (see Figure 2). It appears that the noise from motorways gives higher annoyance at the same noise level. The annoyance from motorways is obtained at an approx. 5 dB lower noise level compared to other roads.

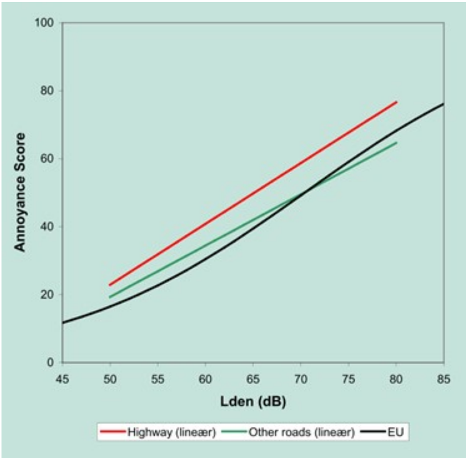

Figure 2 – Relationship between L_{den} and annoyance score for motorways and other roads from Miedema's pre-1992 studies [9], compared with the Miedema (EU dose-response curve) [6].

Two researchers who has contributed to the WHO report from 2018 have been contacted [10][11]. They state that the observation that traffic on local roads causes less annoyance than traffic on motorways at the same L_{den} was well known in the early days of questionnaire-based noise studies but was somehow forgotten. Perhaps the desire for simplicity in communication can explain that the difference has not been elucidated. It was also mentioned that Miedema has not separated motorway traffic from other traffic in his later work because in the later and more extended international data sets, he could not find a significant difference for the two types of road traffic.

4 Danish investigations from motorway M3 and urban roads 2003 to 2009

In connection with the development of noise-reducing road surfaces, the Danish Road Directorate conducted an annoyance survey in 2007 and 2008 before and after the replacement of old road surfaces with new noise-reducing types on two urban roads in Copenhagen [3] [12]. The overall results are based on 2870 respondents. The studies showed that the noise annoyance was reduced and that the dose-response curves were the same in the situation before and after. In 2003 and 2009 the Danish Road Directorate has also carried out a study of noise annoyance in connection with the extension of the motorway M3 from four to six lanes [3] [12]. The before and after situation contain a total of 1350 respondents.
The main results from these two surveys can be seen in Figure 3. The results show that the dose-response curve for the motorway M3 is significantly higher over 58 dB than the curve from the urban roads. At the same time it shows that the curve for urban roads is quite similar to the Miedema curve.
It can be seen that:

- At 58 dB, 9.8 % are highly annoyed by motorway M3
- At 58 dB, 8,9 % are highly annoyed by urban roads
- At 58 dB, 7.9 % are highly annoyed according to the Miedema curve (EU reference)

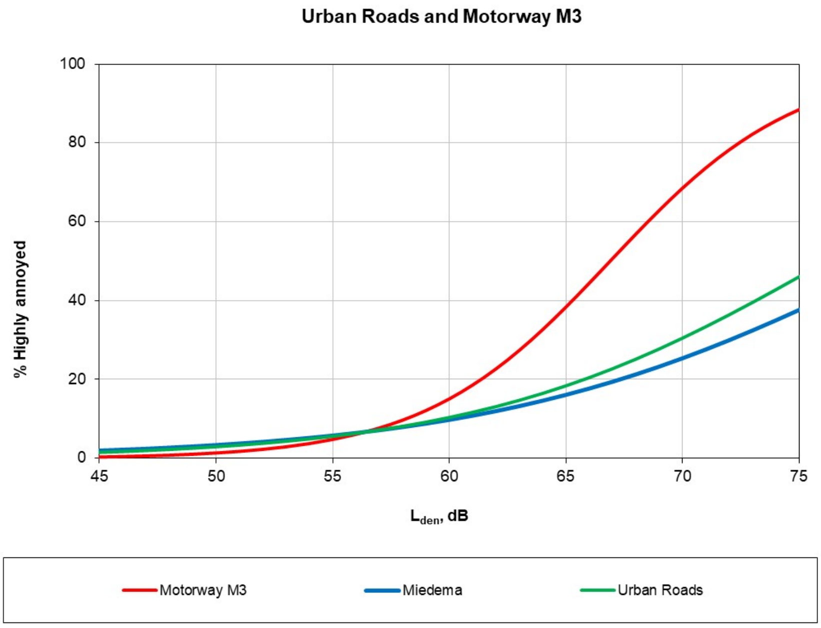

Figure 3 – Logistic regression curves for highly annoyed (average of before and after situation). Motorway M3 (red curve), Urban roads (green curve) and the Miedema curve (blue).
Danish data from 2003 to 2009 [12].

5 Danish Road Directorate investigations of motorways and urban roads 2014

In 2014 the Danish Road Directorate carried out a large study to investigate the differences in noise annoyance from motorways and urban roads [13]. Motorways include 6 sections that affect residential areas in three large cities and affect both urban communities and rural housing throughout Denmark. In total, the 6 sections represent 200 km motorway corresponding to 10 % of the total Danish motorway system. The urban roads include 7 residential areas with a total of 22 road sections in the three largest cities in Denmark. The roads in the cities are both urban roads with little traffic, shopping streets and major busy roads. The overall results are based on 6.761 respondents.
The study must be considered to be very representative of the relation between noise annoyance and noise levels from the current road types in Denmark. The study showed, that the noise annoyance is highest on motorways and that the difference increases with increasing noise levels (see Figure 4). The study showed good agreement with previous studies of urban roads and with the Miedema curve. Throughout the range of noise levels, from 48 to 75 dB, there is a significant difference between the urban and motorway annoyance curves:

- At 58 dB, 21.8 % are highly annoyed by motorways
- At 51.8 dB, 10 % are highly annoyed by the motorways
- At 58 dB, 7.5 % are highly annoyed by urban roads
- At 58 dB, 7.9 % are highly annoyed according to the Miedema curve (EU reference)

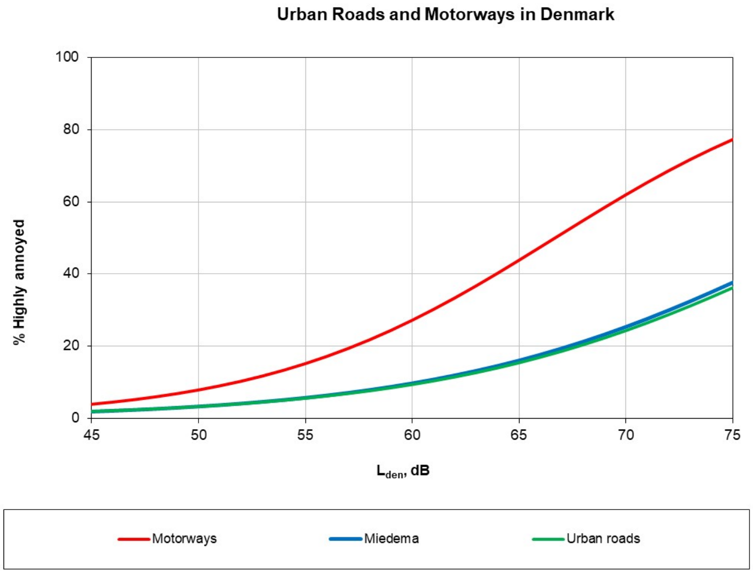

Figure 4 – Logistic regression curves for highly annoyed on urban roads (green) and motorways (red) in Denmark compared to the Miedema curve (blue). Danish data from 2014 [13].

6 The WHO report from 2018

The WHO report "Environmental Noise Guidelines for the European Region" [2] is based on field studies reported in the period 2000-2014 with a total of 34,112 respondents. The studies come from different regions of the world. The Danish studies presented in Section 4 and 5 are not included in the large dataset. There is no division in whether the studies come from urban roads or motorways. It arrives at a total dose-response curve (black curve in Figure 5) which is the basis for a recommended limit value for road traffic noise at L_{den} = 53 dB; the noise level where 10 % are highly annoyed. The Miedema curve can also be seen in Figure 5 as the red curve.

In the background article for the WHO report's section on noise [14], it appears that the full data set for the WHO report includes five studies from alpine Wipptal and Inntal valleys in Austria (the black dots in Figure 5) where the noise annoyance is unusually high, as well as a number of Asian studies (the red dots in Figure 5) including a large study from Hong Kong where the noise annoyance is very low. The article states that the comparability of the alpine studies with studies from more or less flat landscapes as well as the comparability of studies with and without air-conditioned homes (including in Hong Kong) can be questioned.

Therefore, an additional dose-response curve has been calculated for the WHO data set for road traffic noise excluding the five alpine studies and the 10 Asian studies (see Figure 6). It does not appear specifically from the article [14] which studies are excluded in the reduced data set, but when Austrian, Swiss and Asian studies are omitted, 10 studies with a total of 6,775 respondents are obtained. This is the same number of respondents as the large Danish study of annoyance from motorways and urban roads (with 6,761 respondents) precented in Section 5.

The dose-response curve for the reduced WHO data set corresponds better to Danish conditions. According to this curve 10 % are highly annoyed at a level of L_{den} = 59 dB. In [4] a logistics regression of the same data has been performed [4]. This results in 10 % being highly annoyed at a level of L_{den} = 58 dB.

It must thus be concluded that when Asian and Alpine results are removed from the basis on which the WHO report is based, there is no significant difference between the current Danish limit value for road traffic noise at L_{den} = 58 dB and at the value that the background material for the WHO report results in. Incidentally, both do not differ significantly from the previously used Miedema curve.

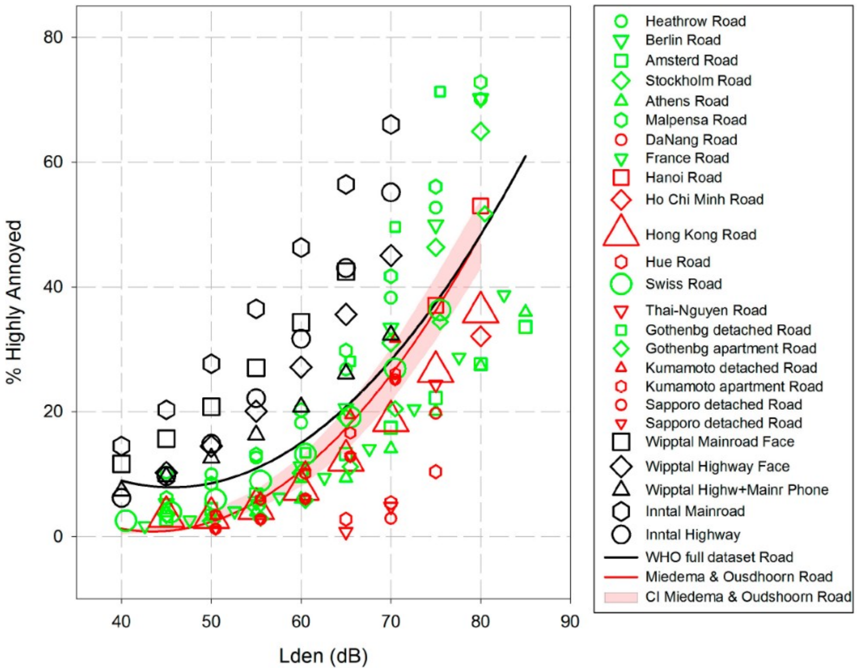

Figure 5 – The overall dose-response curve from the WHO report [2] is shown in black and is based on 25 studies of road noise with a total of 34,112 respondents. The red curve is the Miedema dose-response curve. Black symbols refer to valley studies in the Alps, red symbols refer to Asian studies, and green symbols refer to European studies without a valley. The size of the data points corresponds to the number of participants in the respective study. Figure from [2].

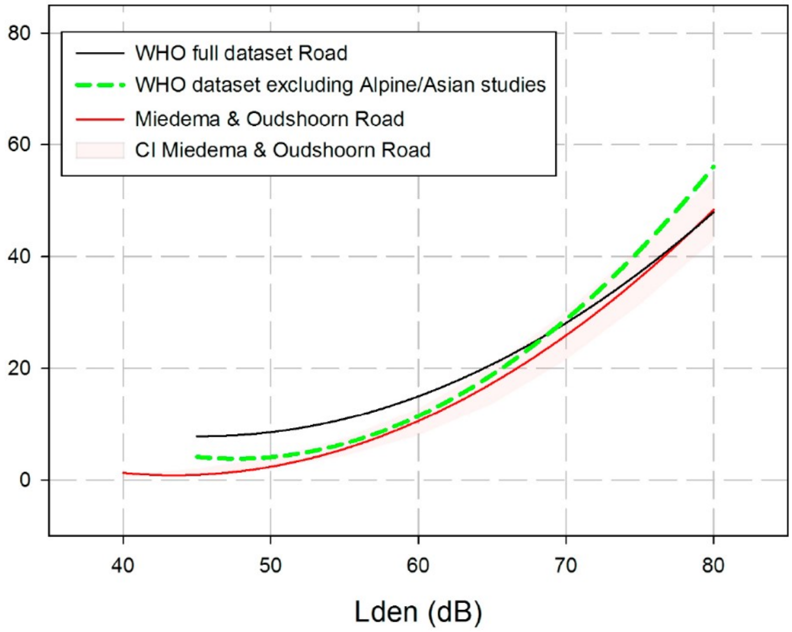

Figure 6 – Quadratic regression curves of the ratio between L_{den} and the calculated percentage of highly annoyed for the full WHO data set with 25 studies (black curve) versus 10 European studies (dotted green curve, same data set but excluding alpine and Asian studies). For comparison the Miedema curve in red is shown. Figure from [14.

It is worth noting that it is mentioned in the background article [14] that the scientific literature shows signs that two factors affect the perception of road traffic noise:

- Availability of a quiet facade
- Motorway versus urban road (supplementary materials, see [14] page 39 with reference to [9].

The response may vary between different studies depending on the proportion of respondents with or without a quiet façade or the proportion of respondents who live near motorways or urban roads, respectively.
The WHO report is an important tool for creating a political focus on the negative effects of noise, but the wide spread in data illustrates the importance of basing local limit values on surveys that are as representative as possible of the current area or country to a greater extent than on the average curve of the WHO report.

7 Austrian survey 2004-2006

In the article [15] there is a comparison between two Austrian regional studies of traffic noise annoyance in two alpine valleys Wipptal and Unterintal performed in 2004 to 2006 with the Miedema curve. There is also an investigation whether there is a difference between annoyance from motorways and other roads. The studies have a total of 5,273 respondents.

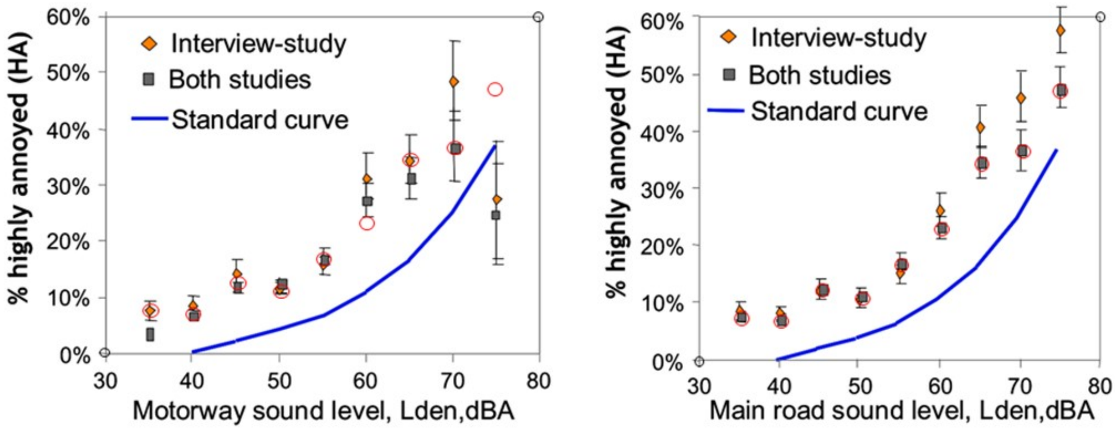

Figure 7 – Dose-response relationships for Wipptal over motorway (left) and main road (right) compared to the Miedema curve (blue). Vertical lines indicate 95 % confidence intervals. The red circles are the response of the main roads (right) which are also plotted on the graph of the motorways to the left to facilitate the comparison of the data points. Figure from [15].

In the Wipptal valley, the annoyance response for both motorways and for main roads is at an approx. 10 dB lower noise level than for the EU curve (see Figure 7). Meaning that the population here is as annoyed as the EU reference curve, just at approx. 10 dB lower levels. Incidentally, there is no significant difference between motorways and main roads.
In the Unterintal valley, the annoyance is generally higher than in the Wipptal valley, and the noise annoyance is generally higher for main roads than for motorways (see Figure 8). The authors of [15] find it surprising. They list a number of factors that may be the cause. It is concluded that in complex situations, the sum of such factors can in some cases lead to greater annoyance from main roads than from motorways, and that the use of international standard curves to assess environmental impacts can lead to misleading regional results.
The article recognizes the standardized annoyance curves (like in the WHO report [2]) as a step forward in implementing an evidence-based policy at national and supranational level. However, they believe that these general curves are not suitable for small-scale impact assessments, such as at regional level, at community level or at project level where an environmental health impact assessment is carried out. This is supported by the large spread seen in the studies that are the background for the standardized WHO dose-response curve (see Figure 5).

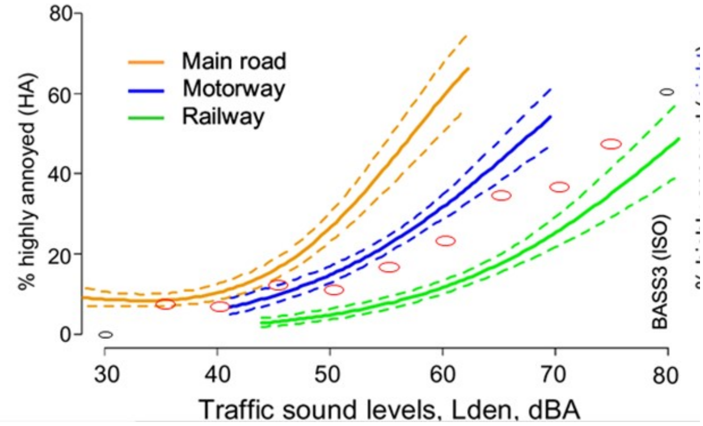

Figure 8 – Noise annoyance in Unterintal. The dotted lines indicate the confidence intervals of the curves. The data points for main roads (Wipptal) are plotted for comparison (red ellipses). Figure from [15].

8 The SiRENE project from Switzerland 2014-2017

The Swiss SIRENE project was conducted from 2014 to 2017 including a total of 5,364 respondents [16] exposed to road noise. A major aim was to establish dose-response relationships that are representative of the average Swiss population affected by transport noise. The study's led to average dose-response curves (see Figure 9), which show that 10% are highly annoyed by road noise at a level of L_{den} = approx. 58 dB.

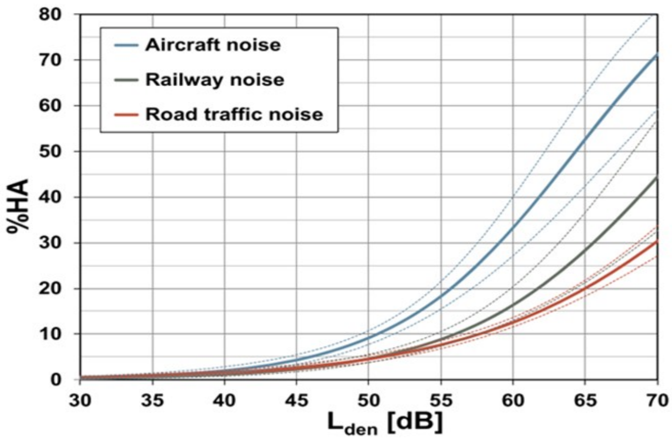

Figure 9 – Dose-response curves for highly annoyed by road, rail and aircraft noise including 95 % confidence intervals. Figure from [16].

It has also been a goal to shed light on the extent to which the acoustic indicator "Intermittency Ratio" (IR) (defined in [16]) which reflects the level of noise events in relation to a background level, influences the perceived noise.
The results also showed that roads with a low Intermittent Ratio (as 10 %), like motorways with heavy traffic gave higher annoyance than roads with a high IR (as 90 %), like roads with light traffic and quiet periods between incidents, roads where the noise consists almost exclusively of single passages with pauses between the noise events which are typically urban roads with less traffic (see Figure 10). There was a shift of about 7 dB between the dose-response curves for low and high IR values which may indicate that highways are more annoying than urban roads at the same noise level.

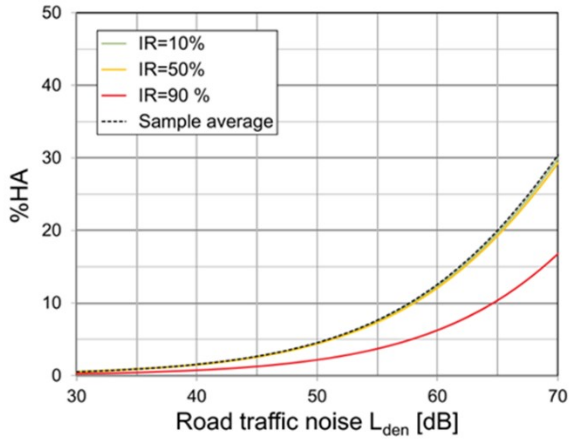

Figure 10 – Modelled percentage highly annoyed of road traffic noise for three different IR values (10 %, 50 %, 90 %). Figure from [16].

9 Conclusions

The WHO report from 2018 is based on a broad collection of noise surveys. If the Asian and Austrian alpine surveys are omitted, a noise limit of L_{den} = 58 dB is obtained for 10 % highly annoyed which does not deviate significantly from the Danish noise limit. The two Danish surveys from 2007-2008 and 2014 which include urban roads with a total of 6,188 respondents provide results that support the current limit value. The Swiss study with 5,364 respondents from 2014-2017 shows that 10 % are highly annoyed by a noise level of L_{den} = approx. 58 dB and thus also supports the Danish noise limit. The here mentioned results are broadly in line with the general European annoyance curves (Miedema curves).

A few early studies from before 1992 show that noise from motorways is more annoying than noise from other roads equivalent to 5 dB or more. The Danish survey of 6,761 respondents from 2014 with representative Danish motorways shows that the noise from the motorways is more annoying than the noise from urban roads. The study shows that at 52 dB, 10 % is highly annoyed by motorways, which is 6 dB less than for urban roads. People living along motorways are significantly more annoyed than the general EU annoyance curves (Miedema curves). The Swiss study shows that roads with a motorway-like noise character, i.e. a relatively constant noise without pauses is approx. 7 dB more annoying than roads with scattered traffic and breaks at the same noise levels. This should be taken into account when determining guidelines for road noise.

The cost-benefit analyses that are often carried by e.g. new road projects, also includes a pricing of the noise load of residential areas. The results could raise a consideration as to whether the noise pricing should be reassessed and increased for motorways.

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References

[1] Vejledning fra Miljøstyrelsen Nr. 4: *Noise from Roads (*in Danish *Støj fra veje),* 2007 See: www.mst.dk.

[2] World Health Organization (WHO) Environmental: *Noise Guidelines for the European Region*, 2018. See www.euro.who.int

[3] Petersen, T. H.; Ray, G. L. *Støjgener fra byveje og motorvej M3*. Vejdirektoratet, Rapport 447, 2013. See: www.vd.dk

[4] Petersen, T. H.; Bendtsen, H. *Annoyance from Road Traffic – a literature study* (in Danish: *Genevirkning af vejtrafikstøj – et litteraturstudie*), FORCE Technology, Technical Note TC-101644, 2021. See: www.mst.dk

[5] Miedema, H. M. E.; Oudshoorn, C. G. M. *Annoyance from Transportation Noise. Relationships with Exposure Metrics DNL and DENL and Their Confidence Intervals,* Environmental Health Perspectives. 109, vol. 109, no. 4, 2001, pp 409-416.

[6] European Commission: *Position paper on dose response relationships between transportation noise and annoyance*, 2002, pp 1-40.

[7] Kastka, J.; Buchta, E.; Ritterstaedt, U.; Paulsen, R.; Mau, U. *The long term effect of noise protection barriers on the annoyance response of residents*, J. Sound Vib., vol. 184, no. 5, 1995, pp 823-852.

[8] Pedersen, T. H.; Plovsing, B.; Backalarz, C.; Ray, G. L. *Difference between the annoyance of noise from motorway and noise from other roads* (in Danish *Forskel mellem genevirkning af motorvejsstøj og støj fra andre veje*), 2013.

[9] Miedema, H. M. E. *Response functions for environmental noise in residential areas*, 1993.

[10] Personal communication with Dick Botteldooren. Autumn 2020.

[11] Personal communication with Peter Lercher. Autumn 2020.

[12] Bendtsen, H.; Pedersen, T. H.; Ray, G. L.; Kragh, J. *Noise annoyance for a motorway compared to urban roads*, in INTERNOISE, 2014.

[13] Fryd, J.; Michelsen, L. N.; Bendtsen, H.; Iversen, L. M.; Petersen, T. H. *Noise annoyance from urban roads and motorways*, Danish Road Directorate, Report 565, 2016. See: www.vd.dk.

[14] Guski, R.; Schreckenberg, D.; Schuemer, R. *Supplementary Materials: WHO environmental noise guidelines for the European region: A systematic review on environmental noise and annoyance*, Int. J. Environ. Res. Public Health, vol. 14, no. 12, 2017, pp 1-39.

[15] Lercher, P.; de Greve, B.; Botteldooren, D.; Rüdisser, J. *A comparison of regional noise-annoyance-curves in alpine areas with the European standard curves*, Proc. 9th Congr. Int. Comm. Biol. Eff. noise (ICBEN 2008), no. August 2015, 2008, pp 562-570.

[16] Brink, M. et al. *A survey on exposure-response relationships for road, rail, and aircraft noise annoyance: Differences between continuous and intermittent noise*, Environ. Int., vol. 125, no. February, 2019, pp 277-290.