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FAMOS - FActors MOderating people's Subjective reactions to noise

Project Report

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FActors MOderating people's Subjective reactions to noise
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by

Sebastian Eggers, LÄRMKONTOR
Christian Popp, LÄRMKONTOR
Søren Vase Legarth, FORCE Technology
Torben Holm Pedersen, FORCE Technology
Christer P. Volk, FORCE Technology
Hans Bendtsen, FORCE Technology
Truls Gjestland, SINTEF

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The Project Executive Board for this programme consisted of:

Sébastien Marcocci	SPW Mobilité et Infrastructures, Belgium
Lene Nøhr Michelsen	Vejdirektoratet, Denmark
Stephen Byrne	Transport Infrastructure Ireland, Ireland
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Ian Holmes	National Highways, England

Consortium Partners:

- FORCE Technology in Denmark (Project leader)
- LÄRMKONTOR in Germany
- SINTEF in Norway

1. Executive summary

1.1. Introduction

The World Health Organization has estimated that about **1.6 million healthy life-years are lost annually in Europe due to road traffic noise** [1]. About half of these can be related to the subjective element: annoyance. Even when the road administrations have used all the technically feasible and economically possible measures to reduce the noise, there might still be a need for a further reduction of the annoyance perceived by people exposed to road noise to help to support noise abatements.

Former analyses of the results from noise surveys reveal that **only about 1/3 of the variance in the annoyance response is caused by the cumulative noise level itself (L_{EQ}, L_{DN}, L_{DEN}, or similar)**, whereas the other **2/3 are partially determined by other factors, often referred to as "non-acoustic factors"** [2]. The surveys display a wide range for the annoyance response. Differences in noise levels of up to L_{den} 20-25 dB to evoke a certain percentage of annoyance are not uncommon. This means that the annoyance response can be altered within wide limits without doing any changes to the actual noise level. So, when all practical noise reduction measures have been applied, the noise impact can still be reduced by making changes in the non-acoustic factors known to moderate the annoyance response.

FAMOS is the acronym for "FActors MOderating people's Subjective reactions to road noise", https://famos-study.eu/. The project consortium consists of three partners:

- FORCE Technology in Denmark (Project leader)
- LÄRMKONTOR in Germany
- SINTEF in Norway

The FAMOS project is about analysing and testing if non-acoustic moderators for noise annoyance can be a promising tool for obtaining an additional supplement to other noise and annoyance mitigation measures to reduce the annoyance without reducing the noise level further. Scientific methods have been used to find, extract, and analyse data and turn the results into models formulated for practical use with illustrative examples. It has been quantified how different factors modify people's subjective reactions to road traffic noise.

Reports from previous surveys have been systematically analysed in order to describe the different annoyance moderators, and the effect of these moderators have been expressed in equivalent subjective decibel changes, the **"Annoyance equivalent noise level shift"**, L_{eas}.. This is the (hypothetical) shift in noise level that will give the same change in annoyance as the presence or absence of a moderator and a practical way to express the effect of a moderator. It should not be confused with any actual changes in noise levels. So, as an example: The existence of a moderator will change the annoyance response in the same way as a reduction (or increase) of a given range in decibels in the noise level. The results of this work are presented in Chapter 3.

1.2. Moderator search and qualification

1.2.1. Identification and literature analysis

As a main fundamental of the FAMOS project, the identification of possible moderators was carried out. Several factors can change the perceived annoyance by people exposed to road traffic noise. Reducing the noise is an obvious factor, but many other factors have an influence on the annoyance. Moderators are factors that can change the relation between the noise exposure and the annoyance response.

A list of possible moderators was systematically derived on the background of the international literature survey on moderators to perceived annoyance performed in the first work package of FAMOS [3].

The non-acoustic factors that will modify the annoyance response can be categorized in different ways:

- The **road itself** and its **immediate surroundings** such as type of road, traffic volume, speed limit, road pavement, barriers, visual appearance, etc. These are factors that to a large extent can be controlled or influenced by the road owner.
- Factors pertaining to the **neighbourhood** such as type and location/orientation of residences, prevalence of community conveniences like shops, schools, parks, playgrounds, etc. neighbourhood traffic conditions and so on. These factors can only to a small extent be influenced by the road owner. Chances for control are better at completely new developments than for projects in existing communities.
- **Relationship** between the local residents and the road owner. Do they feel a personal ownership to the road and benefit from its existence? Have the residents had a chance to be involved the planning and construction process? Do the residents/neighbours trust the decision makers and road administration? These factors deal with public relations and can to a large extent be controlled and managed by the road owner.
- Factors completely **out of control by the road owner**. However, it is important to recognize that such factors exist and to know how they affect the annoyance response. These are typically personal and demographic factors like age, gender, income, noise sensitivity, etc.

1.2.2. Priorities moderators

The results from surveys on annoyance from road traffic noise indicate that the annoyance response is affected by a set of non-acoustic factors. The influence of these factors, *i.e.,* the magnitude of the effect, varies, and the feasibility and practicality of manipulating these factors depends on local circumstances. The FAMOS project should focus on factors that have a large potential for annoyance reduction, and that are easily implemented. In order to prioritize different modifiers, the following criteria have been considered:

- To which degree is this modifier controllable by the road authority?
- What is the potential for shift in the annoyance response?
- What is the quality of existing data that support the conclusions?

The following **preliminary list of modifying factors** for further studies has been developed based on these criteria:

- Visual appearance of the road and its immediate surroundings, e.g., visibility of traffic, greenery and the type and visual appearance of mitigation measures
- Orientation of dwelling, access to a quiet side of the dwelling
- Attitudes and relations between the community and the road authorities
- Neighbourhood soundscape
- Perceived traffic safety

1.3. Data collection and hypothesis testing

Three different methods for data collection were investigated within a limited experimental setup to investigate the suitability of methods for measuring the effect of moderators in future road projects, for Hypothesis testing for already identified moderators and for gap filling for knowledge missing for important moderators retrieved.

The **sound walks** were successful in the sense that they gave a good representation of the sound sources in a sound source hierarchy (sound source taxonomy). The results gave detailed characteristics of the six measuring positions. A “systems factor map” could be constructed, which gave a clear picture of the relations between the six measuring positions, and why they differed. By combining the assessments of annoyance from the sound walks with the measured noise levels it was possible to make a model (dose-response curve) for the annoyance as function of the noise level (L_{Aeq}) with a good fit (R^2 = 0,9). The results for greenery and the visibility of the traffic are summarized as part of the hypothesis testing.

The **mini survey** was designed with limited extent and the non-personal address of respondents. A general correlation and a confirmation of earlier project results was assessed. As for noise annoyance in general, the responses mostly showed an expected outcome although several respondents reported a higher annoyance although the noise levels were supposed to be reduced. Results for as well visibility and greenery as expectations and expectations met were analysed as part of the hypothesis testing. Overall, the results showed that moderators previously identified in the FAMOS project had a contribution to the perceived noise annoyance. A quantification on the effect, i.e., changes in noise level, in CTL or similar, cannot be derived due to the low number of participants.

For the **listening tests**, several locations were selected so that there were variations in moderators of interest (visibility of the traffic, amount of greenery, type, and appearance of noise screens). For all positions, a significant increase of the annoyance with the noise level increasing was found. From the results on the annoyance assessments, logistic dose-response curves could be constructed with a good fit (R^2 > 0.95 on the mean values). The dose-response curves show that the visual perception has a clear and significant influence on the perception of annoyance from the noise. Differences in the annoyance corresponded to level differences, the annoyance equivalent change in noise levels, up to 4 dB for the same sound stimuli. Some of the results deviated from findings elsewhere and it was concluded that it is important that the assessors have a full understanding of the context, e.g. by a short introductory video tour showing the road and its surroundings or by using virtual reality to enhance the assessors envelopment in the scenario.

1.4. Modelling

Supplementing the findings of the former work packages, additional modelling should concentrate on the most relevant moderators already retrieved. Based on input from the two large Danish questionnaire surveys on perceived noise annoyance, the model can demonstrate the effect of various moderators.

The models provide strong evidence for the effect of the moderators that are found significant in this study. The data from the Danish studies had a very high quality and covered a broad range of questions many of which were identified in the literature as relevant. The confirms the findings in the literature study to a large extent. The contribution of the modelling is also to further investigate the potential of including more moderators and more interactions between moderators in a multiple regression model and further qualify the list of “questions of importance” to collect in future studies.

1.5. Synthesis on moderators of noise annoyance

Evidence was found that a **wide range of moderators affects the noise annoyance**. Regarding the “direction” of the effect size, it depends on the situation itself: when implementing a “favourable moderator”, like improving greenery, the effect size works towards “lower annoyance”. Whenever a moderator is removed (like greenery) or changed towards a less favourable situation (like increase in neighbourhood noise), the same effect might occur towards “higher annoyance”.

The selected moderators and their **order of magnitude** can be seen in

Moderator	Effect size
Trust / acceptance	±10 dB
Expectations met	5 to 10 dB
Access to silent side	6 to 9 dB
Low/no visibility of the road	2 to 10 dB
Increased traffic volume	~1.5 dB per doubling
Neighbourhood noise	up to 10 dB
Orientation of outdoor areas	8 to 12 dB
Traffic safety expectations	5 to 8 dB
Vegetation and greenery	6 to 10 dB
Visual appearance of the barrier	2 dB

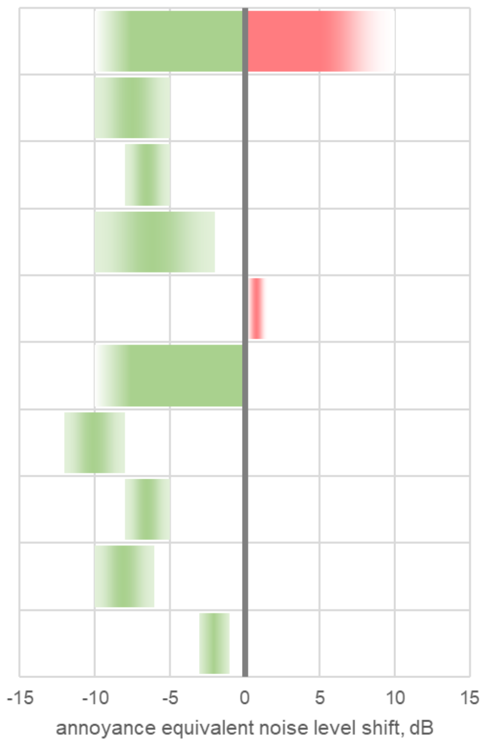

Figure 1. Except “trust/acceptance”, only the “positive effect” is plotted. This depicts the **possible gain that is achievable by NRAs** for each moderator, based on a situation “without positive influence of a moderator”. For “trust/acceptance”, the possible effect size of ± 10 dB shows that this moderator might in most cases have an “average” from which a change is possible in both directions. So even without further influence or consideration, the annoyance might increase.

Moderator	Effect size
Trust / acceptance	±10 dB
Expectations met	5 to 10 dB
Access to silent side	6 to 9 dB
Low/no visibility of the road	2 to 10 dB
Increased traffic volume	~1.5 dB per doubling
Neighbourhood noise	up to 10 dB
Orientation of outdoor areas	8 to 12 dB
Traffic safety expectations	5 to 8 dB

Vegetation and greenery	6 to 10 dB
Visual appearance of the barrier	2 dB

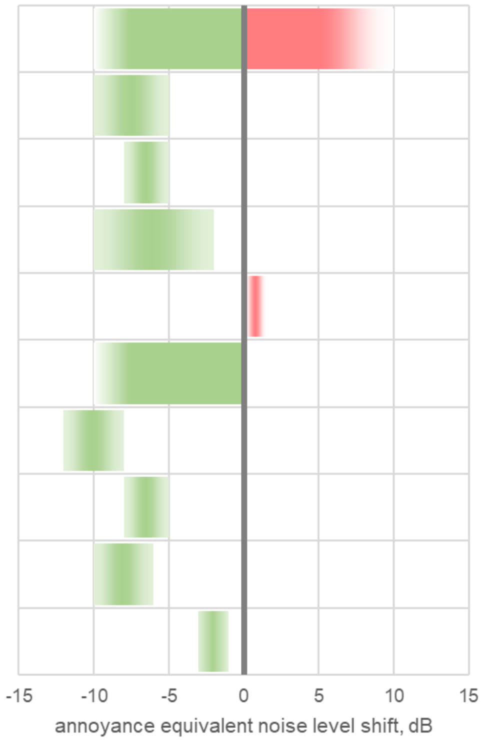

Figure 1: Overview on effect sizes

Regarding uncertainties, the literature analysis shows a **high variance** in the annoyance equivalent noise level shifts for some moderators between different surveys. Results of listening tests, mini surveys and sound walks also showed a high uncertainty, mostly due to a low number of respondents.

For some moderators, **dependencies and interactions** can be found. The effect size suggests that the effects are not simply to combine for different moderators, as they would result in a change higher than actual noise levels (e.g., ± 10 dB for trust, up to 10 dB for expectations, 10 dB for vegetation and greenery and so on).

Different moderators might have a **positive or negative influence on each other**. For most effects, an increase can be expected when interacting. For trust/acceptance, a poor quality of the other moderators can result in negative effects.

Possible positive or negative influence of the different moderators might be:

- The appearance of a green noise barrier might influence the visual greenery and thus have a higher effect.
- Visual greenery might cover the view to a noise barrier and thus make the influence of the visual appearance of the barrier irrelevant.
- If the road is not visible, the perceived safety might increase.
- If access to rooms on quiet side is given, outdoor areas can be oriented there as well.
- Reduced neighbourhood noise can increase the chance of a quiet side.
- Noise mitigation measures like barriers, embankments or noise reducing pavement on a major road might not only decrease noise levels at dwellings, but also in the whole neighbourhood. In opposite, soundproof windows only decrease the noise for residents of single dwellings indoors.

Whenever multiple moderators could apply, these with the highest effect and the highest emphasis should primarily be considered. Those moderators which are just slightly addressed, like a minor change in visual greenery, could be considered with their effects to other moderators but otherwise neglected.

1.6. Outlook

In the FAMOS project, a series of moderators was researched that can change the noise annoyance by people living in neighbourhoods exposed to road traffic noise e.g. from motorways. The effect of these moderators is present even though no measures are taken to reduce the actual noise levels. Primary research subject were acoustic moderators that could be controlled by (national) road administrations. Non-controllable factors and non-acoustical factors (such as personal factors) are not investigated.

To facilitate future data collection, the FAMOS project has also tested three rather simple methods to investigate the perceived annoyance of road traffic noise. Insights on conducting those methods can help road administrations in order to investigate the effect of new road or noise abatement projects (best practice / worst practice). Valuable information includes information on number of respondents, suggestions for common questions, situations/locations for surveys etc.

Results of similar surveys can be used to derive new information about moderators and their effect on perceived annoyance. Elaboration of a common basis for questions to be used in surveys would be helpful for getting more and more reliable data on the effect of the moderators.

An advanced data foundation from surveys will make it possible to improve the models for noise annoyance including the influence of the moderators. Questions relating to the moderators should be included in the survey questions in future surveys (for inspiration find the questions used in the Motorway and Copenhagen study which is basis for the modelling in this project and the mini survey for the Hamburg region).

In addition to this project documentation, a **FAMOS guidebook** (Deliverable D.4.5 of the project) is published. The knowledge found on these moderators has been used as the foundation for developing guidebook that National Road Administrations as well as other administrations can use in planning of new roads, enlargements of existing roads as well as in noise abatement projects.

2. Table of content

Content

3. Preface

This report has been produced as a part of the FAMOS project. FAMOS responds to the questions of the Conference of European Road Directors (CEDR) call in 2018 on Noise and Nuisance: Psycho-Acoustics: Improved Understanding of People's Subjective Reactions to Road Noise.

According to the World Health Organization (WHO), road traffic noise is one of the most important environmental risks to health" and a major contributor to healthy life-years lost in Europe [3]. About half of these can be related to the subjective element "annoyance", which is only by about 1/3 caused by the cumulative noise level itself, whereas the other 2/3 are determined by so-called "non-acoustic factors".

FAMOS quantifies how different factors modify people's subjective reactions to road traffic noise. The project has used scientific methods to find, extract and analyse data from existing annoyance surveys. The most promising findings have been investigated by the use of questionnaire studies, listening testing in the laboratory and soundscape measurements/sound walks. The results are also basis for a handbook on how "moderators" can be used by road administrations to reduce noise annoyance or the effect of the noise abatement measures can be optimized by making changes in the non-acoustic factors.

FAMOS is the acronym for "FActors MOderating people's Subjective reactions to road noise". Information about the FAMOS project can be seen on the project homepage: https://famos-study.eu/. The project is carried out over two years and started in December 2019. The project consortium consists of three partners:

- FORCE Technology in Denmark (Project leader)
- LÄRMKONTOR in Germany
- SINTEF in Norway

This report has been produced within Work Package WP 4 of the project, which deals with "Dissemination etc." and is led by FORCE. This report presents the scientific results of the four work packages of the project. The report includes:

- the results of a large international literature study on noise annoyance surveys
- a derived and prioritized list of moderators
- results of hypothesis testing in listening test, mini surveys, and sound walks,
- additional modelling based on Danish survey results
- a synthesis of the results, also giving orders of magnitudes of moderator effects, uncertainties, and examples of application in practical terms.

The report is produced by Sebastian Eggers from LÄRMKONTOR as Deliverable D.4.6 of the FAMOS project. The report has been quality controlled by Torben Holm Pedersen and Hans Bendtsen from FORCE as well as by Truls Gjestland from SINTEF. The CEDR Transnational Road Research Programme funded by Belgium – Wallonia, Denmark, Ireland, Netherlands, Norway, Sweden, and United Kingdom has financed the FAMOS project.

4. Introduction

The World Health Organization has estimated that about 1.6 million healthy life-years are lost annually in Europe due to road traffic noise [3]. About half of these can be related to the subjective element: annoyance. Even when the road administrations have used all the technically feasible and economically possible measures to reduce the noise, there might still be a need for a further reduction of the annoyance perceived by people exposed to road noise to help to support noise abatements.

Former analyses of the results from noise surveys reveal that only about 1/3 of the variance in the annoyance response is caused by the cumulative noise level itself (L_{EQ}, L_{DN}, L_{DEN}, or similar). The other 2/3 are often referred to as “non-acoustic factors” [1]. The surveys display a wide range for the annoyance response. Differences in noise levels of up to L_{den} 20-25 dB to evoke a certain percentage of annoyance are not uncommon. This means that the annoyance response can be altered within wide limits without doing any changes to the actual noise level. So, when all practical noise reduction measures have been applied, the noise impact can still be reduced by making changes in the non-acoustic factors known to moderate the annoyance response.

Ten percent highly annoyed is defined as the relevant risk increase guidance level in “WHO Environmental Noise Guidelines for the European Region” 2018 [3], and this is a huge challenge for the National Road Administrations. All means for decreasing the annoyance and the consequential health effects are needed and that makes the CEDR 2018 call on Noise and Nuisance an important topic.

The FAMOS project is about analysing and testing if non-acoustic moderators for noise annoyance can be a promising tool for obtaining an additional supplement to other noise and annoyance mitigation measures to reduce the annoyance without reducing the noise level further.

Scientific methods have been used to find, extract, and analyse data and turn the results into models formulated for practical use with illustrative examples. It has been quantified how different factors modify people's subjective reactions to road traffic noise. This has been the content of Work Package 1 of the FAMOS project. A toolbox is provided as a handbook that road owners can use to reduce the negative impact from road traffic noise when actual reduction of the noise level is no longer feasible. This handbook is Deliverable D.4.5 of the FAMOS project.

Reports from previous surveys have been systematically analysed in order to describe the different annoyance moderators, and the effect of these moderators have been expressed in equivalent subjective decibel changes, the “Annoyance equivalent noise level shift”, see the definition later in this clause. So, as an example: The existence of a moderator will change the annoyance response in the same way as a reduction (or increase) of a given range in decibels in the noise level. The results of this work are presented in Chapter 3.

In Work Package 2 of the FAMOS project, three different methods for annoyance data collection have been used and tested. The purpose of the testing phase was:

- Gap filling of knowledge missing for important moderators retrieved in Work Package 1
- Test of the suitability of the methods for measuring the effect of moderators in specific scenarios e.g. for new road projects or reconstruction of existing roads

The methods tested were

- Audio/visual listening tests in the FORCE listening room, where visual context is presented with variations in moderators relevant for this type of testing
- Mini surveys using questionnaires at comparable locations with variations in relevant moderators have been made in a limited number of locations with variations in selected moderators
- Sound walks have been performed at alternative locations with different conditions with regard to selected moderators

The results of this work are presented in Chapter 4.

Based on the results on moderators found in Work Package 2 and 3, work has been performed in order to be able to model the magnitude of different moderators. This is presented in Chapter 5.

Finally, Chapter 6 presents the synthesis of the FAMOS project. This is mainly the final presentation of the moderators found.

In the future, the regulatory system may consider formulating the limits for noise in terms of the percentage of highly annoyed as we have seen in the WHO guidelines [3]. Whether the handling of the non-acoustic moderators will be a measure in line with and comparable with noise mitigation measures has to be researched by future projects, especially with respect to health effects.

Until then, reduction of the perceived annoyance is a goal that will benefit the noise exposed population. The active use of moderators to reduce the perceived noise annoyance along roads and highways can have advantages for the road administrations, such as fewer complaints, fewer lawsuits, less bad media coverage, better relations to the neighbours to the roads and better acceptance for new road projects.

4.1. Definition of Annoyance equivalent noise level shift

The **"Annoyance equivalent noise level shift"**, L_{eas}, is the (hypothetical) shift in noise level that will give the same change in annoyance as the presence or absence of a moderator. This is a practical way to express the effect of a moderator[1]. It should not be confused with any actual changes in noise levels.

An example:

At the same noise level L_{den}, persons who are not affected by one moderator (blue curve in Figure 2, e.g. "traffic visible", left part of Figure 2) could be more annoyed than people that are affected by a moderator (orange curve in Figure 2, e.g. "traffic not visible", right part of Figure 2).

The difference of percentage of Highly Annoyed (%HA) may e.g. be 30 % points. The same annoyance reduction may be observed by lowering the noise level L_{den} by 13 dB. The **"Annoyance equivalent noise level shift", L_{eas}** in this case is **about 13 dB**.

In this example the moderator will change the annoyance response in the same way as a reduction of about 13 dB in the noise level. The "Annoyance equivalent noise level shift" should not be confused with the actual level difference, e.g. between the most and the least exposed façade.

[1] Remark: Although in our experts judgement, some moderators are likely to have an dependence on the time of the day (day, evening, night), a distinction e.g. between daytime and night-time was not considered or possible due to insufficient data. As data was only found in relevance to L_{den}, the changes stated are only valid for this noise index.

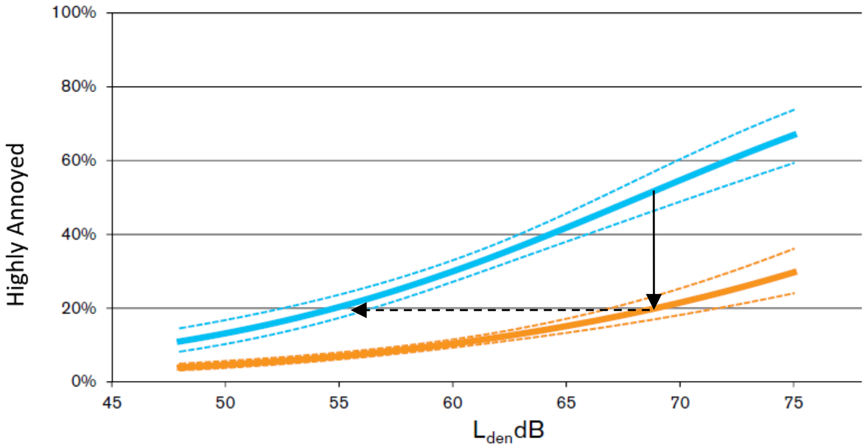

Figure 2: The blue curve shows an example for the percentage of people being highly annoyed in a situation without moderators. The orange curve shows the percentage of highly annoyed in a situation where a moderator has been implemented. Change in annoyance for one moderator with change in annoyance in percent annoyed (solid arrow) and "annoyance equivalent noise level shift" in dB (dashed arrow).

5. Moderator search and qualification

As a main fundamental of the FAMOS project, the identification of possible moderators was carried out. Several factors can change the perceived annoyance by people exposed to road traffic noise. Reducing the noise is an obvious factor, but many other factors have an influence on the annoyance. Moderators are factors that can change the relation between the noise exposure and the annoyance response.

When all conventional noise reduction measures have been applied, the noise impact can still be reduced by making changes in so called non-acoustic factors. We will interpret the term "non-acoustic factors" as: All factors that do not have an influence on the L_{den} at the most expose façade. This means that some acoustic factors also fall in the category "non-acoustic factors" e.g. noise reducing windows and facades, local noise screens in a garden etc. Further distinction is possible for controllable and non-controllable moderators.

The connection of factors and moderators can be seen in Figure 3. Acoustic factors at the noise source, such as the types of vehicles, speed, and road surface, as well as the sound propagation, influenced e.g. by buildings and barriers, lead to resulting noise levels at the most exposed façades. The annoyance itself is "moderated" by factors ("moderators"). Regarding the FAMOS project, they are further distinguished between controllable (by the National Road Administrations (NRA)) and non-controllable moderators.

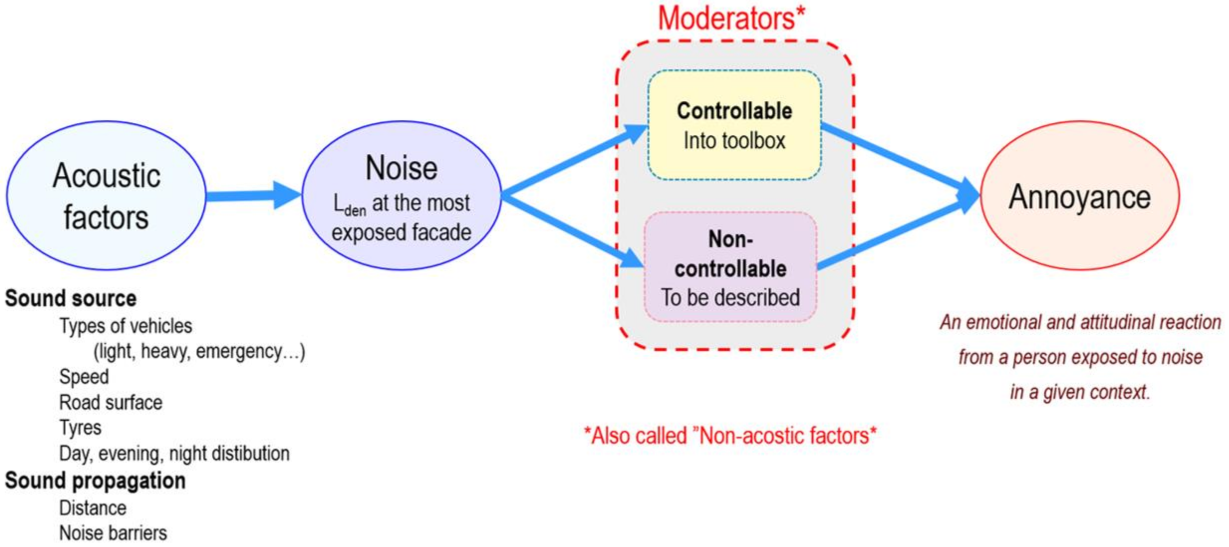

Figure 3: Connection from acoustic factors leading to noise and moderators influencing the annoyance

A list of possible moderators was systematically derived on the background of the international literature survey on moderators to perceived annoyance performed in the first work package of FAMOS [2]. Ongoing improvement, including splitting and joining single moderators, was made in the following project discussion.

The non-acoustic factors that will modify the annoyance response can be categorized in different ways. Some factors pertain to the road itself and its immediate surroundings such as type of road, traffic volume, speed limit, road pavement, barriers, visual appearance, etc. These are factors that to a large extent can be controlled or influenced by the road owner.

Table 1: Factors that can change the annoyance response. The factors of relevance for FAMOS are the ones listed in the cell A1: Controllable by NRA without changing the road and the traffic.

<table>
<tr><th></th><th>A: Controllable by NRA</th><th>B: Normally not administrated/controlled by NRA</th></tr>
<tr><td>1:
FAMOS</td><td>Road and traffic
• Feeling safe in the traffic
• Visibility of traffic
• Visual appearance of noise barriers

NRA and authorities
• Trust in authorities/ traffic noise acceptance
• Communication/expectations alignment

Building and neighbourhood
• Vegetation/Greenery
• Access to quiet side
• Neighbourhood soundscape</td><td>Building
• Detached/apartment
• Orientation of existing dwelling</td></tr>
<tr><td>2:
Not
FAMOS</td><td>Road and traffic
• Road type and surface
• Traffic volume and speed
• Traffic composition
• Distance and Noise barriers
• Day, evening night distribution</td><td>Personal factors
Residential satisfaction
Demographic factors
• Noise sensitivity
• Gender
• Coping capacity
• Dependency of sound source
• Age, education, occupation, income
• Household size, children
• Length of residence

Traffic related
• Tires
• Dust and air pollution
Combined noise
• Rail, Air, Industry</td></tr>
</table>

Then there are factors pertaining to the neighbourhood such as type and location/orientation of residences, prevalence of community conveniences like shops, schools, parks, playgrounds, etc. neighbourhood traffic conditions and so on. These factors can only to a small extent be influenced by the road owner. Chances for control are better at completely new developments than for projects in existing communities.

Some factors deal with the relationship between the local residents and the road owner. Do they feel a personal ownership to the road and benefit from its existence? Have the residents had a chance to be involved the planning and construction process? Do they have a feeling of being treated fairly by the road owner? These factors deal with public relations and can to a large extent be controlled and managed by the road owner.

Finally, there are a number of factors completely out of control by the road owner. However, it is important to recognize that such factors exist and to know how they affect the annoyance response. These are typically personal and demographic factors like age, gender, income, noise sensitivity, etc.

Table 1 shows factors can be controlled by the road authorities (column A) and those who cannot (column B). It has been defined for the project that FAMOS shall have the main focus on the non-acoustic factors that can be controlled by the road authorities (listed in the upper left green cell in the table). At the same time, it has been defined that FAMOS will not include factors related to road and traffic itself (red cell).

5.1. Fundamentals

In the FAMOS project, two different mathematical approaches have been used to describe the perceived noise annoyance from road traffic. These approaches are presented in the following.

The main objective for conducting a noise annoyance survey is usually the need for establishing the connection between the noise exposure level and the corresponding prevalence of annoyance among the exposed population in a particular noise situation.

The results from a study on noise annoyance are typically exposure-response functions, ERFs, also commonly referred to as dose-response or dosage-response functions. These functions show the percentage of the respondents that report themselves highly annoyed (or any other degree of annoyance) as a function of the noise exposure, usually described by the cumulative noise level, L_{den}, or similar.

From a phenomenological point of view the dose response functions is expected to have an s-shape: At low levels, the percentage of annoyed will approach zero and at high levels the annoyance percentage will approach 100%. A smooth transition between these extremes is expected. An example of an s-shaped dose-response function is shown in Figure 4.

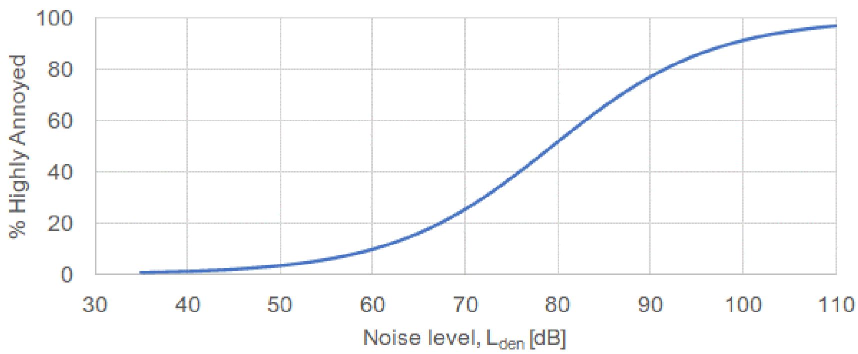

Figure 4. The expected shape of a dose-response function.

Usually for road transport related noise, the lower part of the curve up to 80 dB is the most relevant and this part of the curve is often approximated by polynomial functions e.g., of 2nd or 3rd order.

When making the data processing of survey data, the respondents are grouped in exposure bins and the intermediate analysis result is the percentage of the respondents in each bin reporting a certain degree of annoyance. These data pairs, prevalence of annoyance versus noise exposure level, are plotted in a scatter diagram as shown in Figure 5. In this case the exposure bins were 2 dB wide.

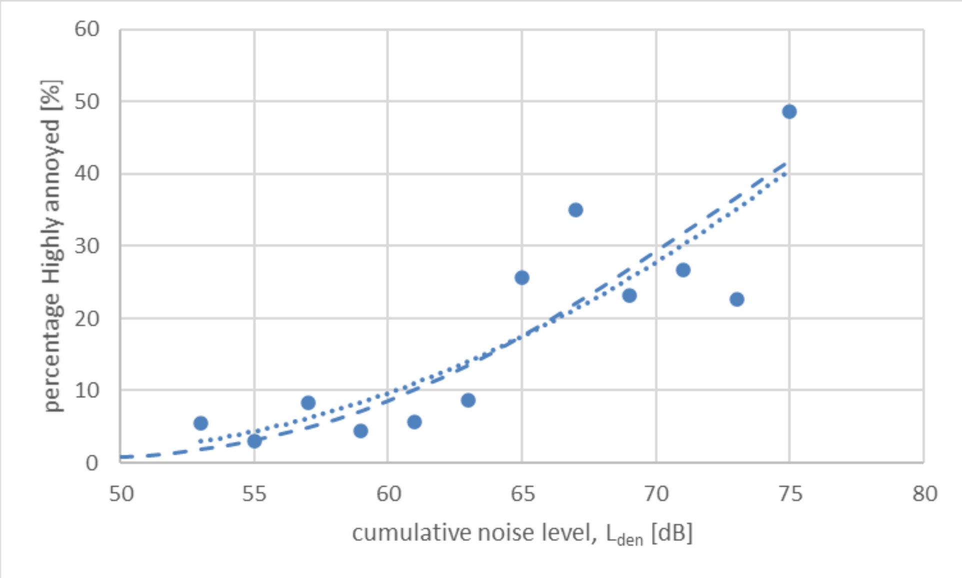

Figure 5. Scatterplot of results from a survey on road traffic noise. The data are fitted with an univariate polynomial regression function (dotted line) or a CTL function (dashed line), see clause 5.1.1. These functions define the exposure-response functions for the survey.

Various techniques can be used to fit a function to the observation data, for instance a univariate polynomial regression function (dotted line) or a CTL function (dashed line). These functions define the exposure-response functions for the relevant survey.

If more surveys are included in the analysis, one could add extra datapoints to the scatter diagram. However, if the size of the exposure bins vary and the number of observations vary, just adding datapoints to the scatter diagram could introduce a bias. Analysts therefore often calculate predicted responses at discrete intervals based on the exposure-response function. The data from Figure 5 in the, for road traffic most relevant range of noise levels, would be transformed as in Figure 6 for further analysis.

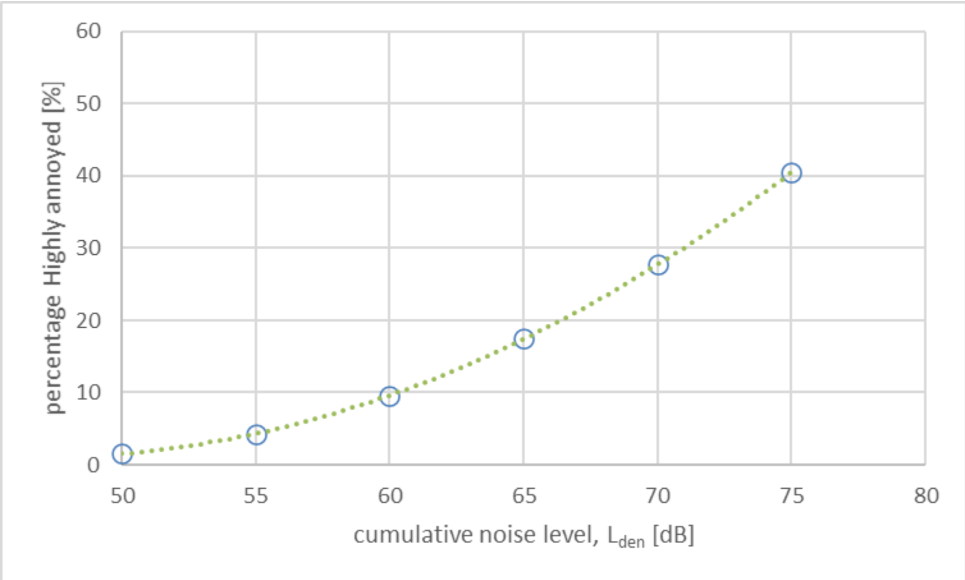

Figure 6. Scatterplot of predicted results in 5 dB intervals from a survey on road traffic noise.

Figure 7 shows an example of a meta-analysis of 25 surveys performed at different geographical locations worldwide. These data were used for the recent WHO recommendations [4]. Each data point has been predicted on the basis of individual exposure-response curves, and in addition the data has been weighted according to the number of respondents in each survey. This weighting is represented by the size of each datapoint. Finally, a new 2nd order polynomial regression function has been fitted to the set of predicted response data (the black curve).

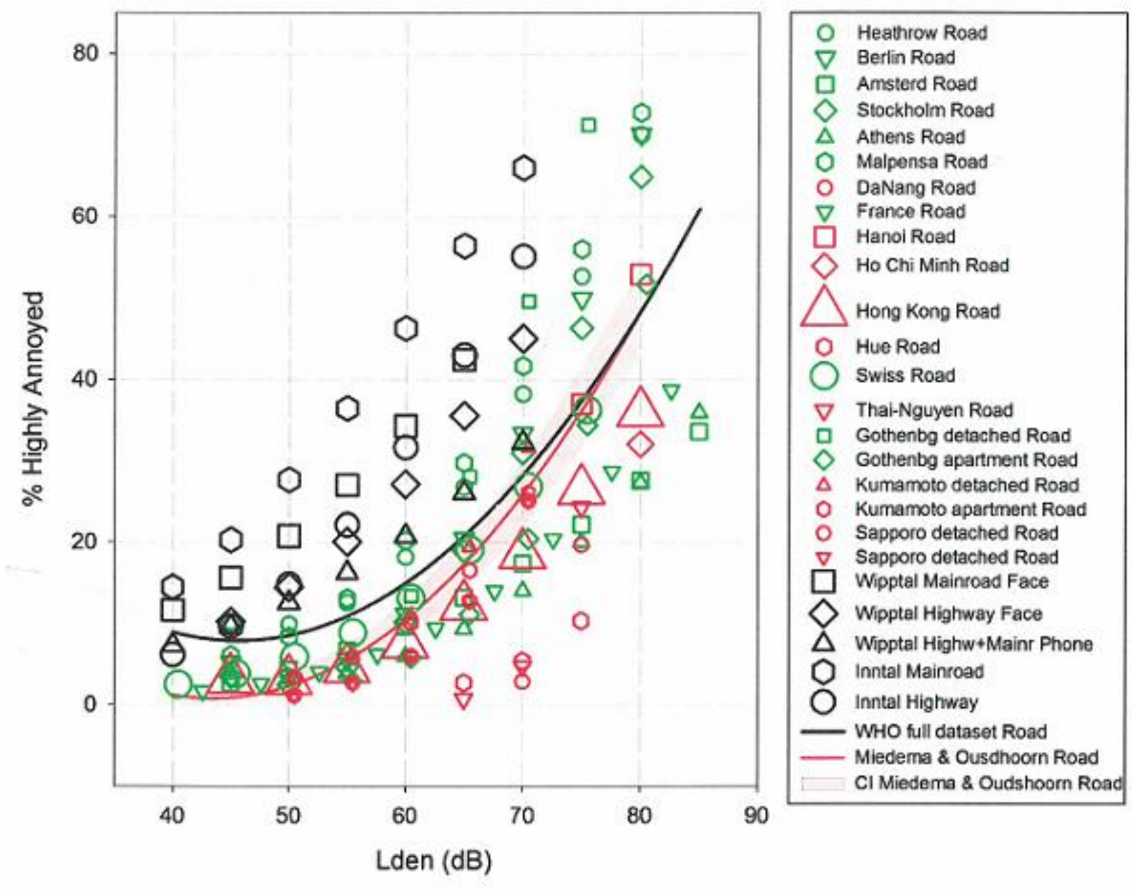

Figure 7. Meta-analysis of 25 surveys performed after year 2000. The black line is a 2^{nd} order polynomial function fitted to the predicted response data [4].

The new exposure-response function, ERF (black curve in Figure 7), for road traffic noise presented by WHO exhibits a minimum HA=7.9 % at L_{den} 45.5 dB. A 2^{nd} order regression function has been used, which shows that the annoyance increases for decreasing exposure levels below 45 dB. This contradicts the fact that the annoyance must be zero when the exposure level is sufficiently low, and that the annoyance always increases with increasing exposure levels. The result indicated by the WHO curve is, of course, just an artifact of the regression method.

To avoid the artifacts of the 2^{nd} order polynomial regression, we have used s-shaped exposure response functions in the FAMOS project. We have used two types of functions:

- The standardized CTL-function see clause 5.1.1, which represents a one-parameter fit, where the slope of the curve is predefined and the position along the x-axis (the exposure axis) is the only variable.
- A logistic fit, see clause 5.1.2, which is a two-parameter curve, where both the slope and the position along the x-axis can be fitted to the data.

The two methods are compared in clause 5.1.3.

5.1.1. CTL – The Community Tolerance Level

According to the international standard ISO 1996-1 [4], the relationship between the prevalence of highly annoyed residents and the noise exposure can be described by a fixed function similar to the duration-adjusted loudness function. However, the position of this function relative to the noise axis (the x-axis) varies depending on the effect of non-acoustic factors like the moderators to the perceived noise annoyance that is analysed in the FAMOS project. The position of the curve relative to the exposure can be described by a single quantity, the Community Tolerance Level – CTL, expressed in decibels.

The exposure-response function is defined by the following equation:

(1)
$$\%HA = 100 * e^{-\left(\frac{1}{10^{0.1(L_{den}-L_{ct}+4.7\,dB)}}\right)^{0.3}}$$

with only one unknown variable, L_{ct}, which characterizes the noise situation. The CTL value, L_{ct} , is the noise exposure level at which half of the exposed population considers itself *highly annoyed.* The average CTL value for road traffic noise surveys conducted across the past half century is L_{ct} = 78.7 dB, [5].

Figure 8 shows the ERF for road traffic noise developed by Miedema & Vos [6] (blue curve) with its flanking 95 % confidence interval and the corresponding ERF based on L_{ct} = 78.7 dB (dotted red curve). The Miedema & Vos curve is currently being used by the European Union as its standard reference curve for annoyance from road traffic noise [7]. For practically the whole exposure range, the CTL-based ERF falls within the 95% confidence interval. From a statistical viewpoint the two curves cannot be characterized as different.

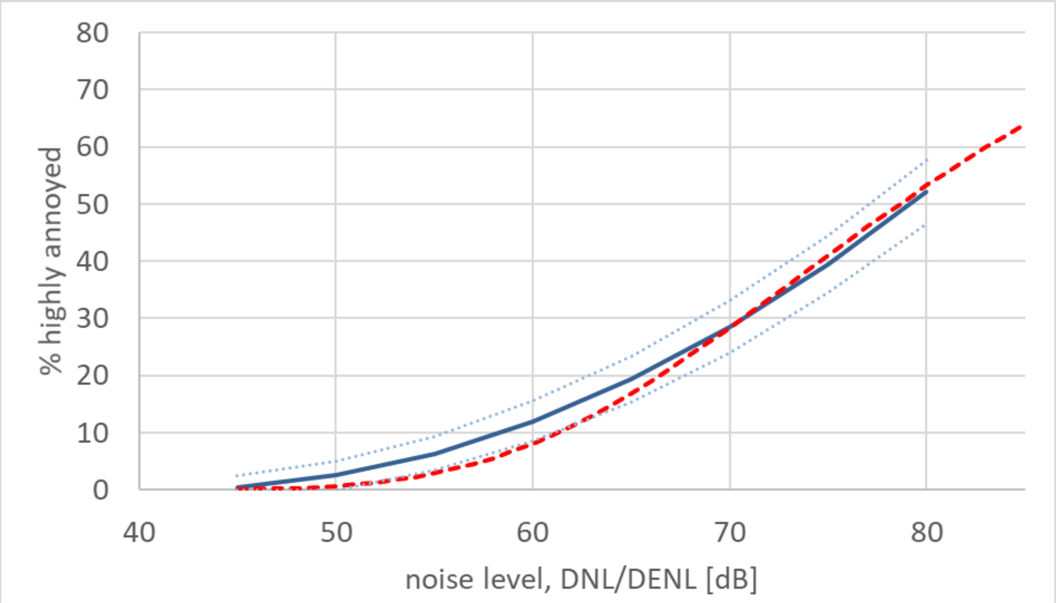

Figure 8: The exposure-response curve developed by Miedema & Vos for annoyance from road traffic noise (solid blue line) with flanking 95 % confidence interval (dotted lines). The dashed red line is the CTL curve associated with Lct = 78.7 dB.

Differences between the results from different surveys, or between different sub-groups within the same survey can be expressed as differences in CTL values. This difference shows how much more (or less) noise one community will tolerate to express a certain degree of annoyance compared with another community. A high CTL value indicates that the community is very tolerant to noise, whereas a low CTL value indicates the opposite, a low tolerance to noise.

The CTL method thus provides a convenient way of describing the influence of various non-acoustic factors.

Gjestland [5] has analysed the results from 61 surveys conducted world-wide during the period 1969-2014. Two exposure-response functions were calculated for each survey using the CTL method and a 2nd order polynomial function. The "goodness of fit", i.e. how well a function fits a set of data points, is characterized by the coefficient of determination, r^2. A comparison of the r^2 values for this set of surveys show that there are no meaningful differences between r^2 for the CTL functions and r^2 for the polynomial regression functions, indicating that from a statistical point of view they both "fit equally well".

A more detailed description of the CTL method is given in the appendix (Section 11.1).

5.1.2. Logistic fit

The logistic fit uses two parameters, the position, f, and the slope, s, to describe dose-response curves between the percentage of annoyed and the noise level, L_{den}. The dose-response curves can be expressed as:

(2)
$$A = \frac{u}{1 + e^{-s(E-f)}}$$

where:

- A is the percentage of annoyed
- 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 an annoyance response of 50%

From Figure 9 it is seen that the logistic fit (green dashed curve) is a good approximation to the Miedema curve (blue).

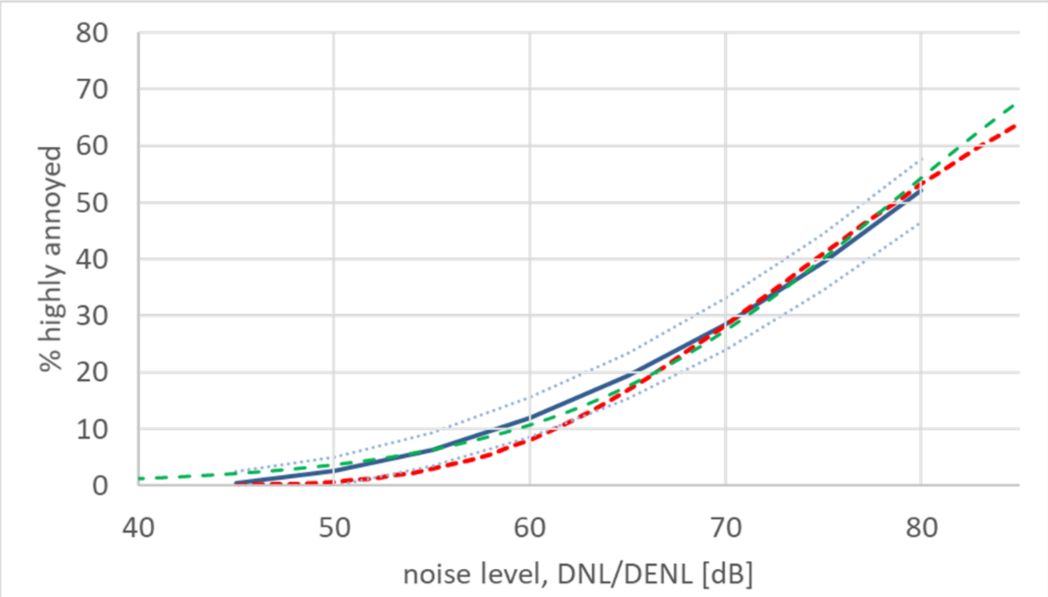

Figure 9. The exposure-response curve developed by Miedema & Vos for annoyance from road traffic noise (solid blue line) with flanking 95 % confidence interval (dotted lines). The dashed green curve is a logistic fit to Miedemas curve. The dashed red line is the CTL curve associated with Lct = 78.7 dB.

5.1.3. CTL and/or logistic regression

Both the CTL and the logistic regression leads to s-shaped dose response functions and none of the methods are more “correct” than the other.

The basic difference between the CTL method and logistic regression is that the CTL method is based on a physical explanation/description of the noise situation and the perception process whereas the logistic regression method is a purely statistical method.

The CTL method assumes that the annoyance increases with the noise level as does the duration adjusted loudness level [8] and the function is similar to the duration-adjusted loudness function.

The logistic regression method also assumes that the annoyance increases with the noise level but is a statistical approach that finds the s-shaped function with "the best fit" to a set of data. As the response from surveys is an average over many situations (e.g., different background noise) and personal factors (e.g., different noise sensitivity), the method does not make a priory assumption that the community response is of the same shape as the loudness function.

Sometimes the results with the CTL method and the logistic regression are similar, as shown Figure 9, and the one-parameter standardised CTL method may be preferred.

In other cases, the possibility of adjusting both the slope and position may give a better fit to the data.

5.2. Effect of moderators from literature analysis

The following sub-chapters will summarize the findings from the literature analysis. The analysis was performed by SINTEF. The results are presented in the report “Deliverable 1.2: Preliminary prioritized list of modifiers (2020)” [2]. For each factor mentioned, a number of sources was analysed on relevant information for moderator effects. The summary of the findings in the following will focus on evidence from surveys and work towards a range of effect.

One of the objectives of the FAMOS project is to identify and quantify non-acoustical factors that have an influence on peoples' annoyance reactions to road traffic noise. A number of such factors have been discussed among the project team. However, this list of factors has been limited to factors that can be managed or controlled to a certain extent by the road administrations. Control is a matter of necessity if the objective is to use this factor actively in road planning and traffic control.

5.2.1. Non-acoustical factors outside regular control

To complete the picture, we will briefly discuss a set of personal and demographical factors that may or may not be important for annoyance assessment. This information may be important when assessing the results from annoyance surveys. Some factors are also partly controllable (e.g. “safety”) and thus part of the list of possible moderators.

Demographic factors

Age

Several authors report an age dependency [9] [10]. People aged 40-50 years seem to have the lowest tolerance to noise, whereas relatively young and relatively old people have a higher tolerance. The difference can be expressed in an equivalent shift in the noise exposure. This shift can be as much as 3-5 dB. In a recent survey on aircraft noise in England, the SoNA study [11], the response data was analysed for two different age groups: 18-85 years old and 45-70 years old. The first group is the normal age range for these types of surveys. The other limited age range was used for half of the surveys included in a recent WHO recommendation on transportation noise annoyance [12]. For the SoNA study the difference between the two groups was equivalent to 4 dB in the noise exposure [11].

Use and dependency on noise source

People who depend on or profit from a noise source are somewhat more tolerant than others. This has been shown for aircraft noise. People who depend on the existence of an airport, either for work or as a customer for goods and services, “tolerate” about 2.5 dB more noise than others. People who are frequent users of the noise source (frequent flyers or drivers) may tolerate 1-2 dB more noise [10].

Home ownership

It is often hypothesized that homeowners are more likely to have a negative attitude towards a noise source since the noise is likely to affect the value of their home negatively. This effect has been found to be equivalent to 1-2 dB shift in the noise level [10].

Other demographic factors

Other factors such as gender, social status, income, education, and length of residency seem to have little influence on the annoyance assessment.

Personal factors

Several personal factors that affect the annoyance response have been identified. For aircraft noise, fear of accidents is by far the most important factors. People that are afraid of a plane crash or other aviation-related disaster may hit them, “tolerate” up to 20 dB less noise in order to express a certain degree of annoyance [13] [10]. Although the personal attitude cannot be changed, the perceived safety on a road or in the immediate surroundings can be influenced (see Sections 5.2.9 and 7.3.2).

Likewise, personal noise sensitivity is an important factor. People who consider themselves highly sensitive to noise “tolerate” 10-12 dB less noise than others [10].

Other personal factors that have been found to affect the annoyance response, but only to a limited degree, are beliefs that the noise exposure could have been prevented, attitudes about the importance of the noise source, and annoyance with other non-noise related impacts. In the latter case noise is being used as a proxy for expressing discontent.

Conclusions

If the participants in a noise survey have been selected according to a proper random procedure, so that all “types of people” have the same probability to give their response, these personal and demographic factors will even out. Calculations have shown that about 300 respondents are enough to keep the confidence interval for the response function within acceptable limits [14]. Personal factors are assumed to be evenly distributed across a community, and it is unlikely that for instance only very noise sensitive persons are located in a specific area.

Some annoyance studies have been primarily designed to study other health effects which requires a special age range for the respondents. The HYENA project, for instance [12], was designed to study hypertension among residents near airports, and therefore the target was people likely to have noise-induced hypertension. The age range was therefore limited to 45-70 years. Due to age dependency the results from that study cannot therefore be readily compared with results from a general survey using a wider age range, 18-85 years old.

5.2.2. Traffic volume

The prevalence of highly annoyed residents in a community that is exposed to noise is assumed to be proportional to the noise exposure level, characterized by the equivalent level or a derivative such as L_{dn} (noise level day-night) or L_{den} (noise level day-evening-night). However, analysis of surveys of annoyance from road traffic noise indicate that there is also a traffic volume effect.

If the number of passing vehicles increases, the noise level will increase and consequently the annoyance will increase, but even for situations with the same L_{dn} level the prevalence of highly annoyed residents seems to correlate with the traffic volume. People that are exposed to a high number of passing vehicles are in general more annoyed than those exposed to a small number of vehicles even if the noise levels are equal.

This “number effect” has been studied on the basis of two Danish surveys of annoyance from different types of roads [15], [16]. In the original reports it was concluded that different dose-response functions characterized the annoyance from motorways and urban roads. A CTL analysis indicates that the same dose-response function can be used for both types of roads, but the CTL value differs depending on the traffic volume.

Data from the SIRENE project [17] indicates a volume effect of about 2 dB per doubling (see Figure 10).

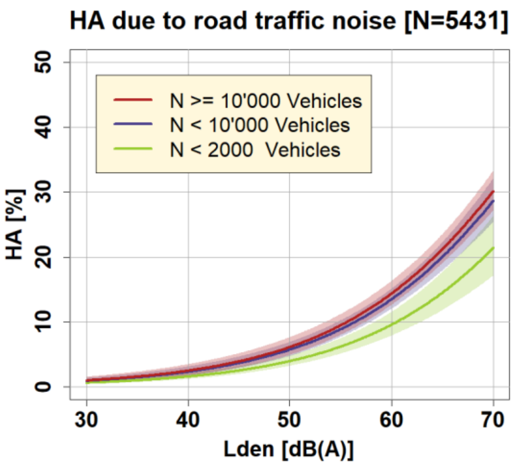

Figure 10: Data on annoyance depending on number of vehicles from the SIRENE project [17]

A recent Swedish report on annoyance from road traffic noise has data from a number of sub-sections together with traffic information. This information can be used to compare similar communities with similar type of housing but with different traffic volume [18].

Using the CTL method, the analysis gives relative differences in CTL values which can be translated into a “traffic volume effect” under the assumption that other non-acoustic factors are similar and/or not dominating. The average CTL value for all surveys included in the FAMOS project is L_{ct} 78.4 dB. Similarly, the average CTL value for the surveys included in the analysis by Miedema and Vos [6] for establishing the EU reference curve (*Miedema curve*) for road traffic noise is L_{ct} 78.7 dB. The traffic volume has not been specified in detail for all of these surveys. However, since we are interested in relative differences between surveys, this quantity is not critical.

As a first rough estimate, the average CTL value for a situation with a traffic volume of about 2000 ADT (Average Daily Traffic) can be set at L_{ct} 78 dB. Then the relative differences found from references [15], [16] and [18] can be used to introduce a traffic volume effect that corresponds to an adjustment of -1.5 dB per doubling of the traffic (about 5*log (N/n)). The following values can be used as a first approximation:

Table 2: Approximation of CTL value for traffic volume

Traffic volume	**CTL value**
1 000 ADT	L_{ct} 79.5 dB
2 000 ADT	L_{ct} 78 dB
5 000 ADT	L_{ct} 76 dB
10 000 ADT	L_{ct} 74.5 dB
20 000 ADT	L_{ct} 73 dB
50 000 ADT	L_{ct} 71 dB
100 000 ADT	L_{ct}69.5 dB

5.2.3. Visual appearance of noise barriers and expectations

A noise barrier alongside a busy road will typically reduce the noise level by 5-15 dB depending on the height of the barrier and the distance to the observation point. A small pilot study in Denmark has been conducted to find out the effect of barriers and people's attitude and expectations regarding noise barriers [19].

In one study area, area A[2], without barriers the noise levels were about 75 dB in front of the houses facing the street. The traffic was 60 000 ADT. The study sample was 113 residents. This is sufficient to give a fairly good indication of the annoyance situation. According to the rough estimate presented in Section 5.2.2, one could expect a CTL level of about 70 dB with this traffic volume. The survey questionnaire did not comprise a question on “annoyance in general” but a CTL calculation based on the response to a question on annoyance outside gives the same result:

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2 Søbredden, Gentofte kommune, Denmark. Three-floor houses along main through-road (Lyngbyvej). 60 200 ADT, speed limit 90 km/h.

L_{ct} 70 dB. In other words, the response to the noise in this community is quite normal. Their expectations regarding the effect of a noise barrier are quite high, and about 2/3 of the residents expect that they will not be annoyed by road traffic noise outside when a barrier is erected.

There was also another study area without a noise barrier, area B[3], but the number of responses, only 20, was considered too small for a meaningful analysis.

In two other study areas noise barriers had been installed [19]. The traffic volume was about 60 000 ADT and 52 000 ADT respectively. A rough estimate would be about L_{ct} 70 dB and L_{ct} 71 dB for these two communities.

In the first area, area C[4], the calculated CTL value is about L_{ct} 66-69 dB which is slightly less than the first estimate L_{ct} 70 dB. This seems to indicate that the barrier has not had any “extra value”, and the effect is proportional to the reduction in the noise levels.

In the second area, area D[5], the two sides of the road have been analysed separately. The calculated CTL value for the two communities, north and south, is L_{ct} 55 dB and L_{ct} 66 dB respectively. This indicates that especially the residents on the north side of the road are relatively more annoyed by the noise after erection of the noise barrier.

When asked about the noise reduction, only 15 % of the residents on the north side think the noise is lower than before. They are also negative to the building process. Only 6 % felt they have been properly informed about the whole process.

These results indicate that when people's expectations about the effect of a planned noise barrier are not properly fulfilled and when they feel alien to the building process, the community becomes less tolerant to noise. In this case the dose-response function has been shifted equivalent to a 15 dB change in exposure. So instead of having about 25 % highly annoyed at a level of 60 dB, the percentage has increased to about 60 % HA.

In this particular case the calculated noise reduction was 5-16 dB for the houses closest to the road. However, the effect of this reduction was almost completely offset by a similar shift in the annoyance response as shown by the CTL calculations. So subjectively, measured as persons highly annoyed by road traffic noise, this noise barrier had almost no effect.

A similar situation regarding expected effect of a noise abatement project has been observed in Austria (see Figure 11). People that were highly annoyed by road traffic noise could apply for improved façade insulation (special windows). However, as their expectations were not met regarding reduced annoyance, the effect of lowered indoor noise levels had no effect on the exposure-response curve. The same effect was discovered in Danish data during the modelling (see Section 7.2.2 and Figure 116).

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[3] Vildkildevej, Ny Fløng, Denmark. Small single-family houses. Main noise source: near-by motor way at 100 m distance. 51 800 ADT, speed limit 110 km/h.

[4] Lyngparken, Buddinge, Denmark. Mixed apartment houses (40 % of respondents) and small detached homes (60 % of respondents). 60 600 ADT, speed limit 110 km/h. Noise barriers have reduced the noise level by 8 – 15 dB (first row of houses).

[5] Fløng, Denmark. Residences on both sides of the motor way. Mostly detached homes. 51 800 ADT, speed limit 110 km/h. Noise barriers have reduced the noise levels by 5 – 16 dB on the north side and by 4 -13 dB on the south side (first row of houses).

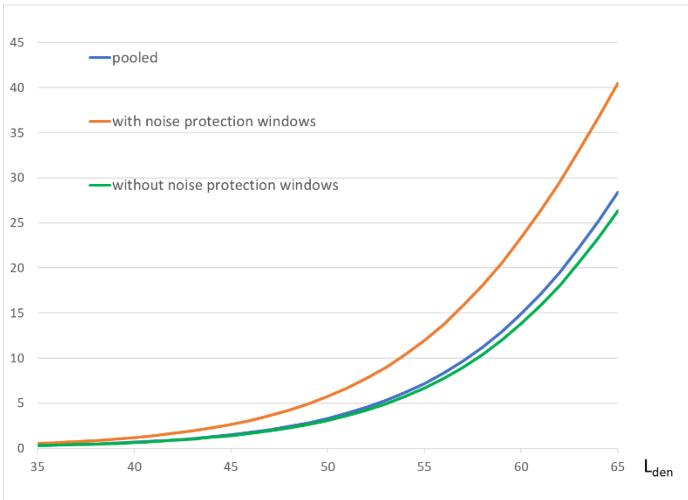


Figure 11: Highly annoyed in situations with and without noise reducing windows applied. Unpublished data from an Austrian study (Lechner C. 2021: personal communication). The Y-axis is percentage highly annoyed.

Regarding the influence of participation in the planning and design process, only few data was found in the surveys. One survey from Germany [20] shows that the annoyance shifted by 2 dB after the residents had participated in the planning and design process of noise barriers (see Figure 12). The red curves are the perceived annoyance before starting a planning process with public participation and involvement. The blue curves are the perceived annoyance after the construction of the noise barriers. The curves with small circles represent the annoyance at daytime and the curves with diamonds represents the annoyance at night-time. Annoyance score in the Y-axis. However, no detail can be derived whether this stems from the influence on the design or the participation itself.

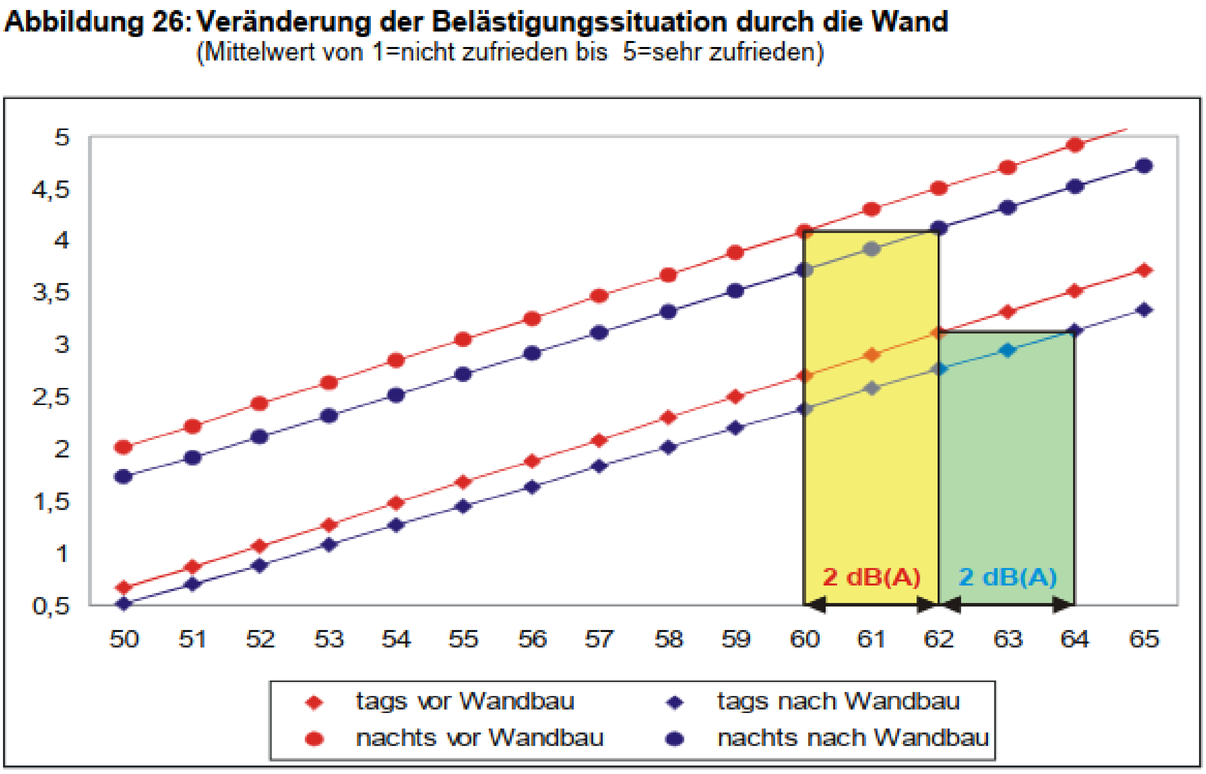


Figure 12: Change of annoyance due to participation in the planning process of a noise barrier. Red curves: perceived annoyance before; Blue curves perceived annoyance after; Small circles: annoyance at daytime; Diamonds: annoyance at night-time. Annoyance score in the Y-axis. [20]

It seems to be important to involve the residents of a community in a proper way when planning and building noise barriers. If people's expectations are not properly fulfilled and if people are left alien to the process, the effect of reduced noise levels (e.g. the physical effect of a barrier) can be offset by a similar shift in the local dose-response function, so the prevalence of highly annoyed people in the community could remain the same.

5.2.4. Vegetation/Greenery

Many studies have been conducted to assess the effect of vegetation along the road. Trees and bushes will only give a marginal noise reduction, except for very wide areas of trees (> 100 meters). The psychological effect, however, *i.e.* the reduction in annoyance has often been observed to be much greater than what could be expected from the actual often marginal reduction in the noise level.

Langdon [21] conducted a survey among more than 1.000 residents in the Greater London area. The respondents were asked to assess different situation with trees/bushes as noise barrier. Langdon concluded that (regarding annoyance) visual greenery could add as much as 15 dB excess attenuation compared to no greenery at all. In other words, greenery will reduce the annoyance considerably.

Langdon reported a multiple correlation analysis for items evaluating environmental amenity. He showed that 70 % of the group variance was accounted for by two items: appearance and parks, and these two continue to play the predominant part accounting for the 25 % of individual variance accounted for by all items. It is therefore reasonable to say that environmental quality as rated by respondents is indeed their perception of the visual appearance of the neighbourhood – the state of buildings and streets and the presence of parks, trees, and green spaces.

Fricke [22] conducted experiments with trees as noise barriers and concluded that the psychological effect of having trees (as opposed to barriers without vegetation) had the same effect as having 10 dB extra attenuation.

Huddard [23] summarized a number of reports on the attenuation of traffic noise by means of trees and shrubs. He also referred to studies reporting a change in the annoyance even if the change in the noise level was minimal. Many researchers have suggested that a major benefit of a vegetation noise barrier might be psychological. Kurze [24] remarked on the possibility of this form of benefit, even when the actual transmission loss is minimal. Kurze had observed that *a row of trees* ranked among the most frequently desired protective measures for outdoor noise control.

Lercher [25] has studied the effect of visual greenery along busy roads, and concluded that an excess attenuation of at least 5 dB may be expected due to the visual appearance of the road.

Van Renterghem *et al.* [26] have studied how view of outdoor vegetation can reduce the perceived annoyance induced by road traffic noise. They refer to own survey results and cite other authors [27] and conclude that vegetation along the road may add about 10 dB excess attenuation.

Reduced annoyance due to visual greenery may be explained by a research paper by Vienneau et al. (2017). They conclude that residential areas with a green appearance are associated with lower mortality.

The use of greenery along roads gives an additional reduction of the perceived annoyance equivalent to about 10 dB reduction in the noise level.

5.2.5. Access to a quiet facade

Many studies both in the laboratory and under actual field conditions have been conducted to assess the effect of having access to at least one quiet side of the dwelling. A *quiet side* is defined as having a noise level at the façade at least 10 dB below the most exposed façade. It is well documented that residents that have access to a quiet side of their dwelling are less annoyed by road traffic noise than people without such access.

Lercher [25] observed that having bedroom windows facing a quiet side of the residence, reduced the perceived annoyance. The reduction was equivalent to 8-15 dB reduction in noise exposure. The effect was level dependent, increasing with increasing noise level.

Gjestland *et al.* [28] conducted a laboratory study comparing a situation (1) with equal traffic noise on all four sides of a residence, with a situation (2) with a high level on one side and low on the other sides. The test persons were asked to adjust the high or the low noise level in situation (2), so that the situation was assessed ‘‘equally annoying’’ as situation (1). The difference between the high and low noise level for equal annoyance was 6-10 dB depending on the absolute noise level.

Öhrström *et al.* [29] conducted field interviews of about 1.000 residents in Stockholm and Gothenburg. About half of the participants in the study had dwellings with access to a quiet side away from city traffic, and the other half did not. The noise level, L_{den}, at the most exposed façade varied between 48 dB and 71 dB. The difference in CTL value for the two situations was 6.3 dB. To protect most people from adverse health effects the sound levels from road traffic noise should not exceed 60 dB ($L_{A,24h}$) on the most exposed façade [30]

Bluhm *et al.* [31] analysed the responses from about 650 residents in Stockholm. They did not quantify the reduced annoyance of having access to a quiet side, but confirmed previous findings by Öhrström *et al.*

de Kluizenaar *et al.* [32] analysed the responses to a mail survey from about 17000 residents. They concluded that people with access to a quiet side of the residence would accept about 5 dB higher noise levels (on the noisy side) to express a certain degree of annoyance than people without such access.

Amundsen *et al.* [33] conducted a before/after study to assess the efficacy of improved façade insulation. About 600 responses were collected in the before study and about 400 in the after study. They concluded that residents having bedroom windows facing a quiet side of the dwelling would tolerate about 6 dB higher noise levels than those that did not have a quiet side of the residence.

A Danish report [15] confirms that access to a quiet side of the dwelling reduces the annoyance (see Figure 13). The prevalence of highly annoyed drops to about one half compared to no such access. The effect is level dependent (cfr. Gjestland et al. 2001, and Lercher, 1996).

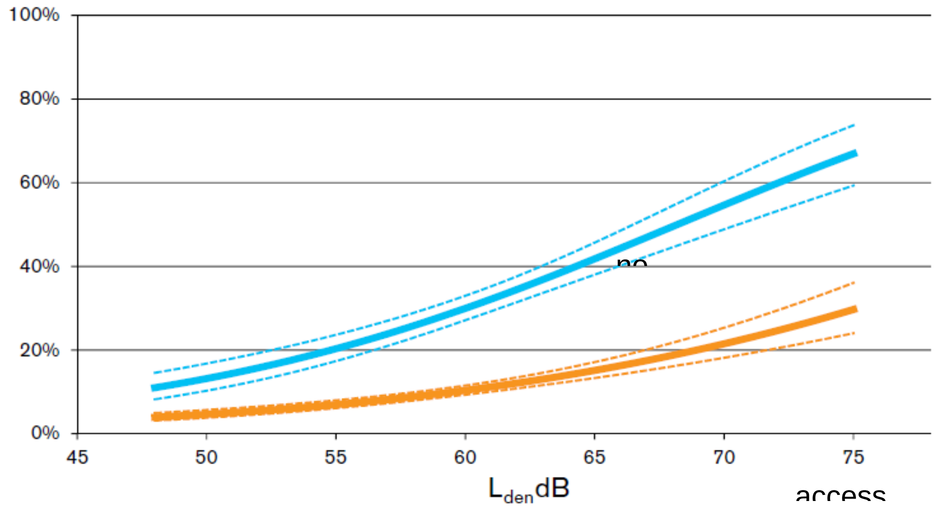


Figure 13: Results reported from a Danish study [15]. Prevalence of highly annoyed vs. exposure level. The blue curve represents residents having no quiet side and the orange curve residents having a quiet side. The difference in annoyance reaction may amount to more than 10 dB in exposure level.

A Swedish research program on soundscape and health [34] concluded that access to a quiet side of the dwelling could be equivalent to a 5 dB reduction in the exposure level.

Another Swedish study [18] provides annoyance and exposure data for 56 sites around Stockholm. The average CTL for road traffic noise surveys is L_{ct} 78 dB. The average value for these 56 sites is L_{ct} 80.3 dB indicating that these residents are somewhat less annoyed than average. A majority of the dwellings have access to a quiet side of the building.

On the background of the above studies, it can generally be concluded that access to a quiet side of the residence away from city traffic will increase the CTL value for that situation is estimated to 5-10 dB, most likely around 6 dB (see also Section 5.3).

5.2.6. Neighbourhood soundscape

It has been shown that the annoyance reported by a resident is not only dependent on the noise level at the (most exposed) façade of the residence, but also depends on the soundscape qualities of the local neighbourhood where they live.

Klæboe *et al.* [36] have introduced a soundscape index which is the difference between the "maximum of L_{dn} in the neighbourhood" and the L_{dn} for the most exposed facade. The *neighbourhood* in this context is the area within a certain distance from the dwelling. In their calculations, Klæboe *et al.* have used a circle with r=75 meters to define the neighbourhood. (Note that the index is based on the maximum L_{dn} and not the regular maximum exposure level) [36].

If this difference is large, people living in the area may be exposed not only to the noise levels in their homes but also to high levels when they go for a walk in their immediate neighbourhood. A small difference on the other hand means that the noise exposure in the neighbourhood is not very different from what they have outside their own house [37].

Consider a situation with a secondary road running parallel to a main street. The houses along the secondary road may be the second or third row of houses as seen from the main street. Special noise reduction measures for the main street may have little effect regarding the actual (physical) noise levels for the houses along the secondary road, but since the "neighbourhood noise" will be reduced, so will the reported annoyance be reduced.

So far Klæboe *et al.* have not been able to quantify the influence of the neighbourhood soundscape.

5.2.7. Attitudes towards authorities and road owners

Many studies indicate that the relationship between the authorities (noise source owners) and the neighbourhood is an important non-acoustical factor. This has been studied systematically in the NORAH study. This study deals with airports and aircraft noise, but it is reasonable to assume that similar relationships exist for road traffic as well.

In the NORAH study [38] considerable differences in exposure-response functions for aircraft noise annoyance were found depending on *trust in authorities, perceived procedural fairness,* and *expectations regarding the air traffic's impacts.* The influence of these three factors was studied using longitudinal survey data.

The "degree of impact" was scored using the modifiers from a verbal scale defined by ICBEN (International Commission on Biological Effects of Noise), for instance:

1 – no trust
2 – a little trust
3 – moderate trust
4 – rather some trust
5 – very much trust

The regular annoyance responses were sorted according to the respondents' *trust in the authorities* and new exposure-response curves were established; one for each "degree of trust". An example is shown in Figure 14 based on the assumption that the effect of “trust” is valid for road traffic as well. These curves have been calculated for road traffic noise based on the results from the NORAH study. The difference between the various ERFs is equivalent to about 20 dB in noise exposure from the highest to the lowest *trust in authorities.*

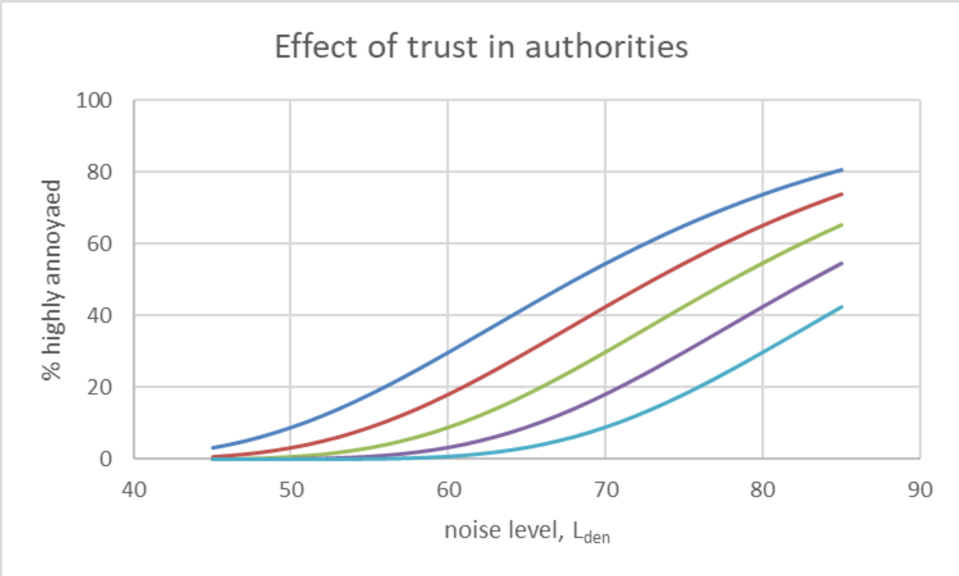


Figure 14: Exposure-response functions for road noise annoyance depending on the respondent's trust in the authorities (calculated based on data from the NORAH study [38]). The top blue curve represents “no trust” in authorities and the bottom green/blue curve represents “very much trust” in authorities.

A similar analysis was also done for *perceived procedural fairness.* In other words, how the respondents viewed the whole process from planning to implementation: did they have any influence in the planning process, did they have a chance to appeal decisions that they considered wrong, were the decisions explained and justified in detail, etc.

The difference between the various resulting ERFs appeared to be equivalent to about 15 dB in noise exposure from the highest to the lowest *perceived procedural fairness.*

The last item that was analysed by Schreckenberg *et al.* was an assessment of the impact of air traffic on the regional development and the residents' quality of life. This is a more *fuzzy* characteristic with many subjective aspects. The biggest difference in the ERFs was therefore equivalent to more than 30 dB in noise exposure.

The example above is from a study on aircraft noise, but it is a fair assumption that similar effects can be found for other transportation noise sources. There is a clear tendency that good relations between the source owner (for instance road authority) and the neighbourhood residents will reduce the annoyance. The effect is rather strong and the difference in reported annoyance for a situation characterized by good relations versus a situation with bad relations is by far larger than the effect of most noise abatement measures. The benefit of investments in good public can therefore have quite positive results.

5.2.8. Controversial plans / expectations

Annoyance in aviation

In the aviation industry it has become customary to classify airports in two categories: “high-rate change airports” (HRC) and “low-rate change airport” (LRC). The annoyance responses at these two types of airports are distinctly different.

Almost all airports experience an increase in traffic. For most airports, this change is gradual, and the rate of change is low. However, some airports experience abrupt changes in operations such as the opening of a new runway, or a major carrier moves its hub to a new location. This can trigger a different response mechanism in the airport population. The same change in the response can be observed if controversial plans for future changes are being launched. Such airports are categorized “high-rate change airports”. Unfavourable media attention can also trigger this type of HRC response. The average difference in the annoyance response has been found to be equivalent to as much as a 9 dB change in noise exposure. So, people at an HRC airport “tolerate” on average 9 dB less noise than people living near an LRC airport [5] [39].

Janssen and Guski have presented a definition of the two categories [39] and have shown that the effect of a change will linger for quite some time in the airport community. Janssen and Guski define an airport HRC if an abrupt change has occurred within 3 years before a survey and if controversial plans for a change less than 3 years in the future has been launched. Gelderblom *et al.* [5] indicate that the effect of a category change can be even longer.

Road traffic noise

There are no reasons to believe that a community exposed to road traffic noise will react very differently from an airport community, but the magnitude of the effects may be different. If the community experiences large abrupt changes (major traffic changes, opening of a new road, etc.) it is likely that this will trigger an annoyance response similar to what can be observed at an HRC airport. Also plans for future changes that can be considered controversial (“you know what you have, but not what you will get”) are likely to trigger an HRC response. Actions of community interests' groups and noise activists may also trigger this response.

In order to avoid this augmented annoyance response, it is therefore vital that plans for future changes are developed in close contact with the community, and the road authorities should strive to develop a mutual trust between themselves and the community.

The launch of controversial plans for a future change in a traffic situation that is not well anchored in the neighbourhood community may change the annoyance response equivalent to a change in the CTL value of 5-10 dB, based on the above-described experiences from airports.

5.2.9. Perceived safety caused by traffic in the local neighbourhood

Results from the modelling and from published [40] and unpublished [41] results from Danish surveys indicate that feeling unsafe because of the traffic in the local neighbourhood is an important moderator for noise annoyance. There are large variations in the findings. Dependent on the survey and type of analysis the difference between feeling unsafe and not feeling unsafe corresponds to an annoyance equivalent noise level shift of 5-15 dB most likely around 6-8 dB at 20 % highly annoyed.

Further investigation will be carried out based on datasets (see Chapter 7).

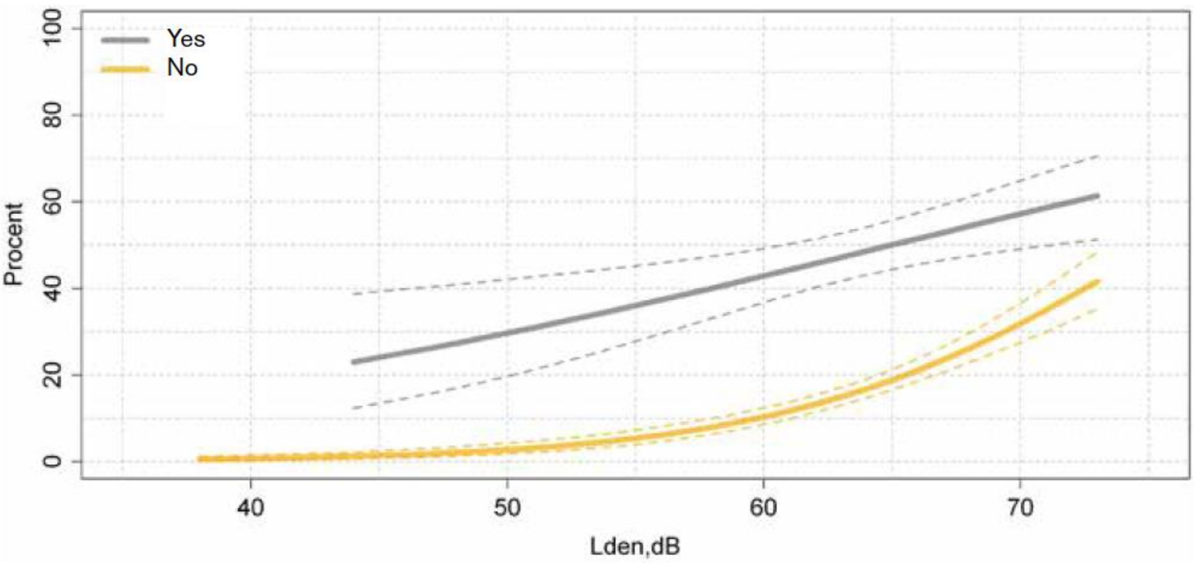


Figure 15: Annoyance response dependent on perceived unsafety in the local neighbourhood [41].. The moderating effect of the question: "If you want to move from this area, what would be the main reason?" The upper grey curve applies if the option: "It is unsafe to go about in the area because of the traffic" was ticked. The lower yellow curve if not. The dotted lines indicate the 95% confidence intervals for the curves [40]

5.3. Further information from contacts to external researchers

Within the FAMOS project it was planned to contact specially selected external international researchers to find out if they could provide additional data and information to the FAMOS project, and to have their assessment of the preliminary conclusions that had been drawn.

The format of these consultations was planned to be either a common workshop or one-on-one contacts. As the Covid-19 situation in 2020 and 2021 made a workshop impossible, fifteen researchers who had published relevant papers on road traffic noise annoyance were contacted. The FAMOS project team subsequently had several exchanges of e-mails with ten of these. The experts were mainly from Europe but also from Australia and the US.

It was soon realized that most of these experts had a psychological approach to the topic, and they were quick to point out that we had omitted personal and demographic factors in our analyses. Personal noise sensitivity was mentioned as one of the main factors for explaining the large variations in the annoyance response. Also factors like age, gender, length of residency, etc. were among those that contributed to the large spread in the survey data.

In the following exchange of information, we pointed out that the FAMOS concentrated on factors that at least to some extent could be altered or manipulated by the road owner. One cannot presuppose that only people with certain personal characteristics will reside along a specific road.

Below some of the comments and data provided by the 10 international experts are precented and discussed.

Access to quiet side

In preliminary conclusions the effect of having access to a quiet side of the residence was estimated equivalent to a shift of around 6 dB in the noise exposure. Many contacts pointed out that this was very conservative. A shift closer to 10 dB would be more appropriate, especially at higher exposure levels. It was pointed out that the importance of this annoyance-reducing factor increased with increasing noise levels.

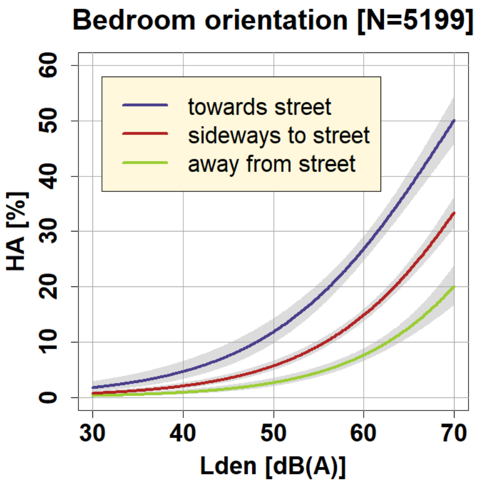


Figure 16: Data from the SIRENE project shows bedroom orientation could amount to a shift in noise exposure equal to about 15 dB [17].

Unpublished results from another survey (obtained from Lechner, C. in personal communication) on noise annoyance confirms the effect of having access to a quiet façade, but the effect is smaller, about 5-6 dB (see Figure 17).

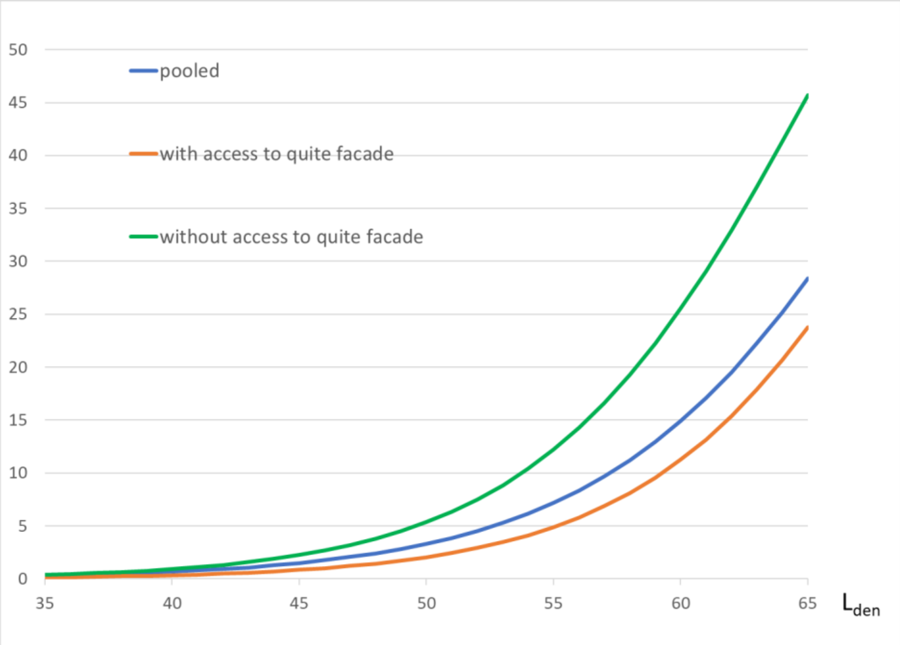


Figure 17: Highly annoyed in situations with and without access to a quiet facade (pooled: both with/without). Unpublished data from an Austrian study (Lechner C. 2021: personal communication). The Y-axis is percentage highly annoyed.

Traffic volume

The findings regarding a *number effect* were also confirmed. At equal noise levels a high number of vehicles is more annoying than a small number of vehicles. We had estimated the effect to about 5*log (N/n) (with N/n as the ratio of traffic between two scenarios). Unpublished data from the SIRENE project [17] (obtained in personal communication) show that the effect may be even larger.

Greenery

In a research paper submitted for publication (Wothge, J. 2021: personal communication) the effect of visual greenery had been estimated to equivalent to 5 dB shift in the noise exposure. This is somewhat less than the FAMOS project concluded. However, an interesting observation was published by Vienneau et al. (Env.Int. 2017, vol 108, p 176): ”More than clean air and tranquillity: Residential green is independently associated with decreasing mortality.” This latter research paper stresses the importance of visual greenery to promote general well-being and thus confirms the annoyance-reducing effect of visual greenery.

Noise protection on the facade / expectations

A clear indication that the annoyance response is controlled by other factors than the noise itself was confirmed by another yet unpublished survey on road traffic noise (Lechner, C. 2021: personal communication). Under a special noise abatement program people that were very annoyed by road traffic noise could apply for funding to have the facades of their residences improved (change to special sound insulated windows). One would assume that this would lower their annoyance corresponding to a lower indoor noise level. However, their annoyance response was still high after the windows had been installed, and significantly higher than those residents that had not applied for façade improvement.

The researcher behind this study offers two alternative explanations. Either the annoyance response is very stable and drastic changes are necessary in order to modify it, or the residents' expectations regarding the improved situation were not met, and this fact eliminated the effect of the lowered indoor noise level.

Attitude

Attitude in general is an important modifying factor. Not only attitude towards the road owner but also attitude towards the environment and the community in general. Unpublished data from a recent study show that people that have a ”pro-environmental attitude” are more annoyed by road traffic noise than those who favour economic growth.

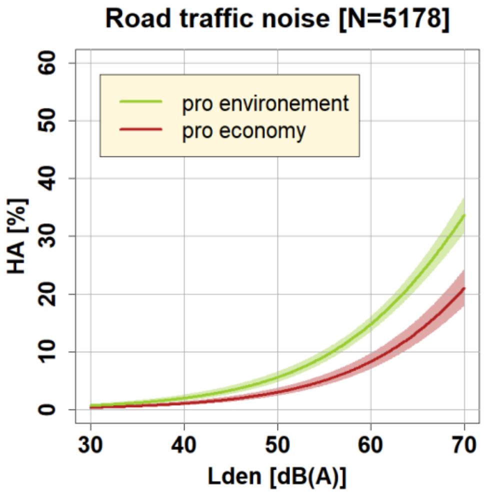


Figure 18: Data from the SIRENE project shows a “pro-environmental attitude” could amount to a shift in noise exposure compared to those “pro economic growth” [17].

Neighbourhood soundscape

The results from a comprehensive study in Oslo (Klæboe, R. 2021: personal communication) revealed that not only the noise level at the most exposed façade, but also the general noise level in the immediate neighbourhood is important for the annoyance response (see Figure 19).

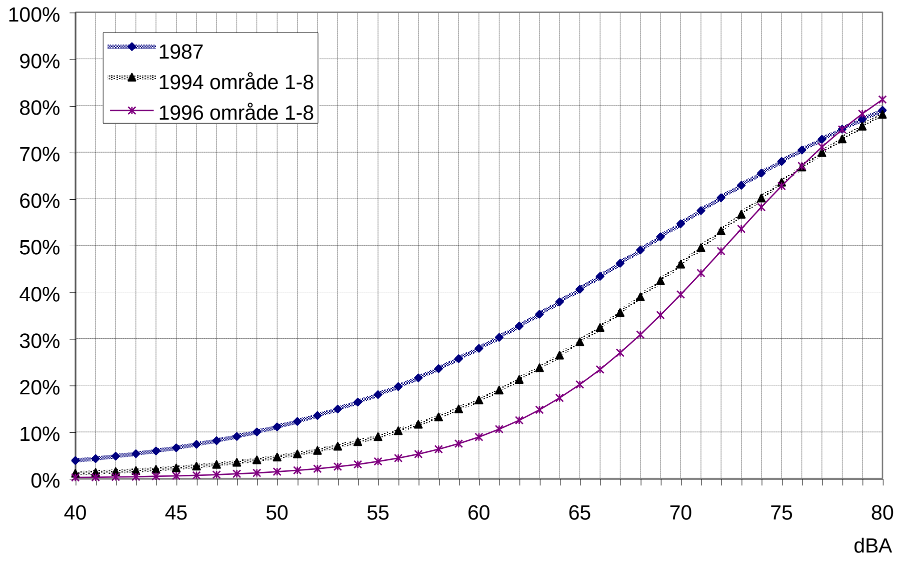


Figure 19: Exposure-response curves for various levels of neighbourhood noise. Percentage of highly annoyed at the Y-axis. From 1987 to 1996 the traffic situation in the community was vastly improved and the general neighbourhood noise was reduced substantially (Klæboe, R. 2021: personal communication).

The traffic situation in a part of Oslo was constantly improved over a period of about ten years. The traffic was concentrated to designated main roads thus reducing the traffic in many small roads throughout the community. Annoyance surveys were conducted at regular intervals to monitor changes in the response. The change in the annoyance response due to a lowering of the neighbourhood noise was quite substantially. After the traffic improvement project was completed the average exposure-response curve for the community was lower than the Miedema curve.

Based on the observations (Figure 19) we estimate that the annoyance equivalent noise level shift may be up to 10 dB.

5.4. Summary - Prioritised moderators

The results from surveys on annoyance from road traffic noise indicate that the annoyance response is affected by a set of non-acoustic factors. The influence of these factors, *i.e.* the magnitude of the effect, varies, and the feasibility and practicality of manipulating these factors depends on local circumstances. It is recommended that the FAMOS project should focus on factors that have a large potential for annoyance reduction, and that are easily implemented.

In a brand-new situation where a whole new community is being developed, noise abating measures must be used to secure that the local noise limits are fulfilled. On top at that, the most effective annoyance-reducing measure is probably to make sure that houses and residences are located in a favourable position/orientation relative to the road. Noise-sensitive rooms should not be facing the noise source, and all dwellings should have access to a quiet side. The noise in the local neighbourhood shall be as low as possible and the traffic safety situation as good as possible in the neighbourhood.

In a new situation it is also possible to pay more attention to the visual appearance of the road and make room for green elements that are known to have an annoyance-reducing effect.

So, the five factors:

- Visual appearance of the road and its immediate surroundings as well as noise abatement measures like barriers etc.
- The use of greenery
- Orientation of dwelling, access to a quiet side of the dwelling

- Neighbourhood soundscape
- Neighbourhood traffic safety

should be studied further.

In a situation where a new road is being planned or a road is being refurbished the location of houses and the community infrastructure is already fixed. In these cases, noise guidelines have to be fulfilled and it may be advantageous to focus on the planning and construction process, involving the residents in the planning whenever feasible and developing good relations between the community and the road owner. These are factors that may have a large impact on the annoyance response.

In a major refurbishing process, the whole traffic pattern in the entire community is often under consideration. Concentration of traffic in chosen preferred streets leaving others with minimum traffic will often lower the general traffic noise level in the neighbourhood, or at least create some areas in the neighbourhood with low (and more agreeable) noise levels. An improvement of the neighbourhood soundscape will lower the annoyance even if the noise exposure from the major through-roads remains the same.

So, the factors:

- Attitudes and relations between the community and the road authorities
- Neighbourhood soundscape

should be studied further.

So far, the results from other surveys and research projects have shown that the annoyance response will vary significantly depending on the presence or absence of other non-acoustic factors. It may therefore be feasible to alter the annoyance response without changing the actual noise levels. This requires detailed knowledge about the different non-acoustic factors and possible interaction between them.

In order to prioritize different modifiers, the following criteria have been considered:

- To which degree is this modifier controllable by the road authority?
- What is the potential for shift in the annoyance response?
- What is the quality of existing data that support the conclusions?

The following preliminary list of modifying factors for further studies has been developed based on these criteria, the magnitude of the modifying effect and possibilities for implementation. Situational variables will determine which one of these that are most suitable in any one situation and thus also the priority.

- Visual appearance of the road and its immediate surroundings, e.g. visibility of traffic, greenery and the type and visual appearance of mitigation measures
- Orientation of dwelling, access to a quiet side of the dwelling
- Attitudes and relations between the community and the road authorities
- Neighbourhood soundscape
- Perceived traffic safety

6. Data collection and hypothesis testing

In Work Package 2 of the FAMOS project, three different methods for data collection were investigated within a limited experimental setup. The purpose of the testing phase is threefold:

- Investigating the suitability of methods for measuring the effect of moderators in future road projects
- Hypothesis testing for already identified moderators in Work package 1
- Gap filling for knowledge missing for important moderators retrieved in Work package 1

The methods tested were

- Audio/visual listening tests in the FORCE listening room, where visual context is presented with variations in moderators relevant for this type of testing (see Section 4.1)
- Mini surveys using questionnaires on comparable locations with variations in relevant moderators (see Section 4.2)
- Sound walks have been performed at alternative locations with different conditions with regard to selected moderators (see Section 4.3)

The results of these types of tests can be dose-response relations for different situations of the moderators selected for testing. Moderators that are well documented from the search, analysis, and modelling phases (Chapter 5) have been included to test the validity of the test procedures used against results from real life survey.

The sound walks represent the holistic perception of various real scenarios. The results of the sound walks will be expressed in perceptual and affective dimensions and will be quantified in terms of a simple soundscape index which expresses the difference between the assessed and the preferred soundscape characteristics.

There are limitations, advantages, disadvantages, and uncertainties for each of the above-mentioned methods:

- In the first, the visual sensory input is easy controllable, but it may not give a full realistic experience. Furthermore, the context is a test situation which may give other results than real life. The results may deviate from real life results, but previous tests performed by FORCE of this type indicate that the results can have a high correlation with these.
- The advantage of the two latter is they relate to real life situations. The disadvantage is, that variations in individual and other context variables also moderates the annoyance effect and it may be difficult to isolate the effect of the moderators under investigation without influence of the other.
- The possibilities for using these tools for measuring the effect of moderators in specific scenarios for new road projects or reconstruction of existing roads has been investigated. Clever design of experiments may give usable results. The relevant methods will be described in the FAMOS guidebook for practical use (Deliverable D.4.5 of the FAMOS project).

Results will in the following be analysed for each test method, but also a summary on the results and suitability is given in Sections 6.4 and 6.5.

6.1. Listening tests

This section presents the testing of listening tests with focus on moderators related to visual appearance of the road and its immediate surroundings. This work is documented Deliverable 2.2 of the FAMOS project [42].

Listening tests were performed in the laboratory simulating alternative locations with three different conditions with regard the selected moderators:

1. Presence of vegetation or greenery situated between and near the road and the people exposed to the noise
2. Visibility of road and traffic for the people exposed to the noise
3. Visibility of different types of noise screening

Listening tests are performed to investigate the perception of sounds by humans. During the listening test the listeners, the assessors, characterises the sound in a number of objectively defined perceptual attributes or they may characterize their own feelings about the sound, i.e. an affective assessment, e.g. the annoyance of the sound. In both cases the answers from a number of assessors will be the basis for mean values and confidence intervals for the attributes tested. Especially for the affective tests the context of the sound and the listening situation usually have a significant impact on the results. Therefore, results obtained in a laboratory setting will probably deviate from the results obtained in real life e.g. obtained by socio-acoustic surveys.

To improve the realism of the laboratory test in this project, we have performed the test as audio-visual listening tests (AV listening tests) by combining the sounds with video recordings of the relevant scenarios. Furthermore, the assessors were instructed to imagine a specific context situation during their assessments.

The hypothesis is that relative changes between alternative stimuli in an AV listening test will change the response in the same way as in real life, even if the size of the effect may differ.

The main purpose for performing listening tests in this project has been to investigate the possibility for using this as a tool for measuring the effect of moderators in specific scenarios in future road projects conducted by national road administrations. The results have been taken into account, when merging findings in other parts of the FAMOS project (see Chapter 6).

6.1.1. Locations

The locations for the video and sound recordings for the listening tests were selected so that there were variations in the moderators of interest, i.e.: the visibility of the traffic and the amount of greenery (trees, bushes, and grass) and the type and appearance of the noise screens. The positions were chosen at major roads and motorways in and around Copenhagen.

Overview

An overview of the positions is given in Table 3 and in Figure 20. The percentage of greenery is calculated as the area of the video image occupied by vegetation. The calculation is approximate and is based on the area of 2-5 rectangles fitted to the greenery in the video pictures for each location.

Table 3: The positions for video and sound recordings to the listening tests.

Positions	Type	Traffic Visible, %	Greenery, %	Screen	Approx. distance to road, m
1. Town Hall Square	Major road	100	0	No	15
2. Gentofte	Motorway	80	17	Glass	20
3. Ishøj	Motorway	100	63	No	15

4. Lyngby 1	Motorway	100	67	No	25
5. Hørsholm 1	Motorway	50	77	No	70
6. H.C.A. Boulevard	Major road	100	57	No	10
7. Holte	Major road	100	78	No	20
8. Buddinge	Motorway	0	22	Steel	(20)
9. Hørsholm 2	Motorway	0	100	No	(50)
10. Lyngby 2	Motorway	0	59	Wood	(15)

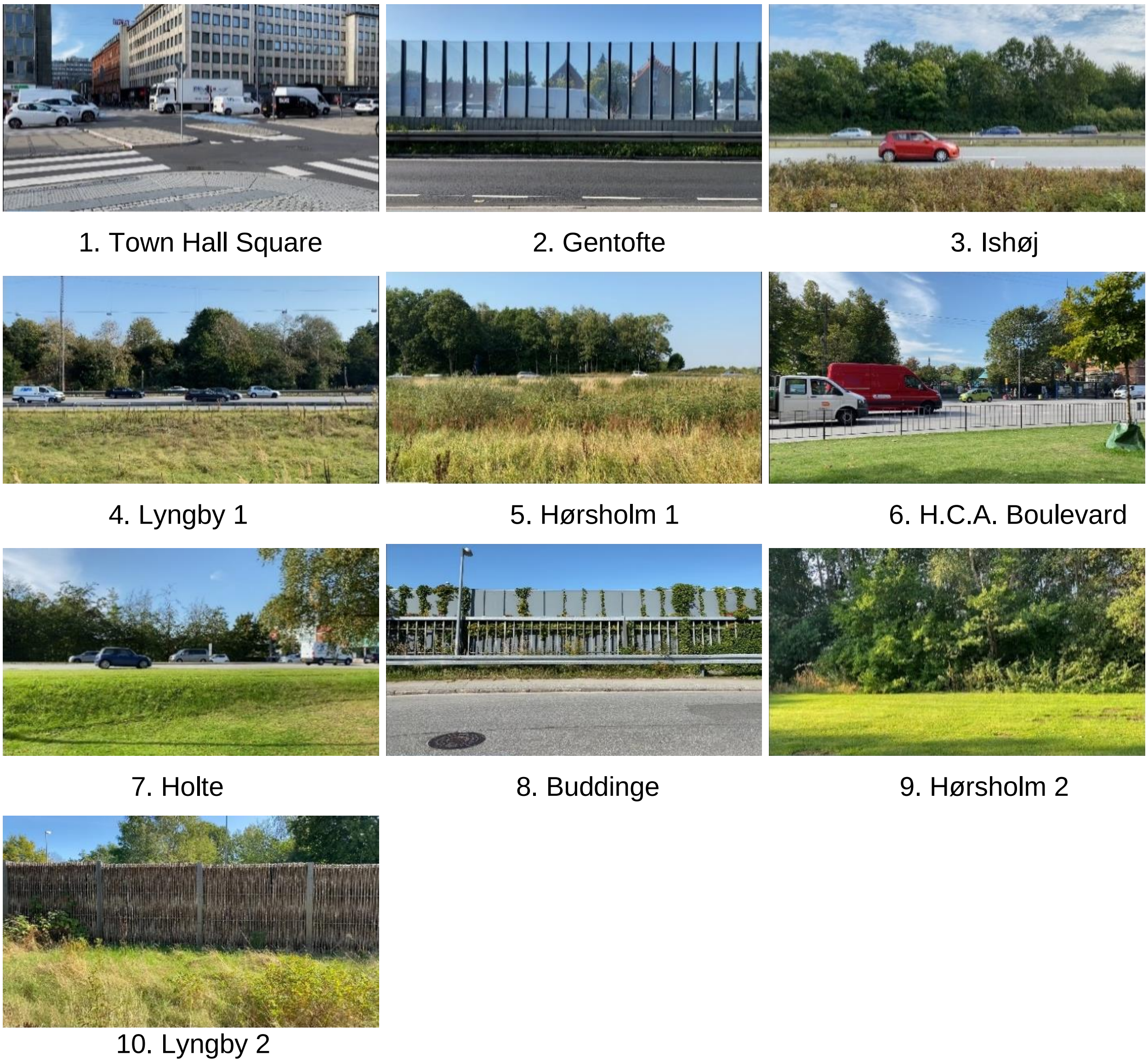


Figure 20: Overview over the recording positions, the visual stimuli.

Positions for recordings

Position 1 – Town Hall Square

This position is at the corner if the Town Hall Square in Copenhagen. The road, the same as in position 6, is one of the busiest roads in the central Copenhagen with four lanes in each direction. There are road crossings and traffic lights at and to both sides 100-200 meters from the measuring position. Speed limit 50 km/h.

Figure 21: Position 1. Picture taken from the video shown at the listening test.
Distance to road: 15 m. 0 % greenery.

Position 2 – Gentofte

The Elsinore motorway E47, north of Copenhagen, in Gentofte with 3 lanes in each direction. The traffic is seen through a transparent glass screen, but the lower part of the vehicles is hidden by the low concrete barrier. It is estimated that the traffic is 80 % visible. A little greenery is seen in front of the glass screen and between the houses on the opposite side of the motorway. Speed limit 90 km/h. The road in the front is a local road with minor traffic.

Figure 22: Position 2. Picture taken from the video shown at the listening test.
Distance to road: 20 m. 17 % greenery.

Position 3 – Ishøj

Køge Bugt Motorvejen, E47, west of Copenhagen, in Ishøj with 3 lanes in each direction. The traffic is fully visible. There is greenery both in front and behind the motorway. Speed limit 110 km/h.

Figure 23: Position 3. Picture taken from the video shown at the listening test.
Distance to road: 15 m. 63 % greenery.

Position 4 – Lyngby 1

The Elsinore motorway E47, north of Copenhagen, three lanes in each direction, near the Danish Technical University, DTU. Traffic fully visible and greenery both in front and behind the road. Speed limit 90 km/h.

Figure 24: Position 4. Picture taken from the video shown at the listening test.
Distance to road: 25 m. 67 % greenery.

Position 5 – Hørsholm 1

The Elsinore motorway E47, north of Copenhagen with two lanes in each direction, near Hørsholm. The traffic is partly hidden by greenery, 50 % visible. Greenery both in front and behind the road. Speed limit 110 km/h.

Figure 25: Position 5. Picture taken from the video shown at the listening test.
Distance to road: 60 m. 77% greenery. Traffic 50 % visible.

Position 6 – H.C. Andersens Boulevard

This position was close to the Town Hall in Copenhagen. The road, the same as in position 1, is one of the busiest roads in the central Copenhagen with four lanes in each direction. There are road crossings with traffic lights to both sides some hundred meters from the measuring position. The traffic is fully visible and there is greenery both in from and behind the road except for the utmost right corner. Speed limit 50 km/h.

Figure 26: Position 6. Picture taken from the video shown at the listening test.
Distance to road: 10 m. 57 % greenery.

Position 7 – Holte

Major road with 4 lanes near the Holte town hall. The traffic is fully visible and there is greenery both in front and behind the road except at the utmost right. Speed limit 50 km/h.

Figure 27: Position 7. Picture taken from the video shown at the listening test.
Distance to road: 20 m. 78 % greenery.

Position 8 – Buddinge

The Ring Motorway M3 around Copenhagen with three lanes in each direction, in Buddinge. The traffic is hidden by a steel barrier, which is partly covered by greenery. Speed limit 110 km/h. The road in the front is a local road with minor traffic.

Figure 28: Position 8. Picture taken from the video shown at the listening test.
Distance to road: 20 m. 22 % greenery.

Position 9 – Hørsholm 2

The Elsinore motorway E47, north of Copenhagen with two lanes in each direction, in Hørsholm near the townhall. The traffic is totally hidden by greenery which fill the whole picture. Speed limit 110 km/h.

Figure 29: Position 9. Picture taken from the video shown at the listening test.
Distance to road: 50 m. 100 % greenery.

Position 10 – Lyngby 2

The Elsinore motorway E47, north of Copenhagen, two south going lanes in Lyngby. The traffic is totally hidden by the wooden screen. Speed limit 90 km/h.

Figure 30: Position 10. Picture taken from the video shown at the listening test.
Distance to road: 15 m. 59 % greenery.

6.1.2. Method

Video and calibrated sound recordings were made at the ten positions near busy roads. The recordings represented variations in the noise levels, the visibility of the traffic, the amount of greenery and the types of noise screens. Combinations of noise played back over a stereo setup and video recordings on a screen were shown to assessors, who assessed the annoyance of the different situations.

The listening tests were performed according to the FORCE guideline [43] for such tests.

Recordings

The recordings were made were made 18th to 29th of September 2020 in good dry weather conditions with moderate wind and with dry roads. The vegetation was still green.

The original video and sound recordings lasted around 10 minutes in each of the ten positions. From these recordings neutral 30 seconds excerpt without any characteristic vehicles (visual or sound) were selected for the test.

The calibrated sound recordings with the measuring microphones were analysed with the NoiseLab noise analysis software.

Figure 31: Photos of the measuring setup

Listening room and sound reproduction

The listening tests with stereo loudspeakers were performed in the listening room, of FORCE Technology, SenseLab.

Figure 32: The SenseLab listening room at FORCE Technology. The sound is played from the stereo setup and the video is shown at the large screen. The projector for the video is outside the listening room. The PC-screen is for the user interface.

In the listening room a 26-channel surround system is installed but only the two front stereo speakers were used for this test.

The listening room and the 26-channel loudspeaker system fulfils ITU-R BS.1116-3 [44], with respect to reverberation time, background noise level and frequency response of the loudspeakers.

The measured background noise were:

- Background and inherent microphone noise: L_{Aeq} = 11 dB
- As above plus ventilation at 20 %: L_{Aeq} = 12 dB
- As above with all 26 loudspeakers on: L_{Aeq} = 19 dB.

The ITU-R BS.1116-3 [44] requirements to the speaker system are +/-3 dB in the frequency range 250-2000 Hz, widening to +3 to -7 dB at 50 Hz. The system is well within these tolerances down to 30 Hz.

The FORCE Technology SenseLabOnline software version 4.0.3 was used for stimulus randomization, playback, and collection of assessments in the listening test.

The sound pressure levels stated, were measured in the listening position without the listener present.

Assessors

In total 24 assessors participated in the listening test. The persons participating were ordinary persons (non-expert listeners) recruited from SenseLabs group of “consumers” via Facebook. The participants received a gift card to shops for their participation. The ages of the participants were between 21 and 66 years with a mean of 40 years with 10 male and 14 female listeners.

No assessors were excluded according to post-screening of the test results.

Instruction and attributes

The instruction to the test persons (the assessors) can be seen in the annex of [42]. They were asked to assess different examples of traffic noise from samples with both audio and video. They were informed that the road is always close by but in some cases the traffic is not visible.

The assessors should imagine that they were at home and that the situation is like in the video, all day.

They were asked to get used to the situation before making an assessment - preferably at least 10 seconds.

They were asked to assess the following two attributes:

- Annoyance: State how annoying you perceive the sound, considering that you have to be in this place for an hour. Annoyance: The sound is bothering or disturbing.
- Does the sound fit: Watch the video and indicate to what extent you think the sound fits the visual surroundings.

The definitions of the attributes were shown to the participants, next to the answering scales.

There were labels next to the continuous answering scale. The labels for the annoyance scale were the ones defined in ISO/TS 15666 [45].

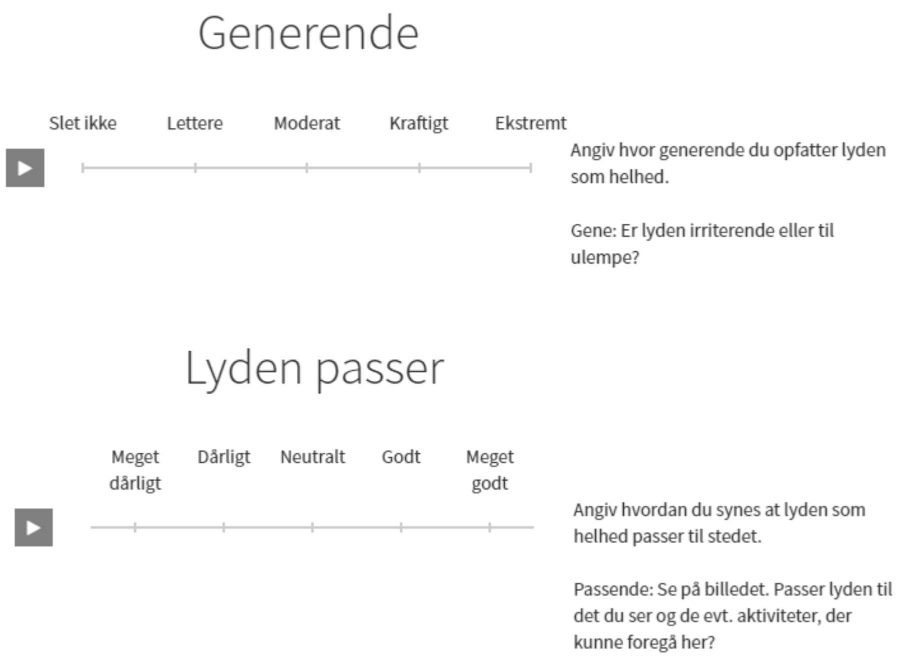


Figure 33: User interface for the listening test and the answering scales used.
Upper scale: Annoyance. The scale labels are: Not at all, Slightly, Moderately, Very and Extremely annoyed.
Lower scale: Does "The sound fit" (to the place). The scale labels are: Very bad, Bad, Neutral, Good, Very good.

Test plan

The listening test was completed in two separate sessions.

In session A the videoclips for all ten positions were shown together with the same neutral excerpt of road noise played back at noise levels of 45, 50, 55, 60, 65, 70, and 75 dB.

This would make it possible to construct dose-response curves for each of the scenarios and would give data enough for multiple regression analysis.

6.1.3. Results

Attribute assessments

In this clause the mean results of the attribute assessments are shown. The data in the graphs are the mean values and 95 % confidence intervals of the assessment for all 24 participants in the listening test.

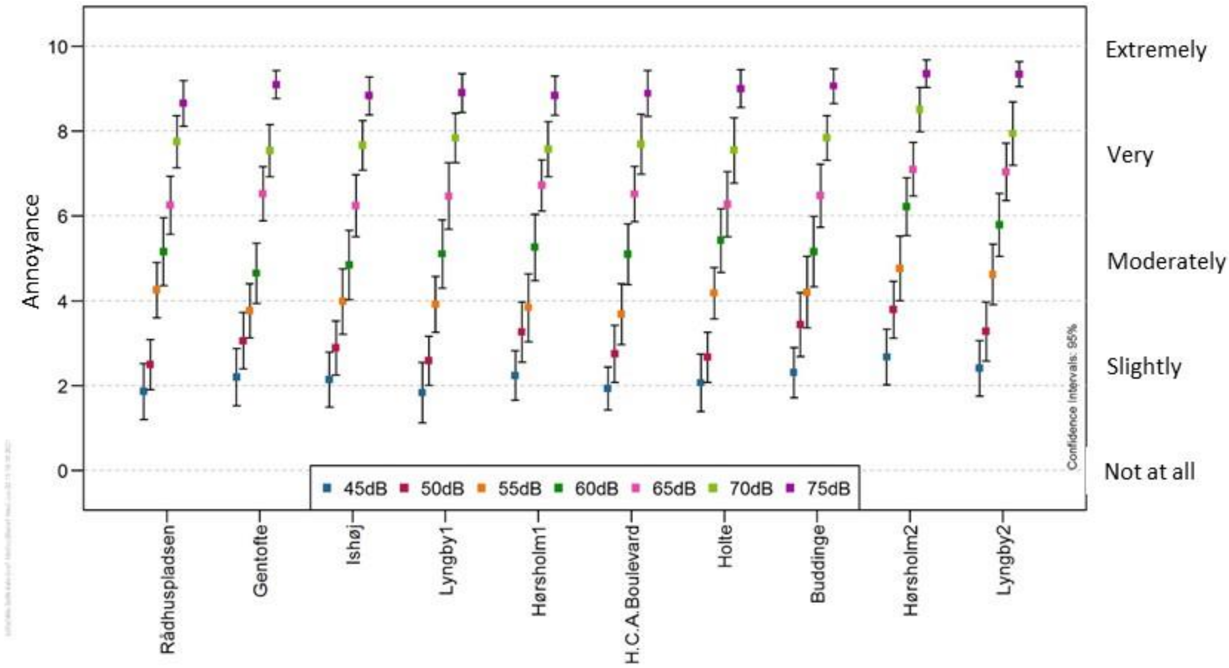


Figure 34: Annoyance. Mean values and 95 % confidence intervals per position and per noise level (L_{Aeq}) The noise levels are L_{Aeq} for the sound samples.

Figure 34 shows the assessments of annoyance. For all positions, the annoyance increases with the noise level, but it can be seen that the annoyance for a specific noise level depends slightly on the position.

Figure 35 is a simplified version of Figure 34 where it is easier to follow the differences in annoyance between the positions for each of the noise levels. The middle levels have larger differences for positions 9 and 10 than the other levels.

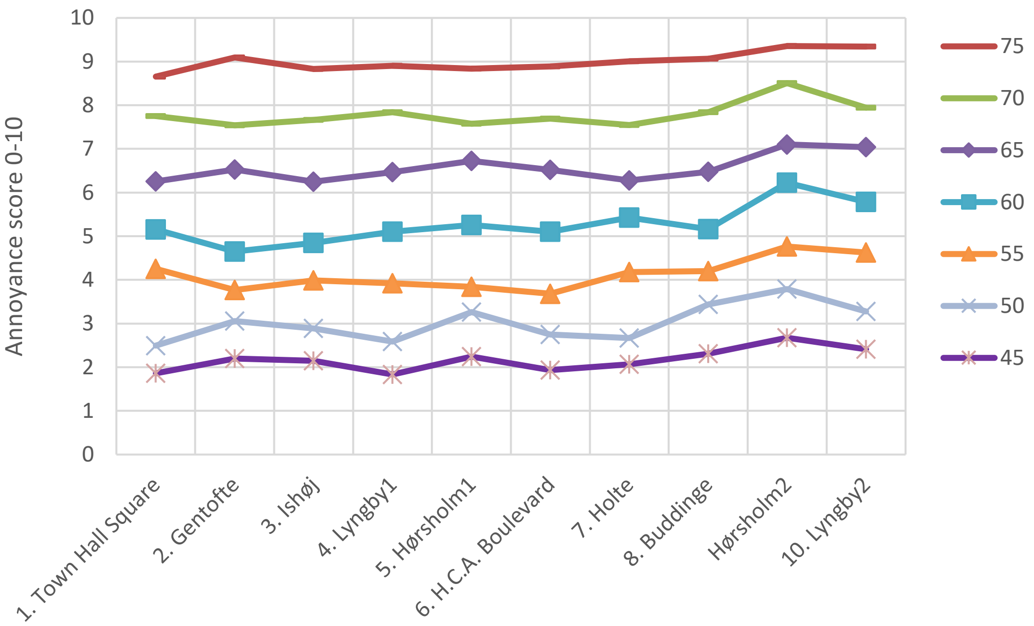


Figure 35: Annoyance stated as annoyance score. A simplified version of Figure 34. The noise levels are L_{Aeq} for the sound samples.

The average for all noise levels positions can be seen from Figure 36. There is a slight increase in the annoyance for positions 8. Buddinge, 9. Hørsholm 2 and 10. Lyngby 2.

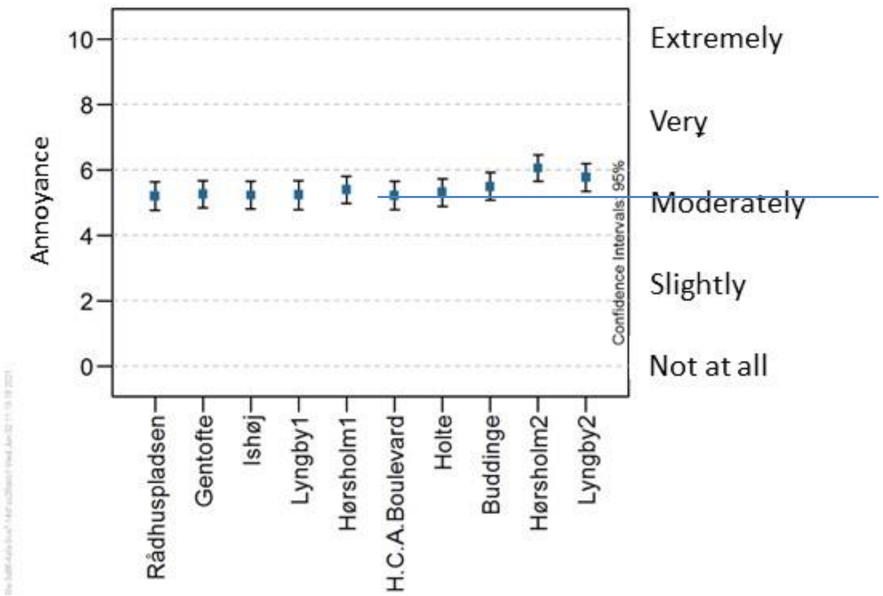


Figure 36: Annoyance. Mean values and 95 % confidence over assessments for all noise levels per position.

Figure 37 shows how the sound fits the video films. It is seen that the L_{Aeq}=75 dB is a bad fit for most positions. This can also be seen in Figure 38 where the fit in average for all positions is poor.

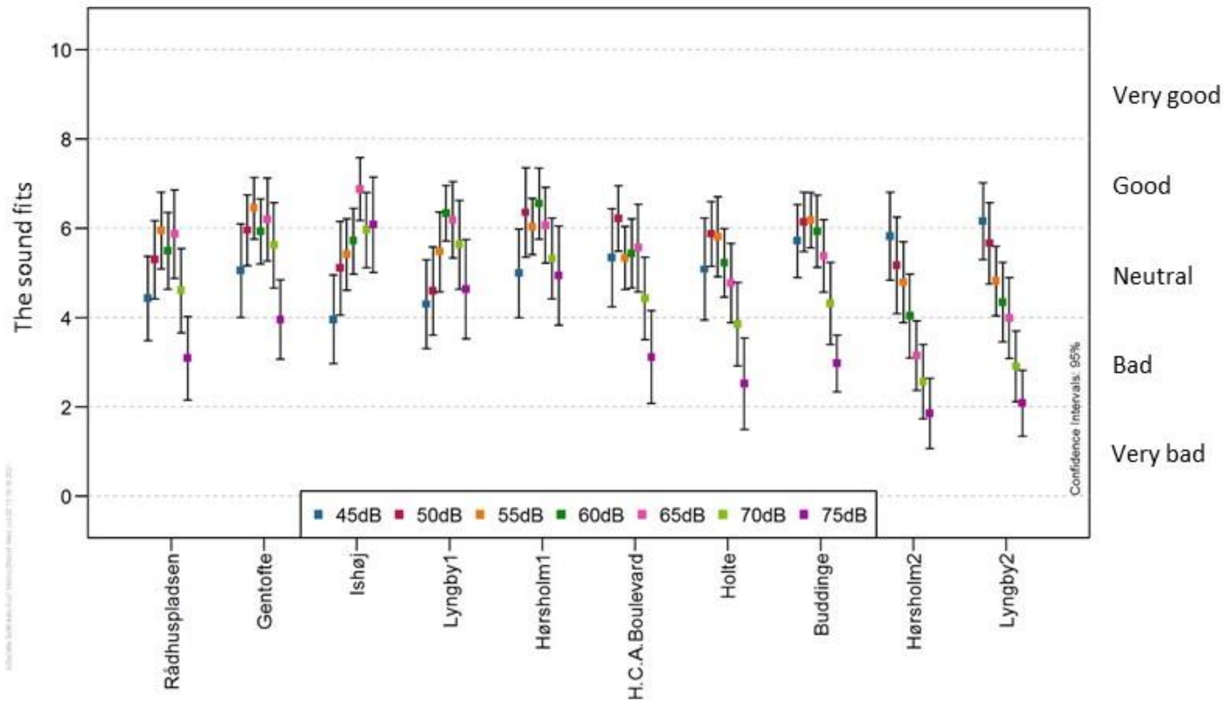


Figure 37: The sound fits. Mean values and 95 % confidence over assessments for all noise levels per position. The noise levels are the L_{Aeq} for the sound samples.

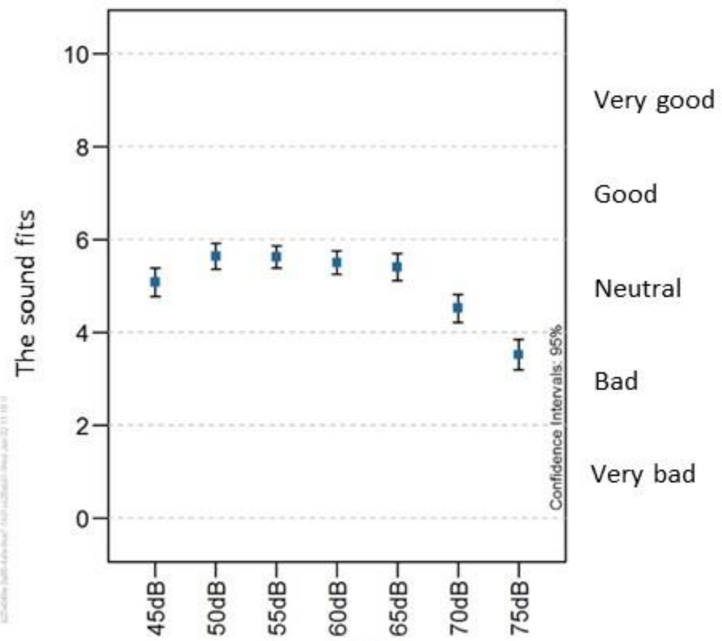


Figure 38: The sound fits. Mean values and 95 % confidence over assessments for all positions. The noise levels are the L_{Aeq} for the sound samples.

From Figure 37 it can be seen that for most positions the highest and the lowest levels are those with the poorest fit to the videos, but for positions Hørsholm2 and Lyngby 2 the best fit is obtained for the lowest levels. This also partly the case for Holte and Buddinge.

The real sound pressure levels (L_{Aeq}) in the measuring positions were in the range 60-70 dB with a few exceptions of up to 72 dB, so the 75 dB is higher than the noise levels in all positions. It was therefor decided to exclude the 75 dB level for the dose response analyses in next clause. In fact, as can be seen in [42], this also gave a slightly better fit to the data.

To conclude:

- For all positions there is a significant increase of the annoyance with the noise level.
- The fit between noise levels and videos were generally neutral to good, except for the highest levels which were bad.
- As the highest level, L_{Aeq}=75 dB, was higher than any of the real levels at the recording positions this level will be excluded in the analysis of the following analysis of dose-response reactions (see Section 4.1.4).

Relations between the positions

From the assessments of the attributes, information about the positions can be deduced.

A principal component analysis, PCA, is a tool to get an overview over the many assessments of the attributes. PCA, is a dimensionality-reduction method that is often used to reduce the dimensionality of large data sets, by transforming a large set of variables into a smaller one that still contains most of the information in the large set. In this case we only have two dimensions: Annoyance and "The sound fits" the visual appearance on the video. According to the analysis (not shown) these two dimensions are almost perpendicular, i.e. independent.

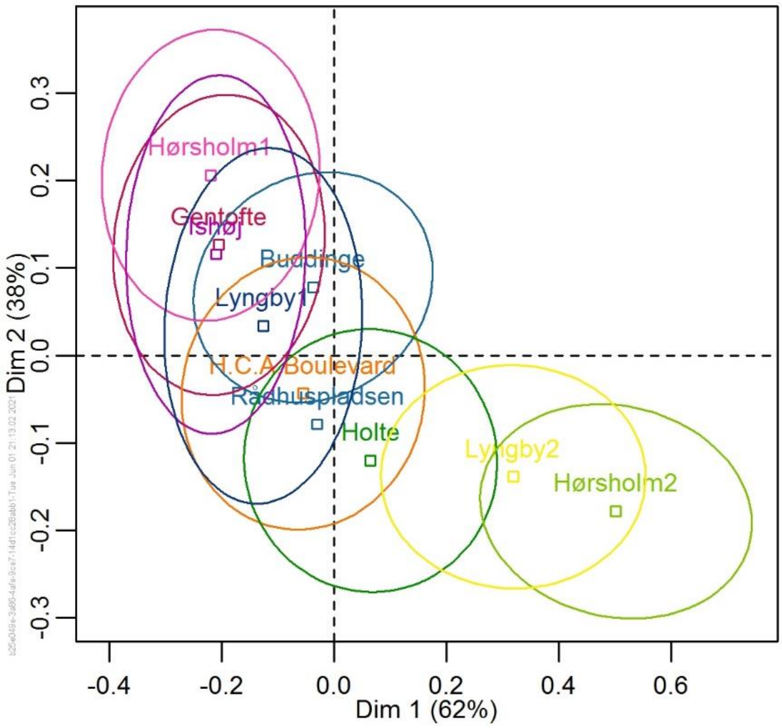


Figure 39: A systems factor map from a principal component analysis (PCA) that show the mean values and confidence ellipses based on the assessments of the measuring positions of the two dimensions Annoyance (Dimension 1) and "The sound fits" (Dimension 2).

From Figure 39 it is seen that the positions form a sort of curved diagonal in the diagram, with Lyngby 2 and Hørsholm 2 in the lower end and Hørsholm 1, Gentofte and Ishøj at the upper end. The rest of the positions is in the middle part.

A cluster analysis based on the same data is shown in Figure 40. The longer the vertical bars are, the more different the clusters they connect are.

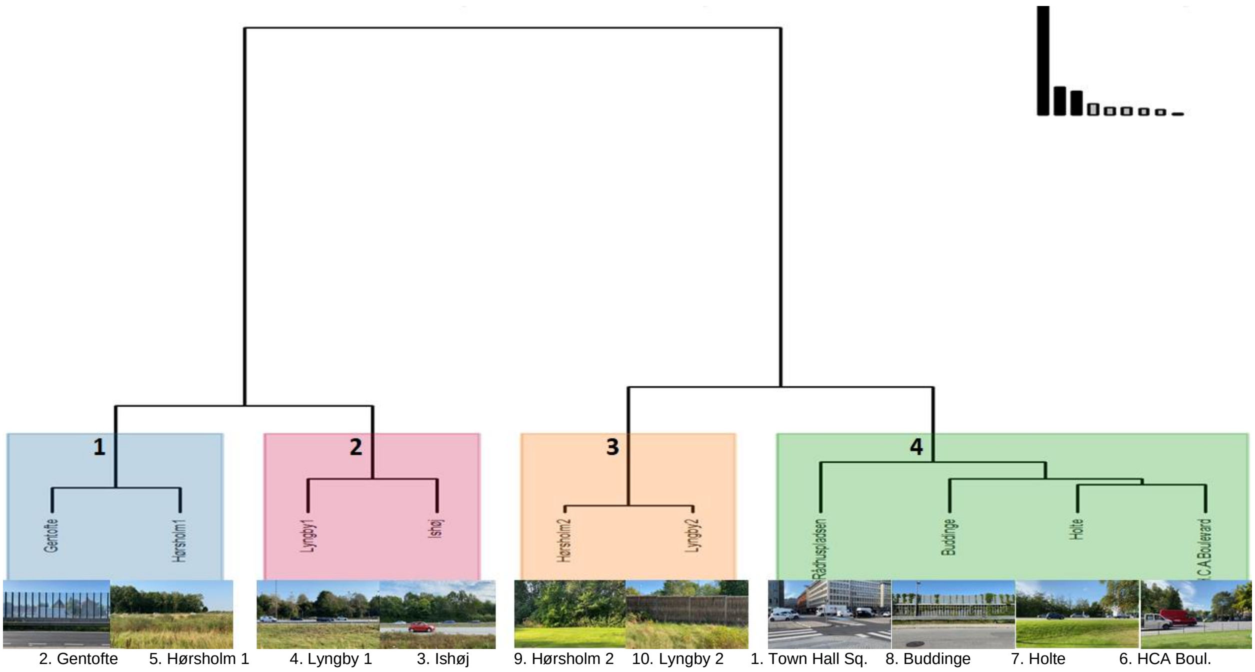


Figure 40: A cluster analysis of the positions based on the assessments of Annoyance and "The sound fits".

It is seen that in Group 1 the traffic is partly hidden by a screen and vegetation. Group 2 is motorways with visible traffic and greenery. In Group 3 there is a lot of greenery, and the traffic is not visible at all. Group 4 is the rest three positions with urban roads and slow traffic various amount of greenery and one position with a steel barrier.

6.1.4. Models for annoyance

Dose-response curves

The relation between the annoyance reaction and the noise exposure can be described with dose-response curves as precented in Section 3.1. Most often these curves represent the annoyance response as function of the noise exposure, L_{den}, where the annoyance responses are averaged over context, social and personal variables.

The responses are normally obtained from socio-acoustic surveys where hundreds to thousands of respondents are asked to assess the annoyance within the last year when they are at home. The annoyance assessment is meant to be the average over time and over the many situations where the annoyance is felt at home.

Although the annoyance measured in the listening test uses the same annoyance scale, the situation is quite different. It is a short-time assessment where the noise and video are more in focus than in the everyday life averaged over a year. Nevertheless, there may be similarities between the dose-response reactions and the non-acoustic factors that modifies the dose response curves.

With the purpose of finding the dose-response curves for the annoyance from traffic noise during the audio-visual listening test, the assessors were exposed for seven different noise levels in the range L_{Aeq} = 45-75 dB, for each video. As mentioned in Section 4.1.3, it was decided to exclude the L_{Aeq} = 75 dB level. From the assessments the annoyance as function of the corresponding L_{Aeq} levels can be found. The curves in Figure 41 shows a model with a logistic fit to the measured data (see Section 3.1.2)

It should be noted that normally the results from socio-acoustic surveys are given as curves showing the percentage of highly annoyed. For the listening tests we have chosen to show the results as the average annoyance response on the 0-10 scale.

The logistic curve is defined by only two constants, the slope, s, and the fifty percent value of the exposure, f (see Section 3.1.2).

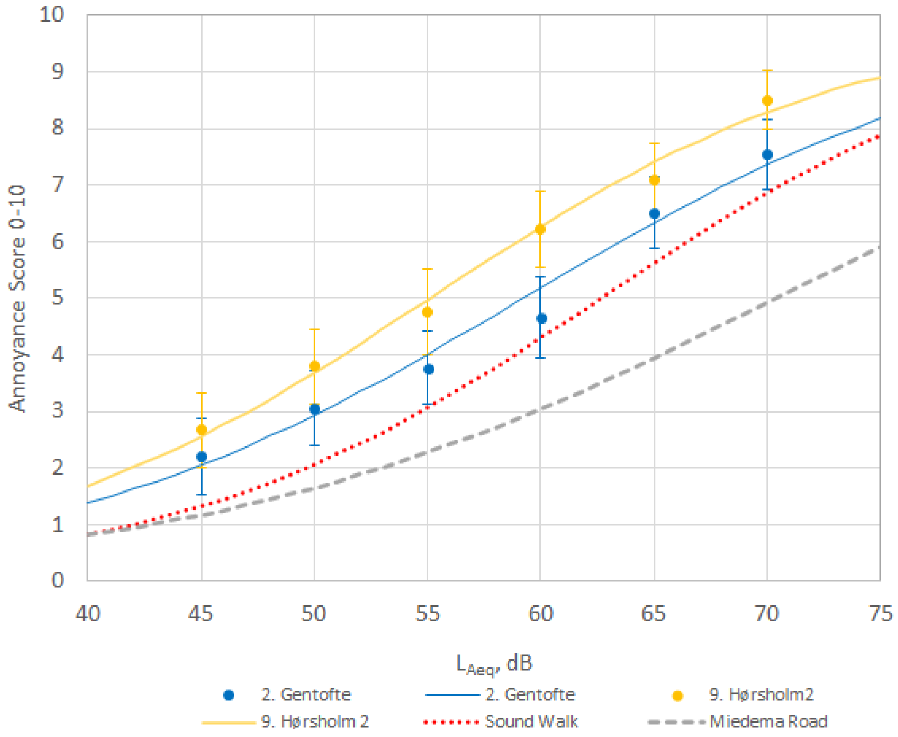


Figure 41: Average annoyance response from the listening test for positions 2. Gentofte and 9. Hørsholm 2. The vertical bars represent the 95 % confidence intervals. The red dotted curve is the annoyance found from sound walks in Copenhagen (see Section 4.3.5 and [46]). The grey dotted curve (Miedema road) is the average annoyance score deduced from [47] according to [48]. For this curve L_{den} is converted to L_{day} (~ L_{Aeq}) by adding 2,4 dB.

The data for the curves in Figure 39 can be found in Table 4.

Table 4: Data for s and f for the curves in Figure 39. See the formula on in Section 3.1.2.

	2. Gentofte	**9. Hørsholm 2**	**Sound Walk**	**Miedema Road**
s	0.0950	0.1057	0.1064	0.0795
f	59.2	55.1	62.7	70.4

In Figure 39 data and curves for the locations with the highest (Hørsholm 2) and lowest annoyance (Gentofte) are shown. As the confidence intervals are not or only slightly overlapping, we can state the difference between the two curves is significant. Also shown in the figure is the results from the sound walks performed in Copenhagen (see Section 4.3.5).

The models from the listening test in Figure 39 gives good fit (R^2>0.97) to the data. It can be concluded that it is possible to find a dose-response curve from the listening test. Furthermore, it can be seen that there is a significant influence of the videos shown together with the noise. The influence corresponds to a level difference of up to 4 dB.

Compared to the corresponding curve from the sound walks it can be seen that the annoyance is assessed higher in the listening tests.

For the Miedema data (the EU standard road noise annoyance curve), the annoyance response is lower than the listening tests and the sound walks and with a less steep slope. This is to be expected because the survey data (the basis for the Miedema curve) is the average over all situations at home where the focus is not specifically at the traffic noise as in the listening tests and the sound walks.

In Figure 42 the dose-response curves for all the positions can be found.

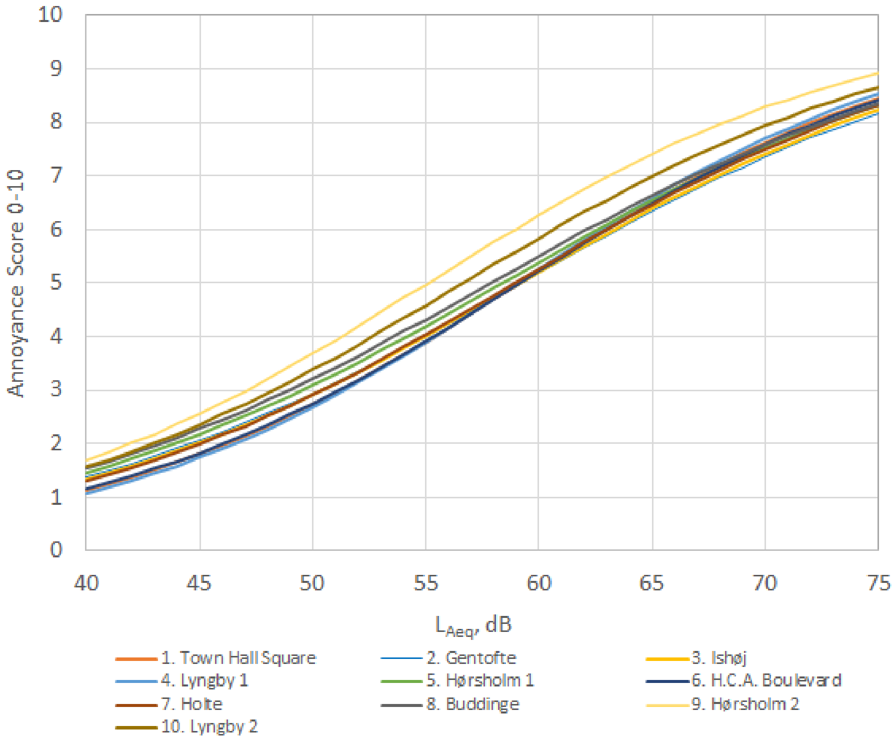


Figure 42: Dose-response curves for each position modelled from the listening tests. The data behind the curves can be found in 9.4, Figure 26 together with the R^2 values. (all > 0.97). The curves that deviate most from the rest is Hørsholm 2 and Lyngby 2.

Influence of moderators

The next relevant topic is to see if the influence of non-acoustic factors can be modelled. Multiple regression analysis was made with all the factors from Table 3, but only the influence of greenery and the visibility of the traffic was found significant.

With the data from Table 3 and the response from the listeners a logistic regression model is made including L_{Aeq}, % greenery and % traffic visible.

According to the three-factor model, see [42], the annoyance found in the listening test can be calculated from:

$$(3) \qquad Annoyance\% = \frac{10}{1 + e^{(0.1014*L_{Aeq} - 0.2528*Visible\% + 0.1533*Green\% - 5.829)}}$$

In [42] also the confidence intervals for the constants can be found. The influence of all the variables, L_{Aeq}, Visible Traffic% and Greenery% is significant.

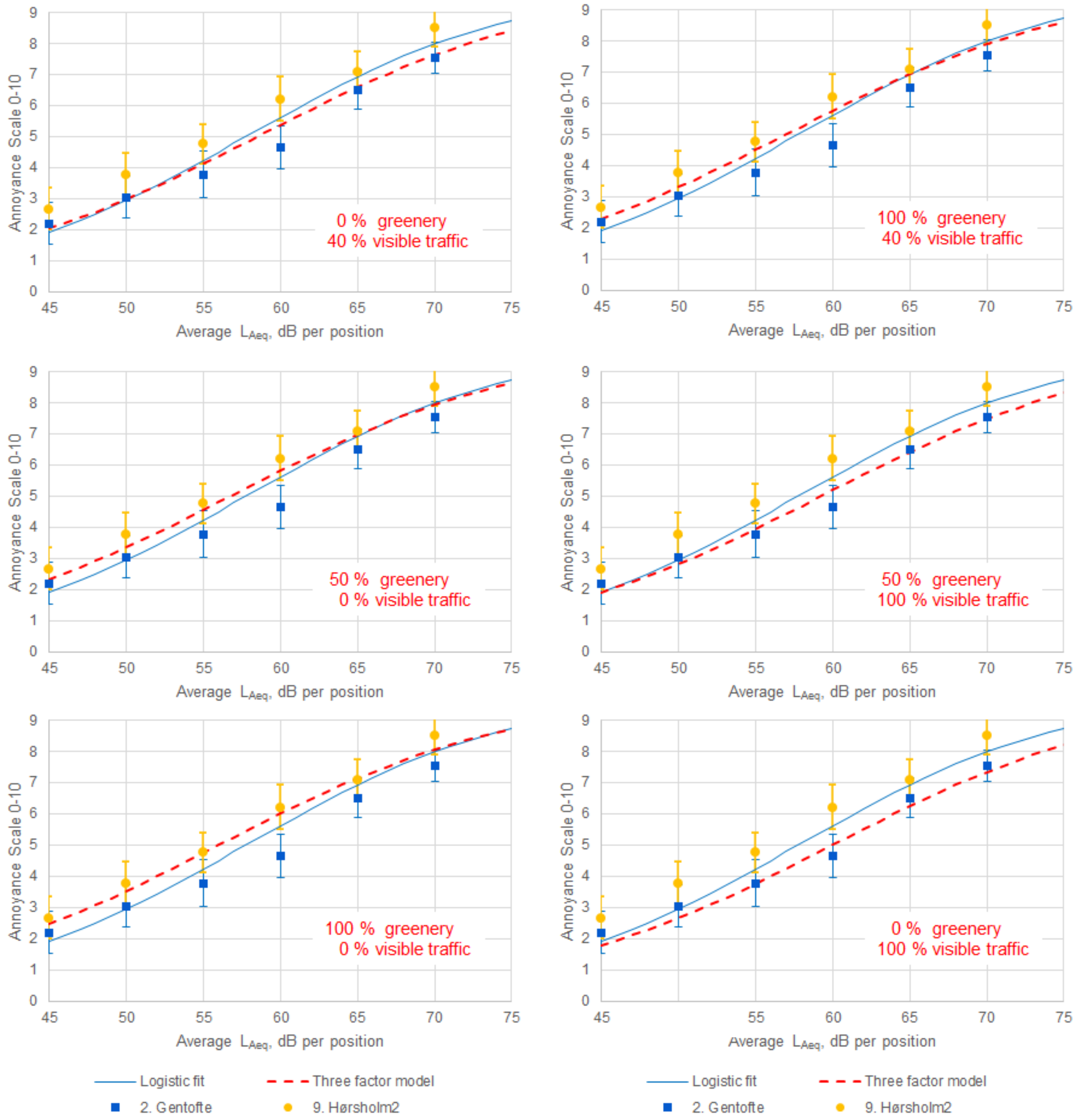


Figure 43: The effect of greenery and visibility of the traffic on the dose-response curve (red dashed curve). The upper two graphs show the effect of greenery. The two middle graphs show the effect of visible traffic, and the two lowest graphs show the maximum influence of greenery and visible traffic.
The blue curve is a dose-response curve calculated with a model including only L_{Aeq}.
The influence of all the variables, L_{Aeq}, Visible Traffic % and Greenery % is significant. The data for Gentofte and Hørsholm 2 are the same as in Figure 41.

The annoyance equivalent change in L_{Aeq} for 0-100 % greenery is 1.5 dB and for 0-100 % visual traffic the change is 2.5 dB. The maximum influence of the visual perception is approx. 4 dB.

Unfortunately, the sign of the constants are opposite to other findings.

- The constant for visual traffic is negative, meaning that the more the traffic is seen the less is the annoyance. This is not in line with practical experience where the annoyance is less if the traffic cannot be seen, [41]
- The constant for greenery is positive, meaning more greenery is giving higher annoyance. This can in fact already be seen from Figure 34 and Figure 35 for the positions Hørsholm 2 and Lyngby 2 when comparing with the other positions. This is in contradiction with practical experience and findings in the literature, see e.g. [26], [49].

We do not have any solid explanation to this, but we have the following hypothesis: When you are presented to a nice video with a lot of greenery and no visible traffic, as e.g. Figure 29, you will expect a rather silent environment. So, when you are exposed to higher noise levels than expected, the noise is perceived more annoying. Although the assessors were told that there was a road nearby in all positions, that information may not have been at the top of their mind when they made their assessments.

This hypothesis is supported by Figure 44. At all levels, except the two lowest, the trend is that the Annoyance increases when "The sound fits" decreases. This could also be seen as when the expectations are not fulfilled, the annoyance increases (see results of mini surveys in Section 6.2.3).

So, we conclude that it is important that the sound and the video fit each other and that the assessors have a full understanding of the context. This might be obtained e.g. by a short introductory tour in the video showing the road behind the screen or the greenery.

There were other differences in the positions than greenery and visible traffic, e.g. different speed of the traffic, traffic flow, road type, screen type and distance to the road. We have made a preliminary analysis of the three last-mentioned, but they were not found significant, maybe because of two few datapoints.

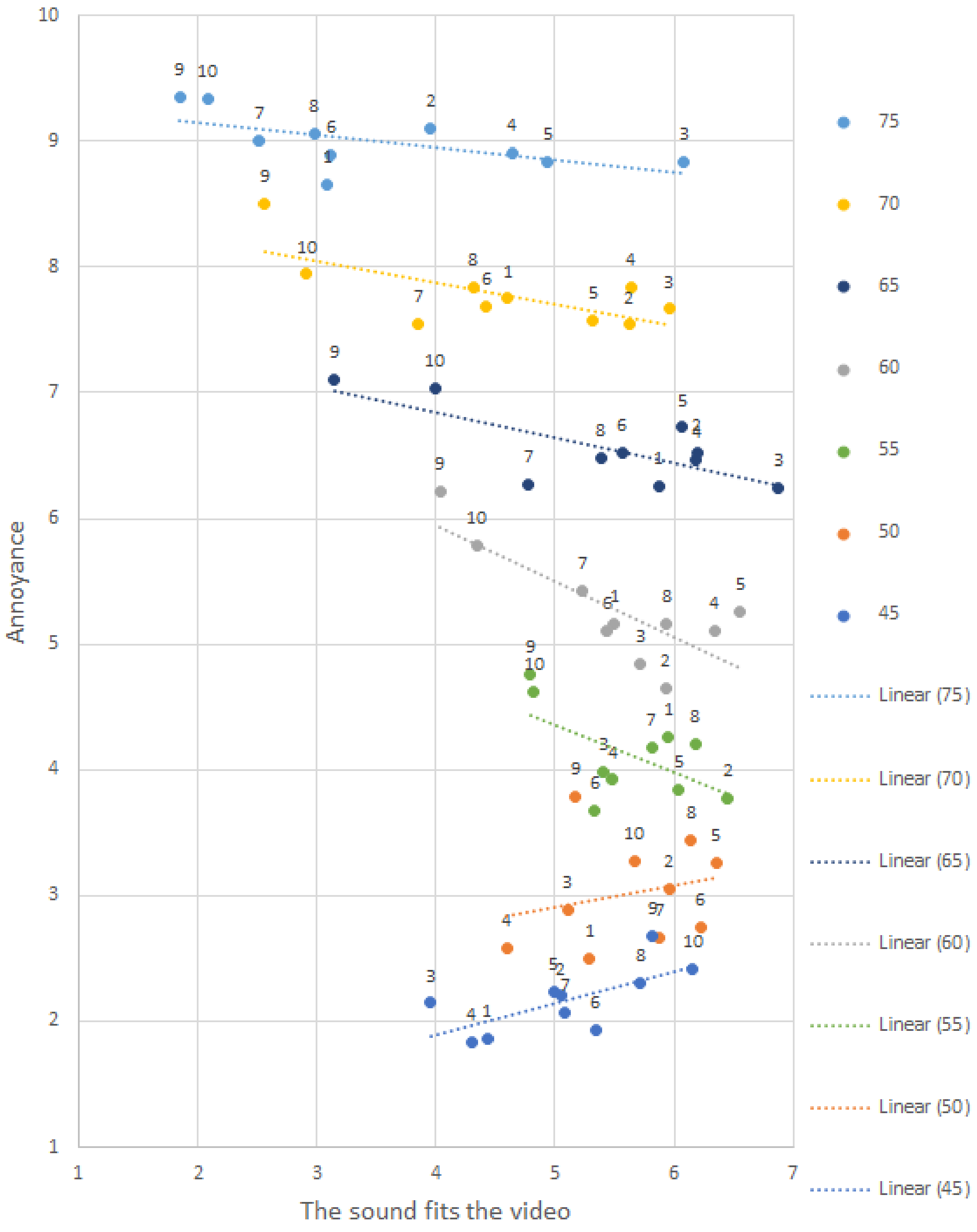


Figure 44: The relation between "The sound fits" the video and the Annoyance 0-10 score. The colours indicate the levels and the numbers in the graph indicate the positions, see Section 4.1.1.

6.1.5. Discussion and conclusions on the listening tests

The positions for the video recordings for the listening tests were selected so that there were variations in the moderators of interest, i.e.: the visibility of the traffic and the amount of greenery (trees, bushes, and grass) and the type and appearance of the noise screens.

For all positions, a significant increase of the annoyance with the noise level increasing was found. There were variations in this increase from the various positions.

The fit between noise levels and videos were generally neutral to good, except for the highest levels, which were the fit was assessed as bad. Furthermore, the highest level, L_{Aeq}=75 dB was higher than any of the real levels at the recording positions. Therefore, this level was excluded in the analysis of the dose-response reactions. Anyway, some of the remaining samples were assessed as having a bad fit to the video.

From the results on the annoyance assessments, logistic dose-response curves could be constructed with a good fit (R^2 > 0.95 on the mean values). The annoyance response was higher and steeper than the “Miedema” curve found from surveys. That was to be expected, as the stimuli, the context and the attention to the noise was more uniform in the listening test than in real life at home. The response was also higher than was found in the sound walks (see Section 4.3.5).

The dose-response curves show that the visual perception has a clear and significant influence on the perception of annoyance from the noise. Differences in the annoyance corresponded to level differences, the annoyance equivalent change in noise levels, up to 4 dB for the same sound stimuli.

Multiple regression analysis has been performed to find the influence of the moderators Greenery and Visible traffic. The variables were the percentage of the area of greenery measured in the video pictures and the percentage of visible traffic estimated from inspection of the video images.

The influence of the moderators Greenery and Visible traffic is summarized as part of the hypothesis testing (see Section 6.4).

So, for the audio-visual listening test we can conclude:

- We have found dose response curves with a high degree of explanation of the variation of the annoyance response (R^2>0.95).
- There is a significant influence of the visual impact on the assessment of the annoyance.
- If audio-visual listening tests are used for this purpose, it is important that they are realistic and give a good understanding of the full context.

6.2. Mini surveys – questionnaires

As a possible tool for further analysis, mini surveys (questionnaires) were planned as part of the FAMOS project as a mean to analyse the effect of non-acoustic factors. This section presents the results of the mini surveys with focus on moderators related to greenery, visibility, and expectations. The work is documented in Deliverable 2.2 on mini surveys [50].

The original plan was to find suitable locations for surveys before and after a change in the overall situation. This may have been a change in greenery (e.g. cutting down trees), a major change in the road traffic volume (increase due to detours or decrease due to construction work) and so on.

Moderators considered in the survey include:

1. Quality of surroundings of the dwelling
2. Presence of vegetation or greenery situated between and near the road and the people exposed to the noise.
3. Visibility of road and traffic for the people exposed to the noise.
4. Information channels
5. Expectations by citizens

The main purpose for mini surveys in this project was to have an assessment on moderators and the local response in a not yet considered location. It was also planned to investigate the possibility for using mini surveys for measuring the effect or relevance of moderators in specific scenarios along roads and highways.

6.2.1. Survey areas

It became evident during the preparation phase of the project, that it was hard to find suitable locations at all (knowing about the measures to be planned) and similarly difficult to get the surveys done in time. As the timeframe of the project was limited, no suitable situation could be located in time for a planned survey. Thus, the survey layout changed to a broader perspective, assessing changes that had already happened.

Suitable locations with similarities but other distinct differences were found in the proximity of the A7 motorway in Hamburg, Germany. With more than 100,000 vehicles per day, this motorway is one of the most frequented motorways in Germany. Plans for a necessary enlargement of the motorway (going from three lanes per direction up to in some parts more than five lanes) resulted in a high level of necessary noise mitigation measures. Final plans for the A7 motorway resulted in three coverings (tunnels) of the motorway with a length of 560 to 2.300 meters.

Tunnel Schnelsen

This tunnel is located in the north of Hamburg. With a length of 560 meters, it covers the A7 in an area with residential buildings of medium density directly next to the A7 motorway. Since June 2018, the traffic was moved completely into the tunnel as the construction of the second part begun. This resulted in a noise level reduction next to the former motorway of more than 20 decibels.

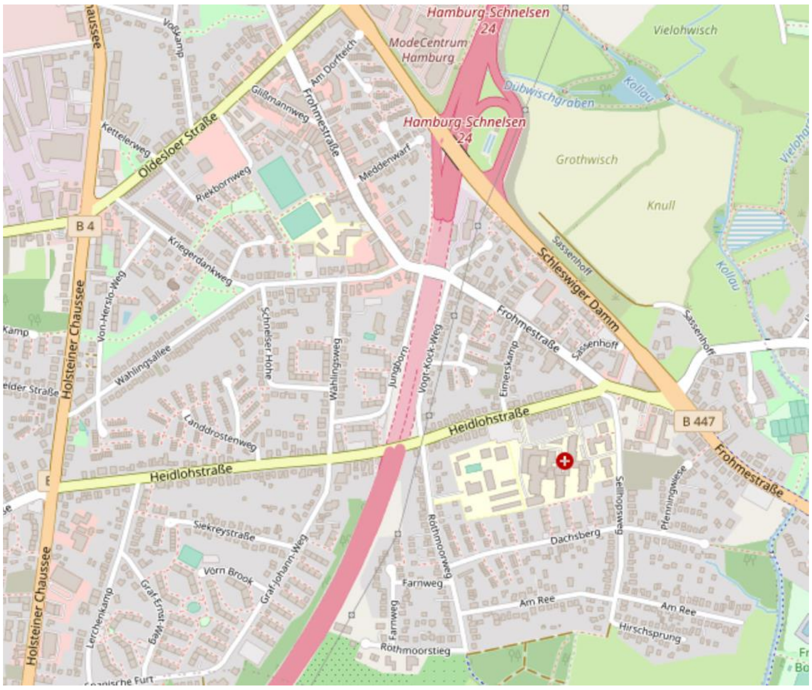


Figure 45: Map of the Schnelsen survey area (© OpenStreetMap contributors, base map and data from OpenStreetMap and OpenStreetMap Foundation).

Figure 46: Visualization of the Schnelsen covering (Source: DEGES/V-KON.media).

Tunnel Stellingen

Started short after the Schnelsen tunnel, the tunnel Stellingen is longer (890 meters) and is located near the probably most frequented part of the A7 in Hamburg with now 10 lanes. Traffic was moved into the first part of the tunnel in April 2019. The traffic noise was reduced by more than 20 decibels in some areas along the tunnel. The second part was opened in 2021, although not all lanes are accessible due to ongoing construction outside of the tunnel. The area surrounding the tunnel is a residential district with medium density.

Figure 47: Map of the Stellingen survey area (© OpenStreetMap contributors, base map and data from OpenStreetMap and OpenStreetMap Foundation).

Figure 48: Visualization of the Schnelsen covering (Source: DEGES/V-KON.media).

6.2.2. Survey and questionnaire

Targeted address of survey participants

Contrary to the original plan, due to the Corona virus the survey had to be changed from partial interview combined with paper surveys to a contactless design. For this purpose, an online survey was developed, comprising 24 questions with several sub-items. For information of residents, a postal mailing was carried out. An information flyer was designed (see Figure 49), giving short information on the project. However, the topic "noise" was not mentioned (besides the company name LÄRMKONTOR) to avoid a strong bias.

Figure 49: Flyer for postal mailing.

Postal distribution / choice of survey area

For postal distribution, the service of "Deutsche Post" (German postal services) was used. Distribution can be carried out according to delivery areas, each in size of about 600 households. The areas chosen can be seen in Figure 50 and Figure 51. A total of about 5,000 households were selected for postal mailing. The mailing was carried out beginning around March 17th within about 1.5 weeks (time varies between the areas, the date is estimated by the response). In addition to the postal mailing, a short notice in a local gazette was placed end of March.

Until April 5th, 185 responses were collected. About 160 responses were valid (answers to questions), at least 140-150 valid responses were given to all questions, the final questions of the survey were answered 142 times (fully finalized surveys). For analysis, all answers with sufficient information on the data points analysed were used, not considering missing answers on the non-relevant data points.

Figure 50: Selection for postal distribution (red) – tunnel and barriers (grey) – Schnelsen (Background: © OpenStreetMap Contributors, http://www.openstreetmap.org/copyright).

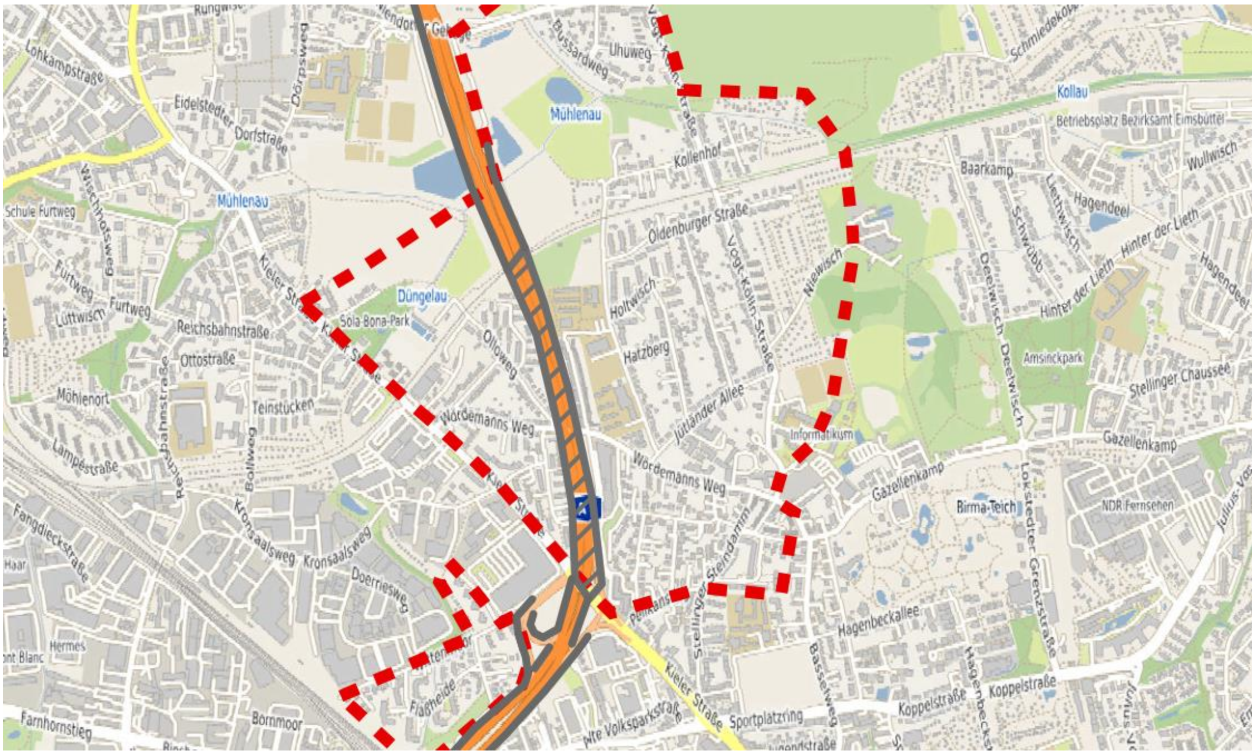


Figure 51: Selection for postal distribution (red) – tunnel and barriers (grey) - Stellingen. (Background: © OpenStreetMap Contributors, http://www.openstreetmap.org/copyright).

Questionnaire

The flyer had a link to an online questionnaire that could be opened in a browser either on a PC or on a smartphone. The presentations were optimized based on the device used, with a touch friendly interface on smartphones.

The questionnaire itself consisted of 24 questions, grouped on three pages, and an additional introduction and a page after completion. The groups were:

- Living conditions, question 1-10
- Motorway A7 and the covering, questions 11-20
- Private data (age, gender, tenancy), questions 21-24

All questions (translated) are documented in the report on mini-surveys (Deliverable 2.2 of the FAMOS project) [50].

Noise data

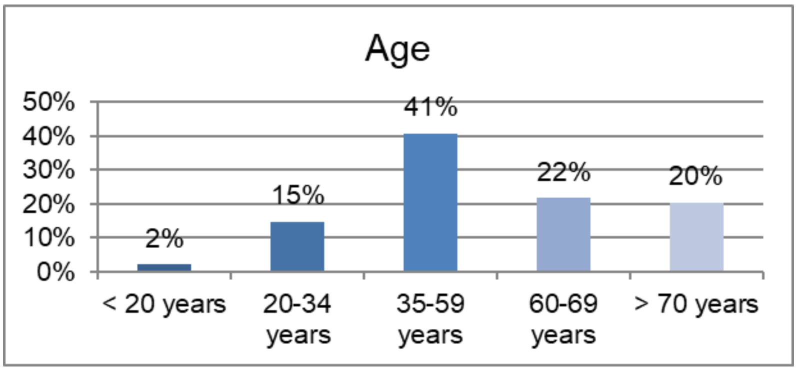
The noise data was obtained from the A7 covering planning process. Noise levels were calculated for multiple receivers for each building with relevant A7 noise levels. Both noise situations with and without covering were analysed.

As no detailed information on exact building locations could be determined from the questionnaires, both the response on the survey area (which was grouped by streets with similar noise levels close to the A7 or areas in greater distance) and the response on distance from the A7 motorway were used to obtain the noise levels. For each area, the noise levels were summarized in dependency of the distance. The maximum level for each building was used in each case. The noise level of each respondent was then assessed by this relation, giving a possible maximum noise level on the dwelling before and after the covering.

6.2.3. Results

General aspects of respondents

Among all respondents, for gender an almost equal distribution between male and female was discovered (see Figure 53). For age[6], a higher number of respondents above 60 was seen, the proportion of people below 35 years was comparable low (see Figure 52). The results show that there were little to no responses of younger people or children living with their parents (younger than 20 years). Other concepts than mailings are necessary to address their annoyance. About 60 % of the respondents are owner of the residence, 40 % are tenants, comparable to the area that shows a mixture of houses with multiple dwellings and single houses (see Figure 54).



[6] Due to changes in the test design, the classes on" age" do not have the same width. It is highly recommended to have equal-sized classes in further surveys!

Figure 52: Age distribution of respondents.

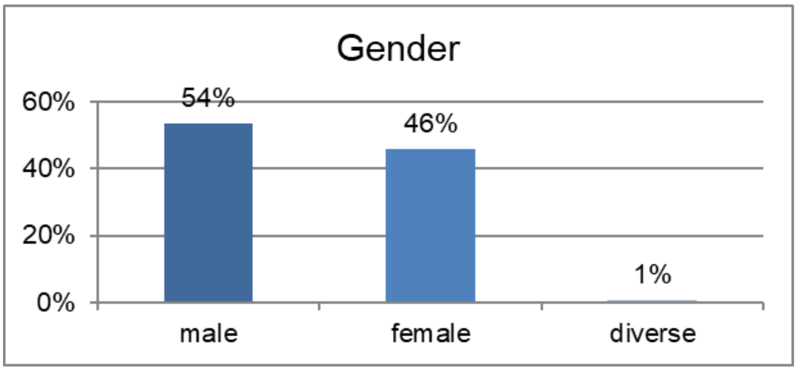


Figure 53: Gender distribution of respondents.

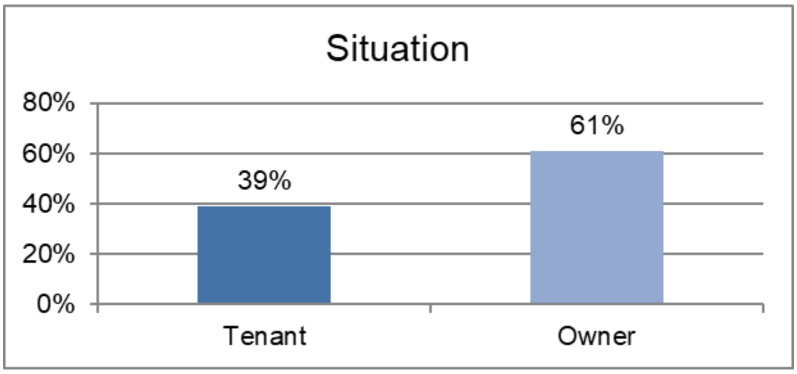


Figure 54: Tenancy / ownership of respondents.

Noise annoyance in general

As for overall annoyance, two questions were placed. The question about noise annoyance in the last 12 months at the beginning of the survey (question 3), about noise annoyance before construction at the end (question 19 of 24) to avoid biased responses. Overall, a clear shift can be seen from higher to lower annoyance (Figure 55 and Figure 56). The perceived change in noise levels is also mainly a reduction (Figure 57).

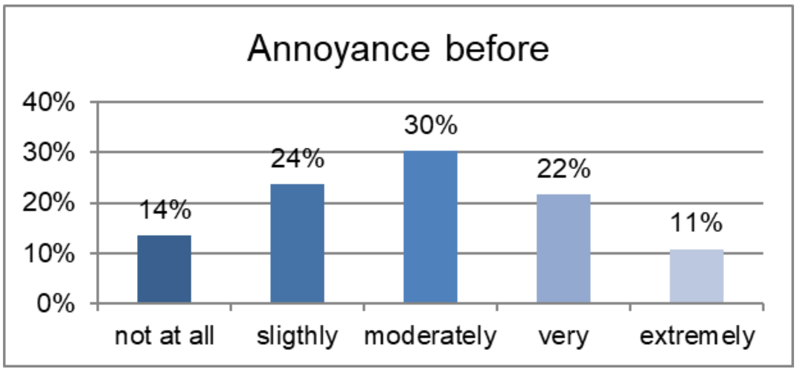


Figure 55: Noise annoyance before beginning of construction.

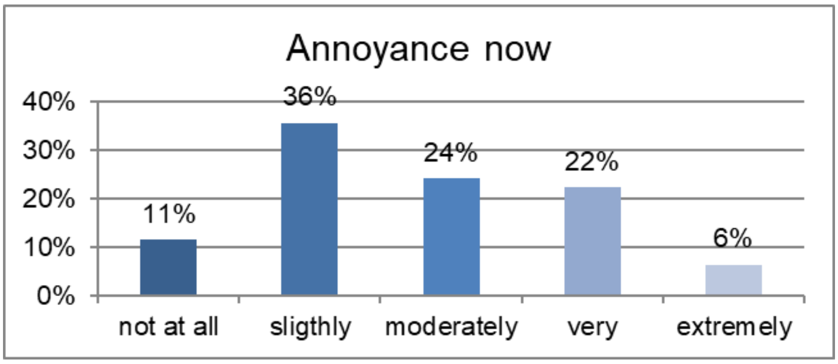


Figure 56: Noise annoyance after completion of construction.

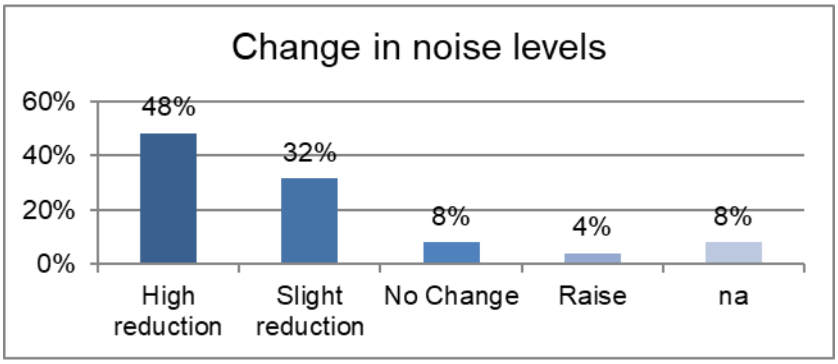


Figure 57: Perceived change in noise levels.

In addition to the perceived and reported change in noise, the change in reported annoyance before and after construction of the coverings was analysed. The change in annoyance is shown in Figure 58 for the total noise. For a point above the black line, the annoyance changed to a higher level of annoyance, below the line, the annoyance was reduced. It can be seen that for higher annoyance beforehand most current annoyance is lower.

Although, the annoyance of people that were “not at all annoyed” before now changed to “slightly” and even “very” in a notable number of cases. Also, the annoyance of people “slightly annoyed” before changes to a higher level in several cases.

Regarding changes from “not annoyed at all”, a detailed evaluation was carried out:

- In four of this six changes to “very”, the A7 motorway was at a distance of 500-2.000 m, only in two cases below 100 m.
- In seven of eight cases with change to “slightly”, the A7 motorway was at a distance of about 300-500 m.

Based on these numbers, the annoyance seems to be influenced from other noise sources than the A7 motorways. For most respondents (13 of 14), the A7 motorway was not the only most disturbing noise source but rather of lower influence. For the changes from “slightly annoyed” to a higher annoyance, no clear trend regarding distances or dominating noise source could be found.

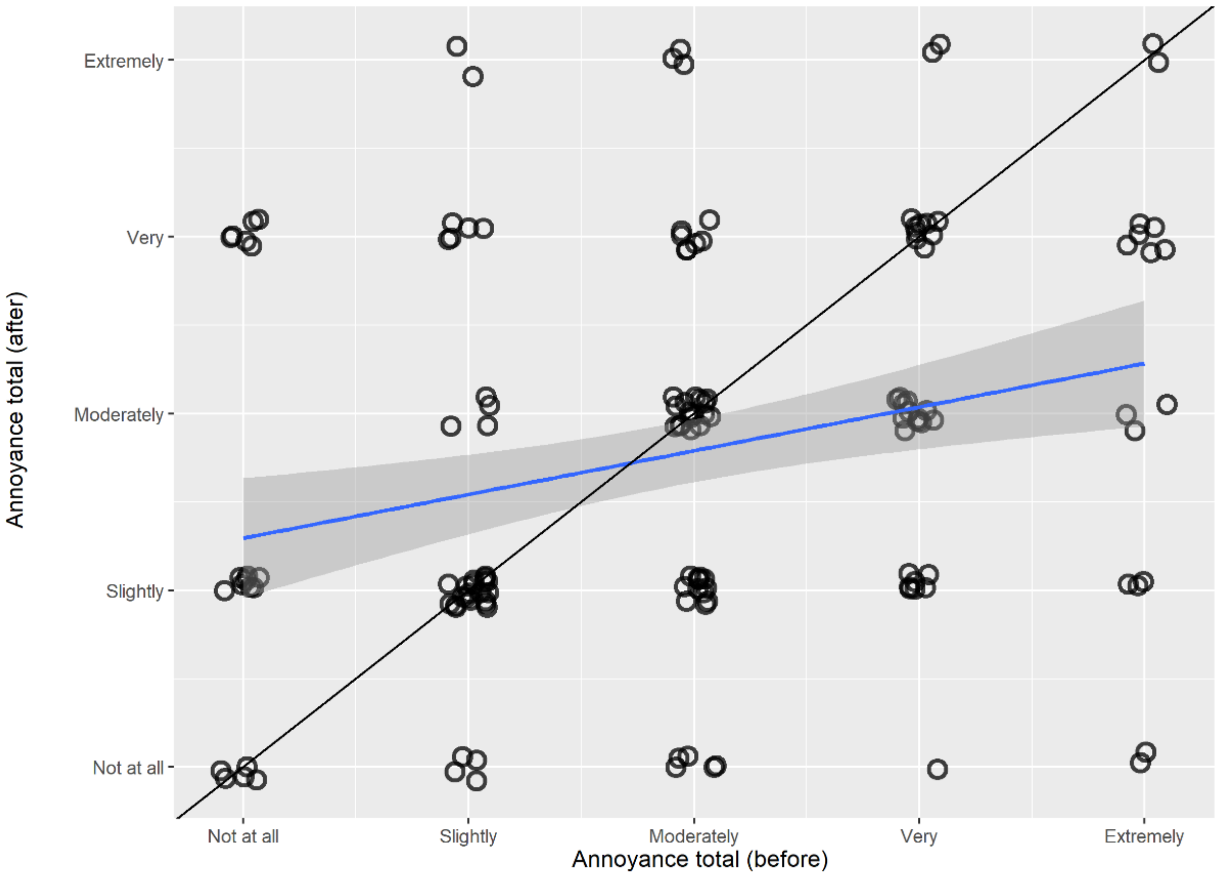


Figure 58: Changes in annoyance (overall) blue curve (jitter added to data points for better identification).

Sources of noise annoyance

To determine the source of noise that contributes to the perceived overall noise annoyance, question 3 was followed by a matrix of possible influences (question 4). The overall noise annoyance (question 3) is added in Figure 59. As a relevant number of households was investigated that was not in close proximity to the A7 motorway, the influence of other sources can clearly be seen. The overall noise annoyance is just partly influenced by the A7 motorway, leading to a higher annoyance by other sources.

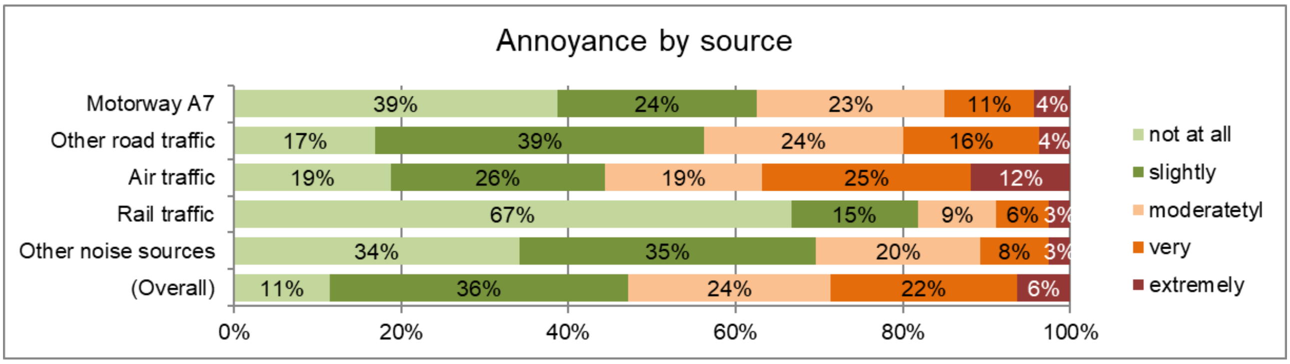


Figure 59: Annoyance by source.

As for air traffic, the area at the Stellingen tunnel is located beneath a flight path to Hamburg airport with the runway about 3 km to the north. Thus, the noise expected reach comparable high levels as motorway noise or noise from other major urban roads.

Regarding railway noise, the same area at Stellingen is partly near a major railway line. However, only few buildings of the survey area are located in a distance of less than 1,000 meters. Most buildings are screened from railway noise. At Schnelsen, only a suburban railway line is in proximity to the area, but no buildings of the survey area are closer than about 300 meters. For all other buildings, screening by buildings results in low noise levels anticipated.

As a first conclusion, the overall noise annoyance seems lower than the maximum of noise annoyance by the dominant noise source. Regarding road traffic, the major impact of the A7 motorway has only local effects, the annoyance caused by other roads exceeds that of the A7.

Silence

As one factor that expresses the overall quality of living condition, the “silence” (or “quietness”) in vicinity of the dwelling was asked in question 2. Results show that perceived silence is depending on the perceived annoyance of noise from A7 motorway (Figure 61) rather than depending on the absolute noise level of A7 motorway (Figure 62).

This was expected as both reactions are subjective. For a good perceived silence, either the annoyance due to a major road has to be lowered or other sources contributing to overall annoyance have to be dealt with. As an example, in Figure 60 most answers of “very bad” perceived silence (red dots) are visible at around 50 dB of A7 motorway noise. However, in three cases the annoyance by the A7 motorway was answered “not at all”, three cases “moderately” and four cases “very” or “extremely”. On the other hand, only few cases of “good” or “very good” perceived silence are found at locations where the annoyance due to the A7 motorway exceeds “moderately”.

Figure 60: Noise levels and annoyance by A7 motorway, perceived quality of silence.

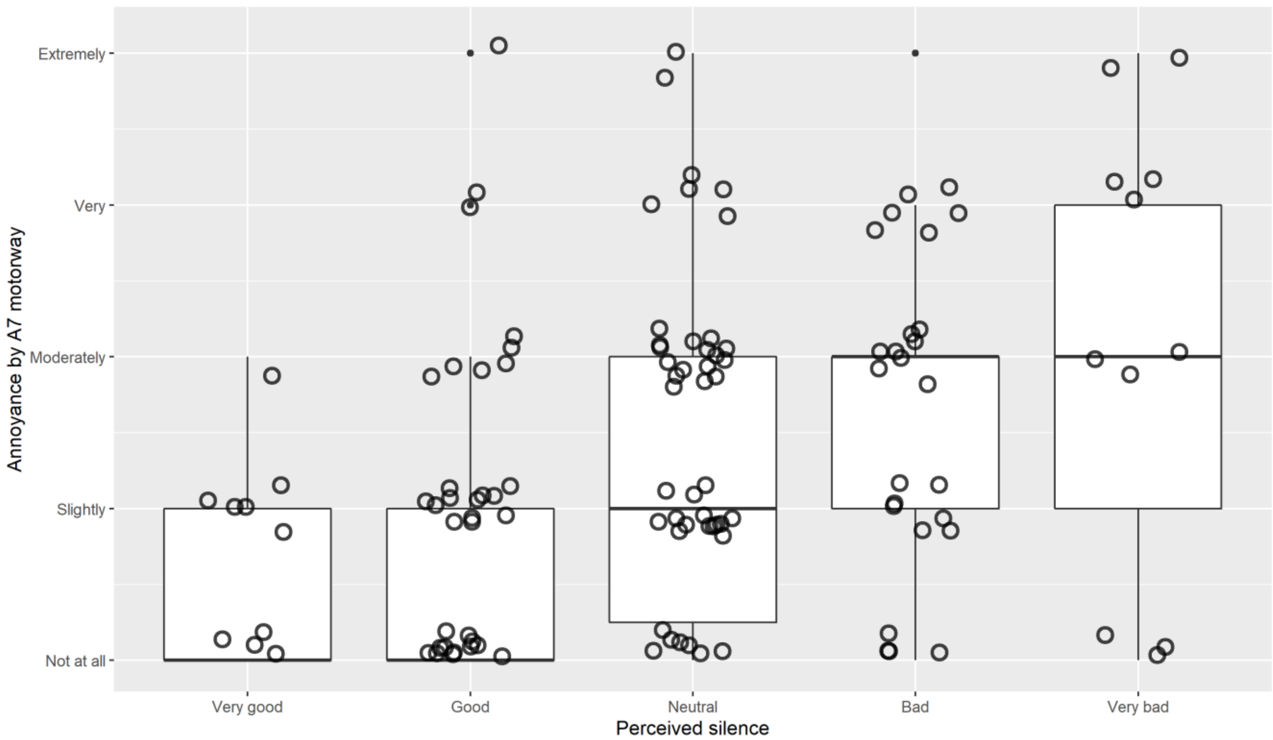


Figure 61: Perceived silence and annoyance by A7 motorway (box plot with upper and lower quartiles, median and outliers).

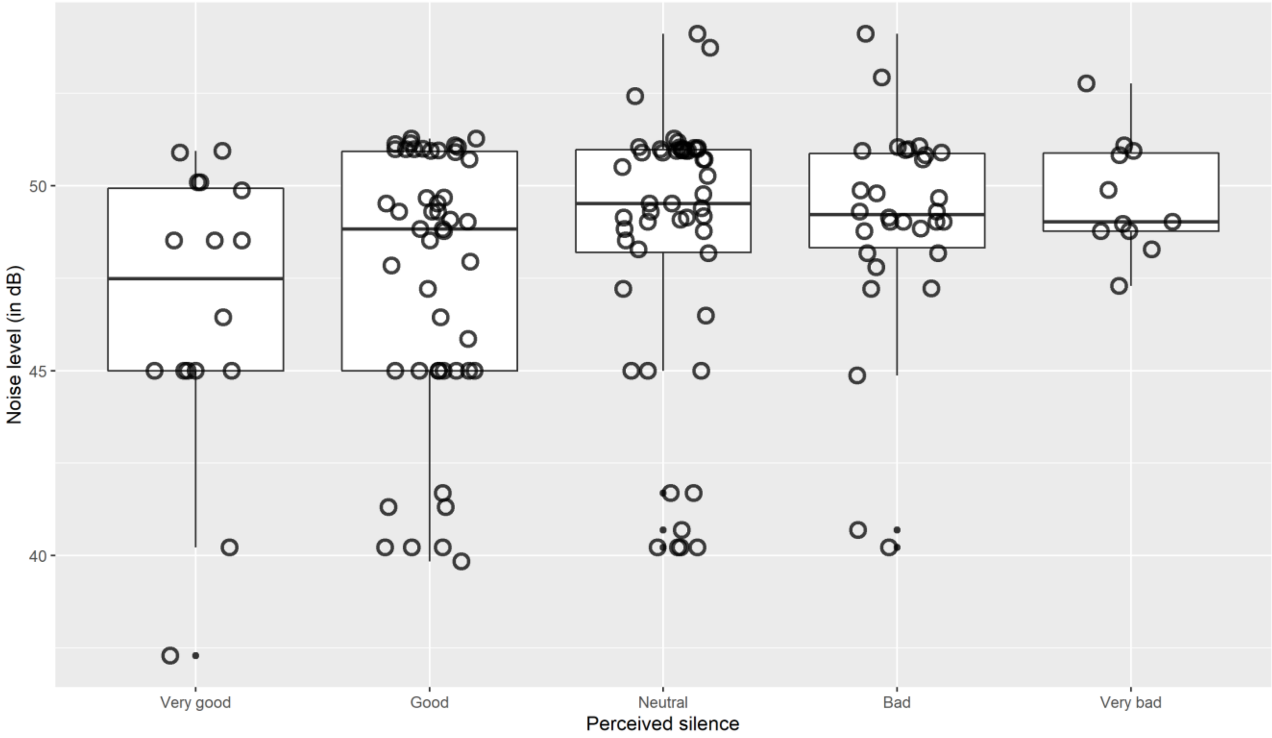


Figure 62: Perceived silence and noise levels of A7 motorway (box plot with upper and lower quartiles, median and outliers).

Visibility and greenery

As one of the possible moderators that can affect people's subjective response to noise, visibility and greenery were part of the survey design. The importance could also be analysed by the response shown in Figure 63 on the importance of greenery. It was highly expected to have greenery on the cover instead of plain concrete structures or other uses.

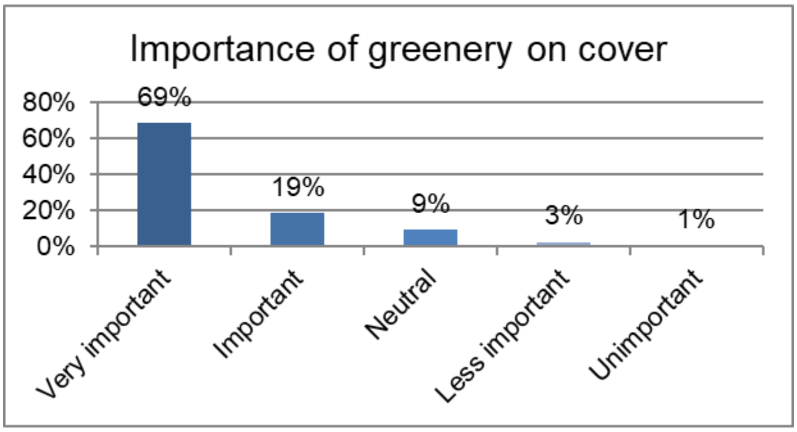


Figure 63: Importance of greenery.

One question covered the overall visibility of the A7 motorway, about one third of the respondents had no blocked view to the A7. For about two third, the view was blocked (Figure 64), mainly by buildings (about 55 percent of all respondents), but also greenery (about 31 percent of all respondents).

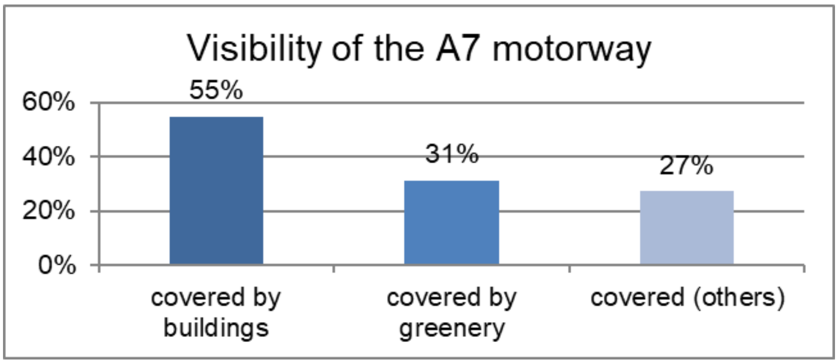


Figure 64: View to A7 covered (multiple answers possible).

One question focused on direct effects caused by the covering mentioned by the respondents (Figure 65). About 89 % of the respondents had no direct effect which is easily explainable by the distance to the covering. For about 8 % of the respondents, the covering resulted in deconstruction of former visible noise barriers which could lead to a possible improvement of the property (better view, more sunlight). For about 4 % the quality of view was reduced. This can be caused by the covering that in some situations exceeds the ground level, the visibility is then similar to a concrete barrier. Less than 3 % of respondents were affected in that way that their property size was reduced, and the covering was moving closer to the residential building.

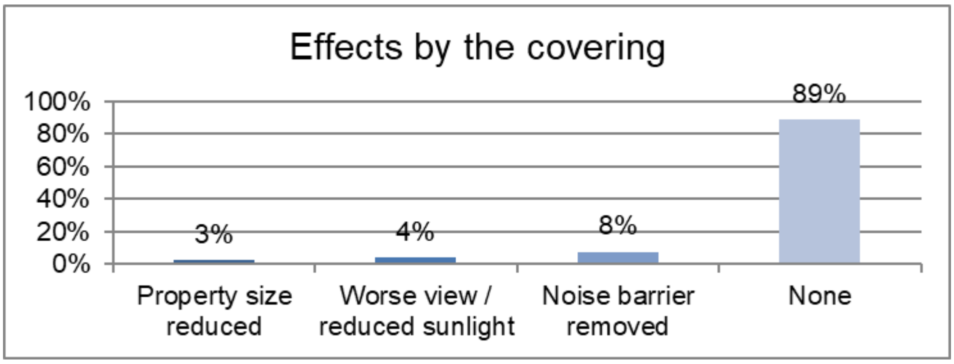


Figure 65: Direct effects of the covering on the property and building (multiple answers possible).

When analysing the effects of visibility and greenery, a small but constant dependency can be assumed. For those cases where the view is blocked by any obstacle (Figure 66) or specifically blocked by greenery (Figure 67), the annoyance seems lower. However, the effect is not significant due to the low number of responses.

Although the effect seems more distinct for a blocked view (all kinds of obstacles) it can be the result of lacking details on the exact location of the building and/or rooms. For analysis, only the maximum noise level was considered depending on the distance to the A7 motorway, thus dwellings oriented only towards a quiet side and/or with a blocked view may result in lower noise levels that also result in lower annoyance. For greenery, the effect on noise levels is mostly negligible, so the change in annoyance only derives from subjective responses.

For visibility from sleeping rooms (Figure 68) or multiple rooms in a dwelling (Figure 69), the effect is more distinct. As can be seen from both figures, the annoyance increases with visibility.

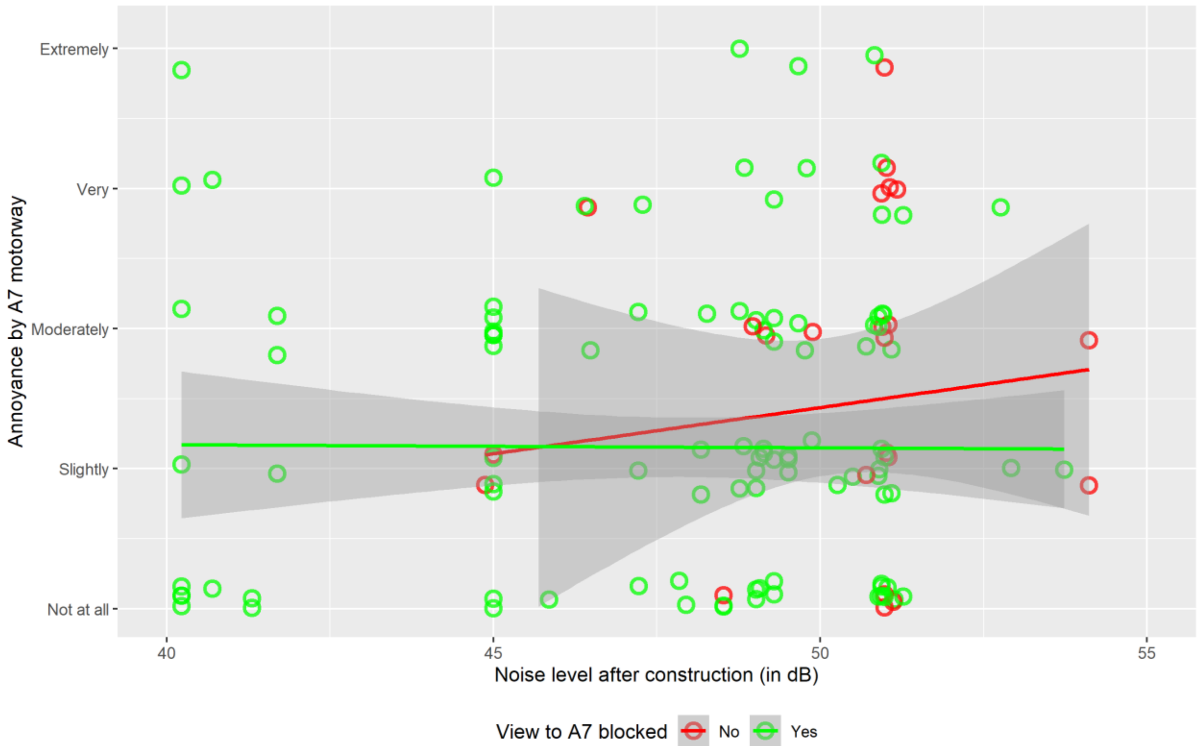


Figure 66: Annoyance by A7 motorway dependent on noise level and blocked view.

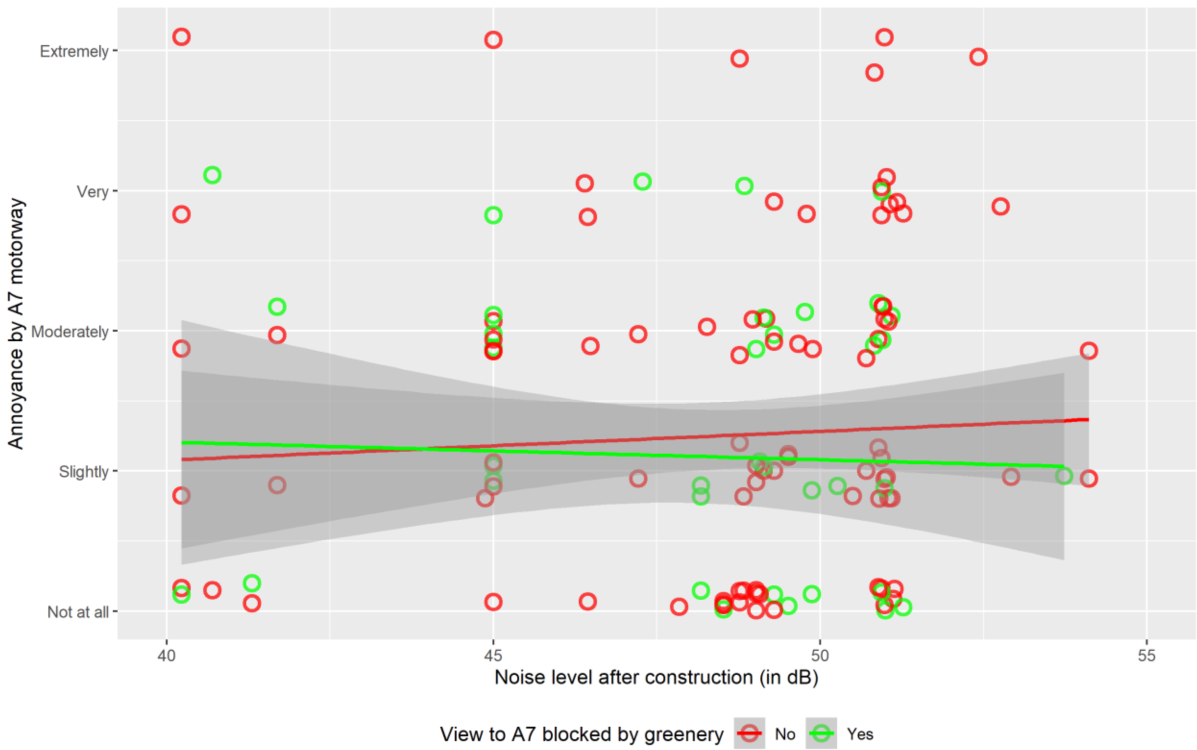


Figure 67: Annoyance by A7 motorway dependent on noise level and blocked view by greenery.

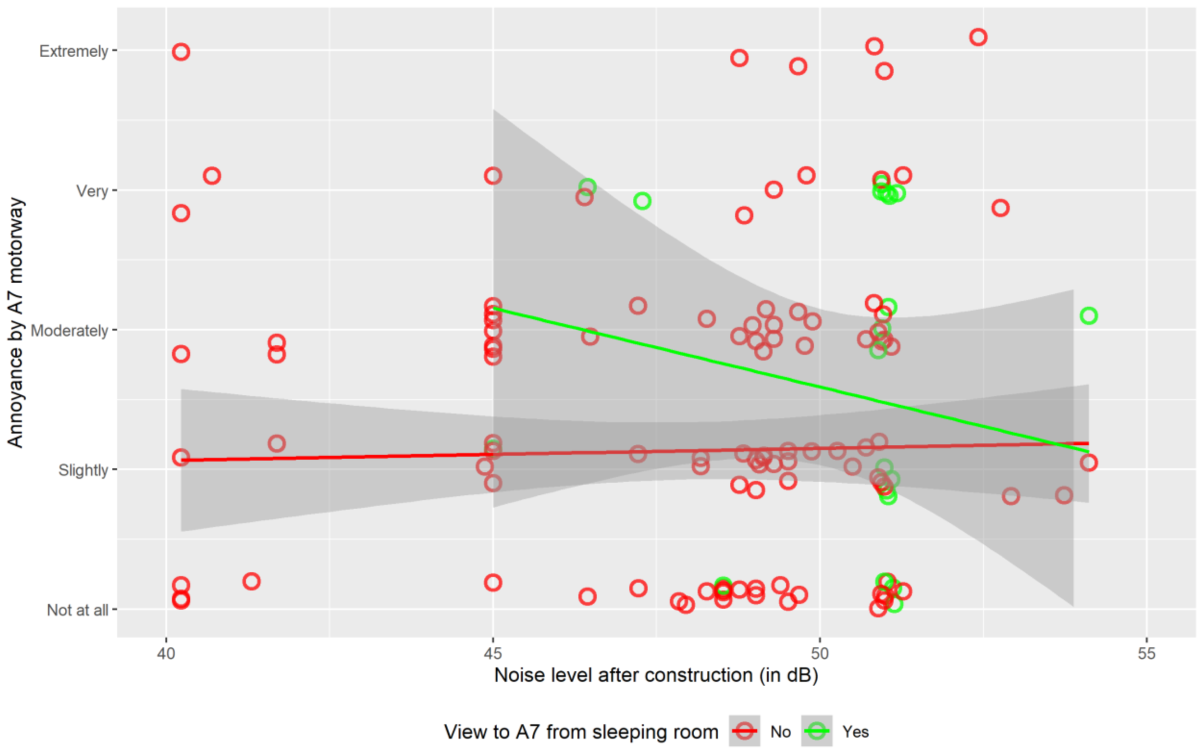


Figure 68: Annoyance by A7 motorway dependent on noise level and visibility from sleeping room.

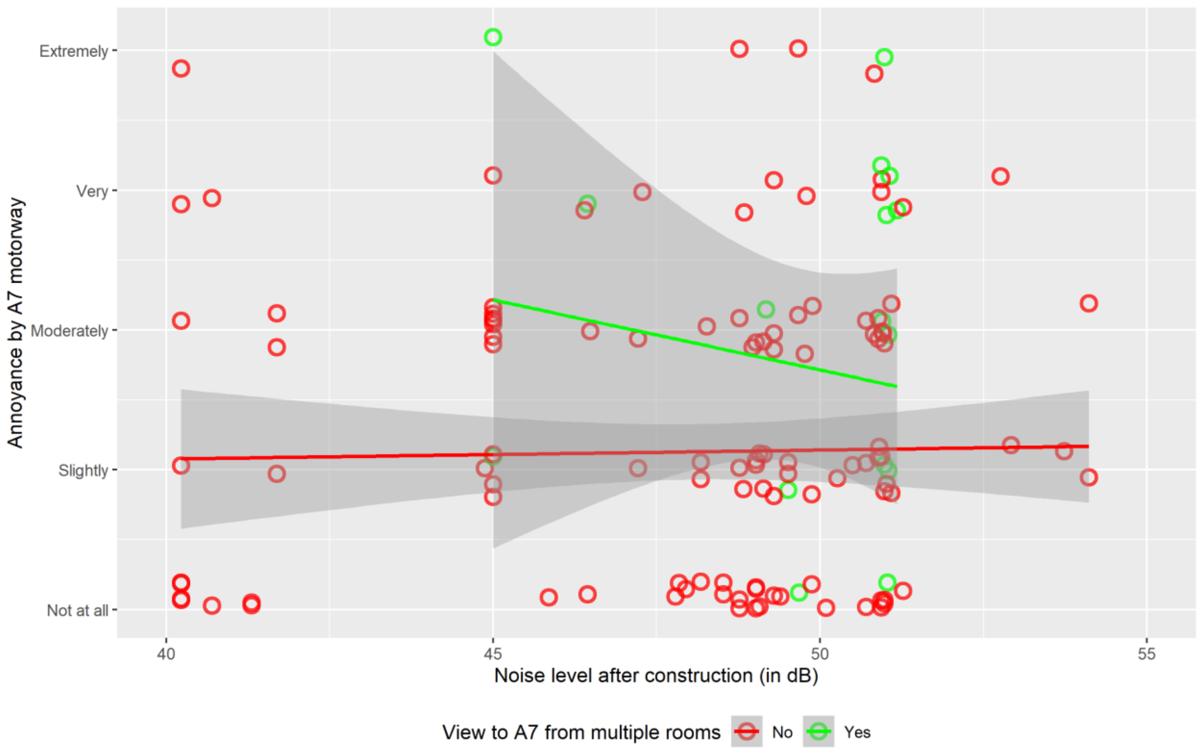


Figure 69: Annoyance by A7 motorway dependent on noise level and visibility from multiple rooms.

Expectations

Questions about expectations show that most people expected different kinds of improvement by the A7 covering (Figure 70). About 90 % expected a reduction in noise levels, and in most cases, expectations were met (Figure 71). Only few people experienced a lacking improvement.

An analysis of the response of met expectations on lower noise levels over the noise level change (Figure 72) shows that most answers fall into the band of a reduction of 0-10 dB. Noise level change of only a few decibels cannot be perceived by most people, especially not in direct comparison (between “before” and “after”, several months or even years passed). So, it can be assumed that communication of “lower noise levels” led to an exaggerated expectation that could not be met in a relevant number of cases.

An effect maybe connected can be observed for expectations that the situation worsens. Less than 5 % (of 116 responses) expected this outcome, but a high number of respondents (about 48 % of 101 responses) answered that their expectations (that would be “the situation does not get worse”) was not met! However, the reason for a worsening situation was not given (lack in response options).

For some topics, the response on expectations met are not clear. This might be connected to low controllability (air quality) for one part of the topics as well as the not completed construction work and the ongoing view on construction sites (greenery).

An analysis met expectations on more greenery shows a possible small improvement in Figure 73. For those with met expectations on more greenery, indication is given that the annoyance of the A7 motorway is slightly lower.

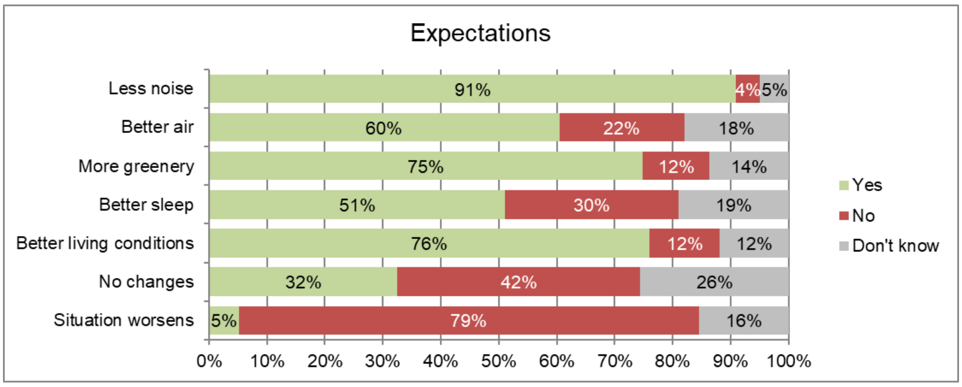


Figure 70: Expectations on the effects of the A7 covering.

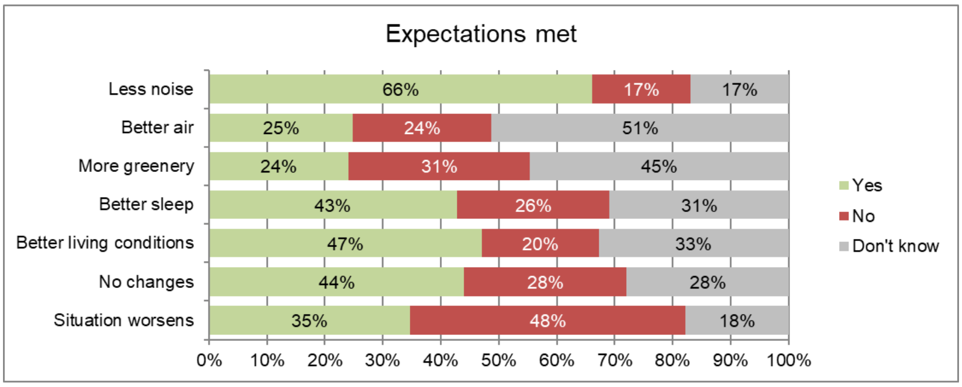


Figure 71: Expectations met on the effects of the A7 covering.

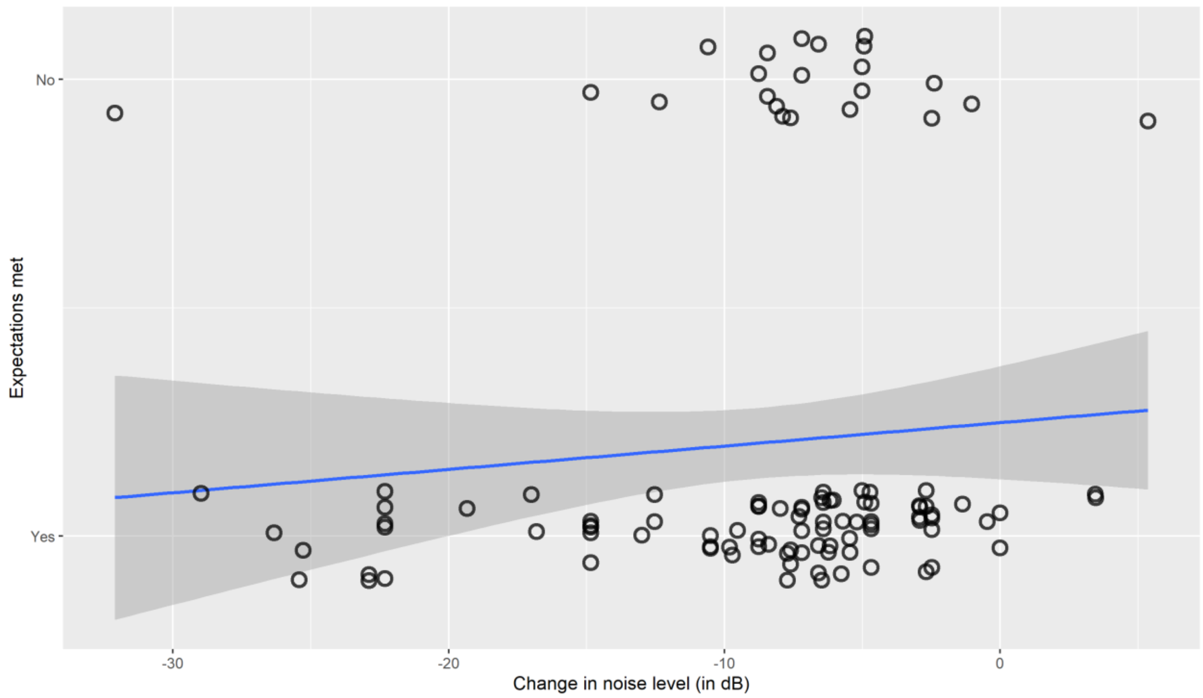


Figure 72: Expectations met on lower noise depending on change in noise levels.

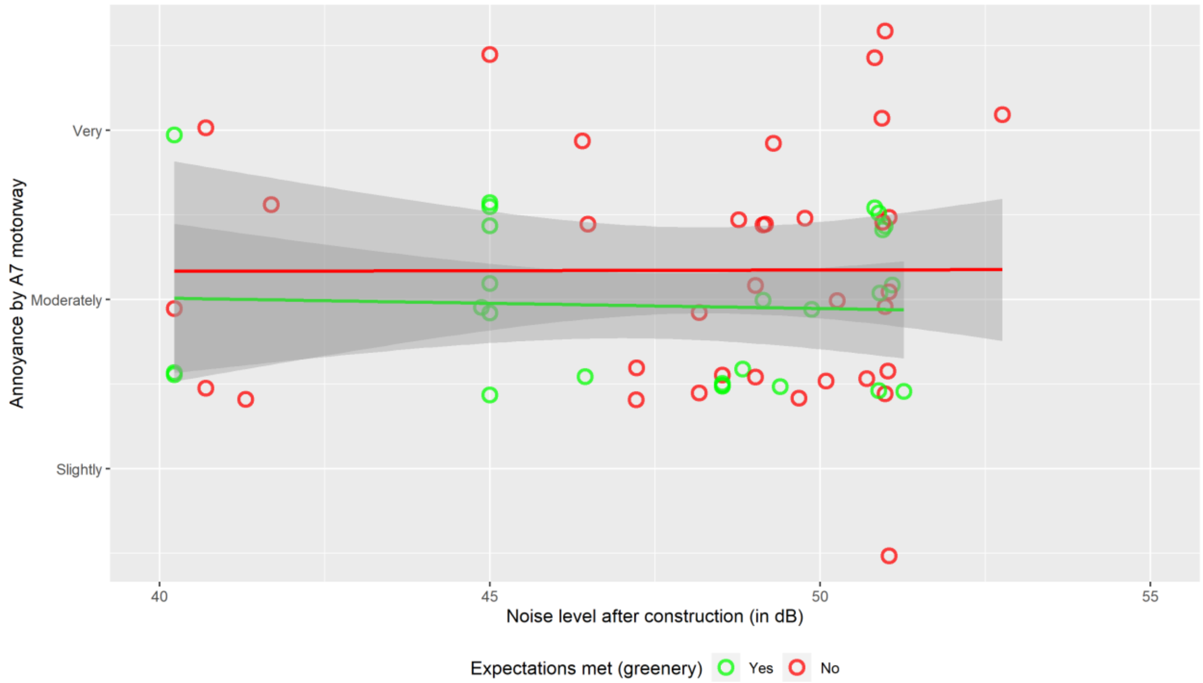


Figure 73: Expectations met on greenery and annoyance by A7 motorway.

Information

One block of questions involved the perceived quality of information by several sources, as authorities, site offices, press coverage and citizens initiatives. As for the latter, the option of a covering instead of noise barriers was driven by citizens initiatives[7]. There were also initiatives against the project (e.g. from allotment holders close to the A7, that were planned to be moved onto the covering), but their web site has been inactive for the past several years.

A part of the results is shown in Figure 74. More than 30 % each, as well a local site office close to the construction site as information from citizens initiatives was not perceived by the respondents. For the local site office, the aim was mainly to enable dialogue with residents close to the A7 during the construction process to deal with complaints on the resulting construction noise. The largest coverage was achieved by the press, only 3 % of the respondents got no information by this source.

The best quality of information can be seen coming from the press (40 % "good" or "very good") or local authorities (37 %). If considering the high number of people that were not informed by the local site office (e.g. they did not visit due to the distance or did not even know about it), the 25 % of at least "good" informed people come close to the quality of press and authorities.

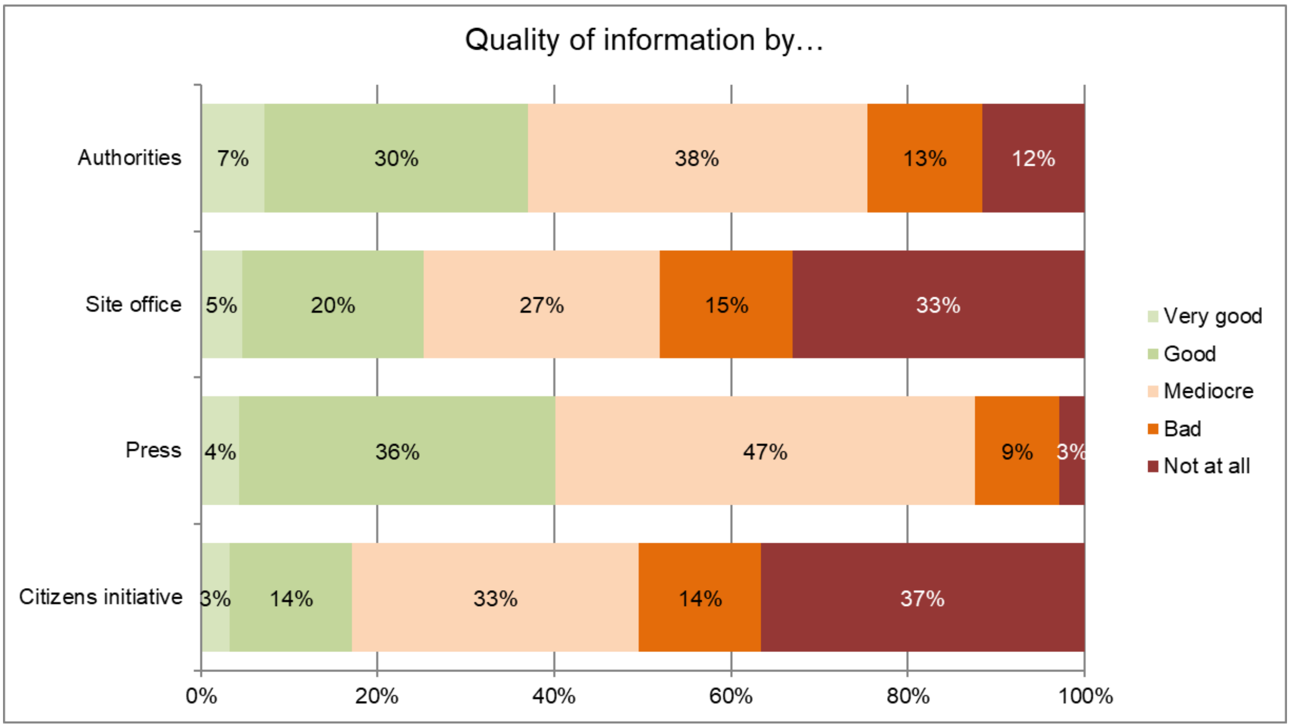
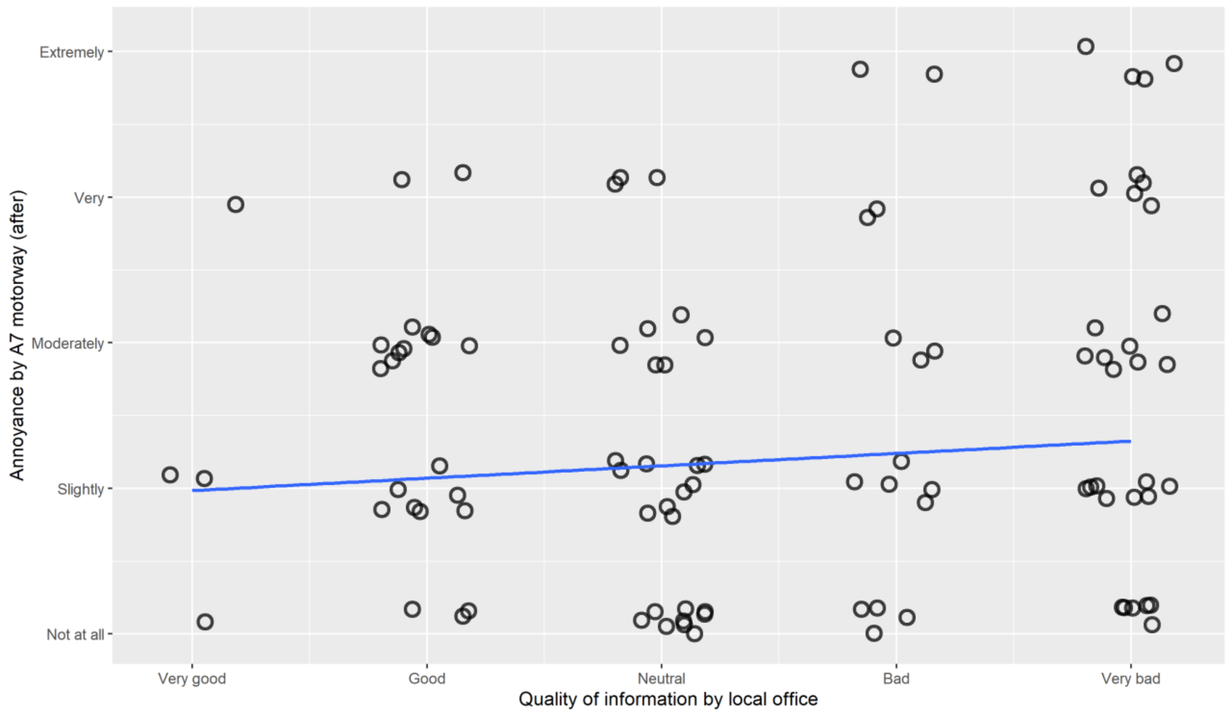


Figure 74: Quality of information by different sources.

Further in-depth analysis was discontinued as the number of respondents seemed too low to give good quantitative results. For about 100-150 respondents, divided by five possible quality measurements, only a handful of respondents remains in each category, leading to highly volatile curves on annoyance reaction. The overall reaction indicates that the annoyance is slightly higher with bad information. The dependency is thus unclear: is the reaction worse due to bad information, or is the perceived information worse due to higher perceived annoyance (influenced by other factors).

[7] http://www.ohnedachistkrach.de/ and http://www.stellinger-deckel.de/



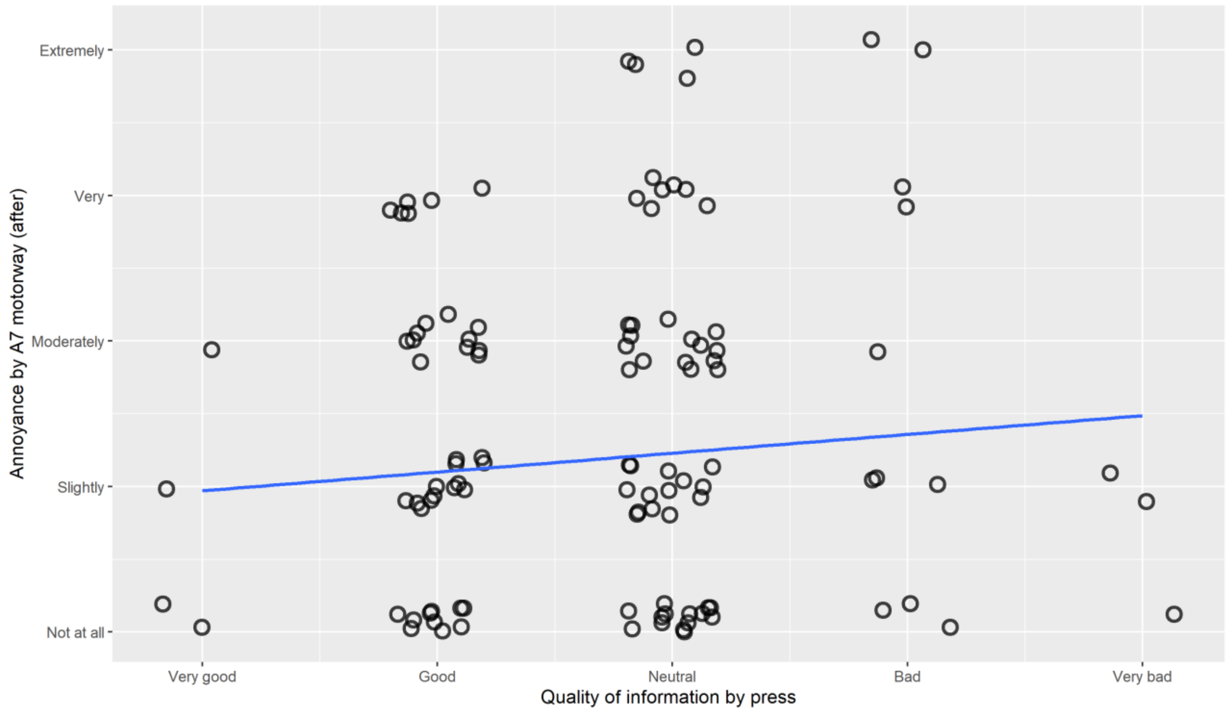


Figure 75: Annoyance and quality of information by local office or press.

6.2.4. Conclusions

In addition to the literature sources, a mini survey was planned within the FAMOS project. The execution was delayed due to the corona virus situation in Germany in 2020 and thus the design of the survey had to be modified compared to first planning.

As a result of the survey design as just a “mini survey” with limited extent and the non-personal address of respondents, both the number of respondents was limited and the quality on noise information (by exact location) was low. Therefore, a real quantitative analysis was not performed. Instead, a general correlation and a confirmation of earlier project results was assessed.

As for noise annoyance in general, the responses mostly showed an expected outcome although several respondents reported a higher annoyance although the noise levels were supposed to be reduced. The A7 motorway as a major noise source was, as expected, a major contributor to noise annoyance. The overall noise annoyance was however lower than the individual annoyance from single sources.

Results for as well visibility and greenery as expectations and expectations met were analysed as part of the hypothesis testing (see Section 6.4).

Regarding information channels, press was identified as the option with highest coverage and good quality, however direct information by authorities (mailings, flyers, website) also showed a high quality in information.

Overall, the results showed that moderators previously identified in the FAMOS project had a contribution to the perceived noise annoyance. A quantification on the effect, i.e. changes in noise level, in CTL or similar, cannot be derived due to the low number of participants.

6.3. Sound walks

Soundscape measurements were to be tested as a mean to quantify the effect of non-acoustic factors. This section presents the testing of soundscape measurements with focus on moderators related to visual appearance of the road and its immediate surroundings. The soundscape measurements are documented in the report Deliverable 2.2 of the FAMOS project [46].

Sound walks were performed at alternative locations with different conditions with regard the two selected moderators:

1. Presence of vegetation or greenery situated between and near the road and the people exposed to the noise.
2. Visibility of road and traffic for the people exposed to the noise.

The main purpose for making soundscape measurements in this project is to investigate the possibility for using this tool for measuring the effect of moderators in specific scenarios along roads and highways.

6.3.1. Soundscape measurements

A soundscape measurement is a new type of measurement in which one registers both the acoustic surroundings and people's perceptions of them. The concept of soundscape is defined in the standard ISO DSF / ISO / DIS 12913-1, cf. [51], as: The acoustic environment as perceived or experienced and/or understood by a person or people, in context.

The idea of the soundscape measurement is to get a holistic picture of the sound environment in a given place in order to obtain information about how the sound environment is perceived and which factors are influencing the perception. Soundscape measurements are seen as supplement to the traditional noise measurements. The soundscape measurement described in this investigation has been carried out according to the principles of the draft standard ISO DSF / ISO / DIS 12913-2, cf. [52], with various additions and omissions.

The soundscape measurements consist of three elements:

1. Sound walks where test persons fills out a questionnaire.
2. Sound measurements/calculations.
3. Interviews.

In this project only the first two points are addressed. A systematic procedure is used to obtain reliable assessment of the soundscapes. The assessed attributes in the sound walks are defined in the questionnaire and several people rate the same soundscapes at different times to get representative averages. Noise measurements are made simultaneously at the same positions.

The sound walks represent the holistic perception of the selected scenarios/moderators (here visibility and presence of greenery). The results of the sound walks are expressed in perceptual and affective dimensions and is quantified as a simple soundscape index which expresses the difference between the assessed and the preferred soundscape characteristics.

In the practical implementation of the sound walk method the test persons walk from position to position but while they answer the questionnaire related to a specific measurement position they stand still while perceiving and evaluating the soundscape at the measurement position.

There are limitations, advantages, disadvantages, and uncertainties for the soundscape method:

The advantage is that it relates to real life situations. The disadvantage is that variations in individual and other context variables also moderates the annoyance effect, and it may be difficult to isolate the effect of the moderators under investigation without influence of the other.

6.3.2. The measuring positions

The measuring positions for the sound walks were selected so that there were variations in the moderators of interest, i.e.: the noise levels, the visibility of the traffic and the amount of greenery (trees, bushes, and grass). The positions were chosen in the central part of Copenhagen, within walking distance of each other for practical reasons. The speed limit in the area is 50 km/h.

An overview of the positions is given in Table 5 and pictures can be seen in the following figures.

Table 5: The measuring positions for the sound walks and their main characteristics.

Positions	Type	Traffic Visible	Greenery	L_{Aeq} dB	L_{A50} dB	L_{A95} dB
1. HCA Boulevard	Major road	100 %	47 %	71	70	65
2. Rådhuspladsen	Major road	100 %	3 %	66	66	59
3. Studiestræde	Minor street	100 %	0 %	60	54	48
4. Larslejstræde	Minor street	100 %	11 %	60	57	52
5. Kongens Have pos. a	Park	50 %	100 %	55	52	46
6. Kongens Have pos. b	Park	0 %	100 %	52	52	47

The traffic was fully visible in positions 1-4. In position 5 the traffic could be seen through trees and bushes and in position 6 the visibility of traffic was complete blocked by a large hedge.

The percentage of greenery is calculated from the horizontal angle where greenery could be seen from the measuring position.

The noise levels indicated are the average values from measurements in each sound walk. L_{Aeq} denotes the energy average of the sound levels in the measuring periods (3-8 minutes). L_{A50} indicates the level that has been exceeded 50 % of the time, and L_{A95} is the level that has been exceeded 95 % of the time

Annotated level recordings that give an impression of the soundscapes can be found in the annex of [46].

Position 1 – H.C. Andersens Boulevard

This position was close to the townhall facade with view to the road which is one of the busiest roads in the central Copenhagen with four lanes in each direction. There are crossings with traffic lights to both sides some hundred meters from the measuring position.

Figure 76: Position 1. Photos taken during the sound walks. The noise measurement equipment can be seen.

Position 2 – Town Hall Square

The measuring position is next to and in the same distance to the same road as in position 1.

The noise level is slightly lower partly because of the lack of reflections from the town hall facade, and maybe also because of slower traffic at that point. Not much greenery is seen in this position.

Figure 77: Position 2. Photos taken during the sound walks.

Position 3 – Studiestræde

This is a small narrow street with only little and local traffic. Besides a small cafe and a shop, not much is going on near the measuring position. Only a few cars are passing now and then, and the traffic from major roads in the area is heard as background noise.

Figure 78: Position 3. Photos taken during the sound walks.

Position 4 – Larslejstræde

This street seems like a small and calm street just like in position 3, but a school at each side of the street, and some building activity in the far end of the street gave the feeling of a rather chaotic soundscape.

A major road with slow and sparse traffic at the end of Larslejstræde was not heard much during the measurements.

Figure 79: Position 4. Photos taken during the sound walks.

Position 5 and 6 – City park

The measuring positions 5 and 6 are both surrounded by grass, bushes, and trees all around. The nearest road is a two-lane road with slow traffic. The distance to the road is approx. 30 m on both positions.

In position 5 the traffic can be seen through trees and bushes, in position 6 the traffic cannot be seen due to a large dense hedge.

Figure 80: Measuring positions 5 and 6 in the city park: Kongens Have.

Figure 81: Position 5. Photos taken during the sound walks. The road and traffic can be seen in the background.

Figure 82: Position 6. Photos taken during the sound walks. Here no traffic can be seen.

6.3.3. Method

Sound walks were performed where the participants assessed the soundscapes using a questionnaire in 6 positions along the route. At the same time, noise measurements were performed in the same positions.

Sound walks

Four sound walks with four groups of persons were made 5th and 6th of October 2020. The vegetation was still green and there was some bird activity in the trees. Outdoor activities were taking place (people on cafes, children playing, people talking etc.).

In total 18 assessors participated in the sound walks in four groups. The persons participating were ordinary persons (non-expert listeners) recruited from SenseLabs group of “consumers” via Facebook. The participants received a gift card to shops for their participation. The ages of the participants were between 24 and 58 years with a mean of 40.3 years with 50 % male and female.

To create a balanced order effect of the positions, and the starting times, two of the four sound walks started in position 1, then 2, 3, 4, 5 and 6 while the two other sound walks began in position 6 and the positions in reverse order.

Monday 05-10-2020

- Dry, partly cloudy to cloudless, 14-17 degrees C. Easterly wind 3-4 m/s
- 9:00 start from position 6. 5 participants
- 12:00 start from position 1. 5 participants

Tuesday 06-10-2020.

- Dry, partly cloudy, 12-14 degrees C, South westerly wind 4-5 m/s
- 9:00 start from position 1. 3 participants
- 12:00 start from position 6. 5 participants

Before each sound walk the participants were introduced to the task and to the attributes and the scales used. The participants were instructed that “traffic noise” did not include trucks backing and unloading and emergency vehicles with sirens.

In each position the participants assessed the 14 attributes listed in Table 6 for the soundscape on iPads with direct connection to the SenseLabOnline software for listening tests. The assessments took approx. 5 minutes for each group in each position. The 14 attributes are part of the soundscape procedure developed by FORCE technology.

The definitions of the attributes were shown to the participants next to the answering scales, see Figure 83.

Table 6: The attributes with which the soundscape was assessed. Attributes 1-4 and 11-14 came in the order indicated while attributes 5-10 came in random order for each position and each person.

No.	Attribute	Definition	Scale
1	Local traffic noise	To what extent do you hear noise from local traffic on this/the nearest road?	Not at all, Slightly, Moderately, Very, or Extremely?
2	Traffic noise	To what extent do you hear noise both from local traffic and from more distant roads?	Not at all, Slightly, Moderately, Very, or Extremely?
3	Sounds from humans	To what extent do you hear sounds from people? (speech, laughter, children, footsteps…)	Not at all, Slightly, Moderately, Very, or Extremely?
4	Nature sounds	To what extent do you hear sounds of nature? (birds, animals…, water ..., wind in the trees…)	Not at all, Slightly, Moderately, Very, or Extremely?
5	Pleasantness	State how you perceive the sound as a whole. Pleasant: Gives satisfaction, joy, or well-being. Unpleasant: Gives dissatisfaction, unwillingness, or reluctance.	Unpleasant, Neutral, Pleasant
6	Event richness	State how you perceive the sound as a whole. Event-rich: Characterized by variety and exciting or interesting events. Event-poor: Monotonous and without exciting or interesting events or any other kind of variation.	Event-poor, Neutral, Event-rich
7	Exciting	State how you perceive the sound as a whole. Exciting: Fascinating, attractive, or interesting. Boring: Without invigorating or interesting elements.	Boring, Neutral, Exciting
8	Chaotic	State how you perceive the sound as a whole. Chaotic: Characterized by disorder or confusion. Calm: Free from disturbances, characterized by calm and regularity.	Calm, Neutral, Chaotic
9	Stressful	State how you perceive the sound as a whole. Stressful: Causes tension. Soothing: Make yourself relaxed, safe, peaceful; provides peace of mind.	Calming, Neutral, Stressful
10	Loudness	State how loud you perceive the sound as a whole. Volume: The perceived loudness.	Soft, Strong
11	Annoying	Indicate how annoying you perceive the sound as a whole. Annoying: Is the sound annoying or bothering?	Not at all, Slightly, Moderately, Very, or Extremely?
12	Intrusive	Indicate how intrusive you perceive the sound as a whole. Intrusive: Which presses on the consciousness; which strongly affects the sound perception.	Not at all, Slightly, Moderately, Very, or Extremely?
13	Like	State how you like the sound as a whole. Like: Do you like what you hear?	Very bad, Bad, Neutral, Good, Very good
14	The sound fits the place	State how you think the sound as a whole fits the place. Appropriate: Look around. Does the sound fit what you see and the possible activities that could take place here?	Very bad, Bad, Neutral, Good, Very good

Normally there is a high correlation among attributes with negative connotations[8] and a high correlation among attributes with positive connotations.

There are two reasons for having all 14 attributes in the test:

- Nuances in the attributes and the understanding of these may give extra information.
- The participants are kept in an active listening mode for approx. 5 minutes when assessing the 14 attributes.

The Ideal Profile Method[9] was used for the test. The method uses two scales for each attribute: One scale for the assessment and one scale for the ideal point, i.e. the ideal size of the attribute according to the holistic perception in the actual situation, see Figure 83.

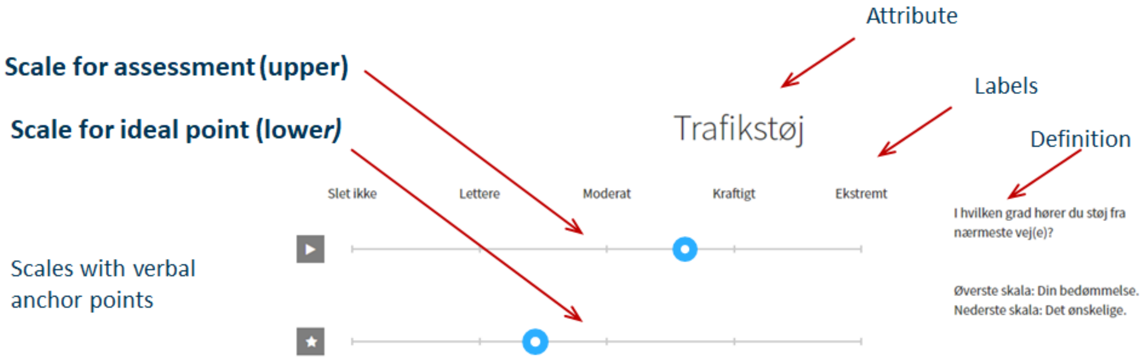


Figure 83: Example on answering scales according to the Ideal profile method for the sound walk. This example is for the assessment of traffic noise. For other attributes, definitions, and scale labels (translated to English), see Table 6. In the data processing the position of the sliders are measured on a 0-100 scale.

In each position also a questionnaire with a table on paper had to be filled. The questionnaires contained the following:

- Note which sound sources are heard, in order of decreasing prominence.
- Only one sound on each row, and a total of up to the most 8 prominent.
- Fill the sounds in the tree columns: Bad Sounds, Neutral, Good Sounds.

Noise measurements and sound recordings

Four channel sound recordings were made with a hard disk recorder in the same periods in time, and in the same positions as the assessments. A stereo setup with measuring microphones for loudspeaker reproduction and noise analysis and a dummy head for recordings to 3D headphone reproduction was used.

The equipment was made portable in a setup shown in Figure 84.

[8] A feeling which a word invokes for a person in addition to its literal or primary meaning.

[9] The Ideal Profile Method is a sensory methodology. It is performed by the participants who are asked to rate each product (here a measuring position) on both their perceived and ideal intensities for a list of attributes.

Figure 84: The portable equipment for the sound recordings. The “hair” on the HATS is a windscreen.

The calibrated sound recordings with the measuring microphones were analysed with the NoiseLab noise analysis software (see https://noiselabdk.wordpress.com/product-overview/). Detailed results and annotated level recordings can be found in [46]. These can be consulted for a better understanding of the soundscapes in the six positions.

6.3.4. Results

Sound source hierarchical classification

It is relevant to know which sound sources create the soundscape. The hierarchical classification (i.e. the sound source taxonomy) of the sound sources lists the sources in the measuring points where the assessors were standing. It is deduced from the answers on the paper questionnaire. The hierarchical classification can be reported as shown in Table 7.

Twenty-nine different sound types have been mentioned. The vast majority of the sounds in the city are caused by human activity. Only three sound types, birds, dogs barking, and wind are not related to human activity. The sounds that get the most dominant role come from motorised transport (mainly road traffic, lorries and busses).

Table 7: The hierarchical classification of the sounds in the measuring positions as evaluated by the 18 assessors.

Outdoor acoustic environment				
	Urban acoustic environment			
		Sounds generated by human activity		
			Motorized transport	
				Road traffic noise
				Lorry's
				Busses
				Motorcycles
				Car horns
				Emergency horns
				Helicopter
			Human movements	
				Footsteps
				Bicycles
			Mechanical sounds	
				Car doors
				Hammering
				Work machines & tools
				Compressors
				Lorry's idle
				Road work
				Garden works
				Goods delivery
			Human sounds	
				Adult talk, laughs
				Whistling
				Children passing
				Children playing
				Radio/mobile
			Social/communal	
				Bells (Church, townhall)
				Music
				Traffic light beeps
				Lorry reverse alarms
		Sounds not generated by human activity		
			Nature	
				Birds
				Wind in trees and leaves
			Domestic animals	
				Dogs barking

Sound source diversity

The participants were asked to name the most prominent sound source, the next prominent and so forth up to the eights at most. In Figure 85 the number of occurrences of the most prominent is weighted with eight, the next prominent with seven and so forth. The purpose of the weighting is to give the most prominent sound sources the largest weight in the analysis. Figure 85 shows the results for each of the 6 measurement positions.

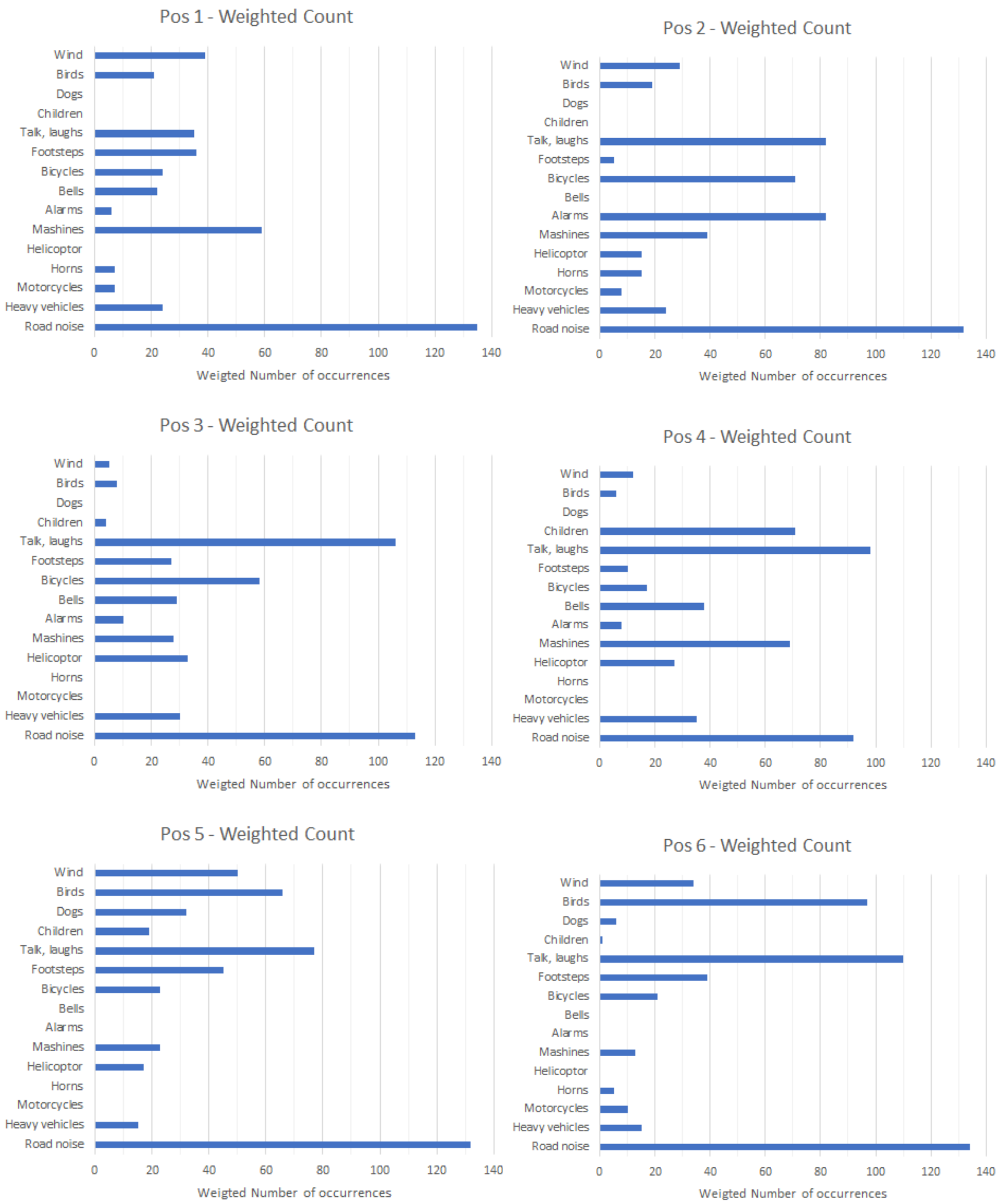


Figure 85: The weighted number of occurrences of various types of sound sources in each position. The most prominent is weighted with eight, the next prominent with seven and so forth.

Position 1 and 2 are both close to the same street with high traffic volume. It is seen that the assessment of road noise sources is the same, but the sound source diversity is larger in position 2. This may be because it is close to a road crossing and the town hall square with benches nearby.

In position 3 and 4 the road noise sources are less (low traffic volume), and other sounds are prominent also. The activity from schools and building activity is seen as a higher diversity in position 4.

Finally, it is a bit surprising that the traffic noise sources are rated that high in position 5 and 6 situated in a park area close to a two-lane road with slow traffic. The explanation may be that although the traffic noise levels are lower, the traffic is still the most dominant source. Sources as wind, birds and other are also prominent in these positions.

The results also show that the method used can give informative and consistent results relating to soundscapes investigated.

The participants were also asked to note the above-mentioned sources in three columns: Good, Neutral and Bad. The results are shown in Figure 86.

Figure 86: The percentage of Good, Neutral and Bad sound sounds in each of the measuring positions according to the participants assessments.

It is seen that positions 1 and 2 close to the road with high traffic volume have the highest percentage of Bad sounds and that positions 5 and 6 in the park have the highest percentage of Good sounds. Position 3 and 4 have a high percentage of neutral sounds, and the higher activity in position 4 gives rise to a higher percentage of Bad sounds than in position 3.

Perception of soundscape

In this clause the results of the perception of the soundscape evaluated by the 18 assessors are presented as the mean results of the assessment of the 14 attributes. The attributes are defined in Table 6, and the scales used are shown in Figure 83 as well as in Table 6. In the following the verbal scales used for the attributes are converted to a numerical scale ranging from 0 to 100. The assessors were asked to evaluate the actual soundscape at each measurement position (in the following named “actual” situation).

They were also asked to evaluate how the ideal soundscape at each measurement position should be according to their preferences according to a holistic perception of the situation (in the following named “ideal” situation). The data in the graphs are the mean values of the assessment of the actual situation and of the ideal situation in each position for all 18 participants in the four sound walks.

By comparing the evaluation of the actual and the ideal situation, it can be seen how far from ideal the soundscape is for each attribute in each position.

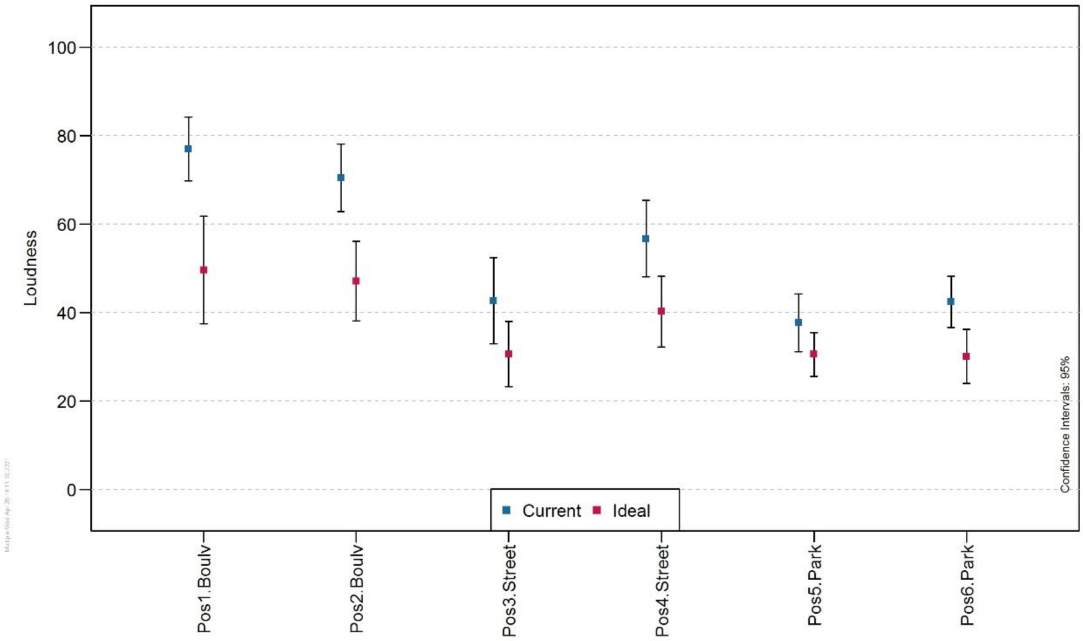


Figure 87: Loudness. The mean assessments and 95 % confidence intervals in each position.

From Figure 87 it is seen that position 1 and 2 are perceived as the loudest and that position 4 is perceived louder than positions 3, 5 and 6. In all positions less loudness is preferred (the ideal), this is most pronounced in positions 1, 2 and 4. The same tendencies are seen for traffic noise in Figure 88.

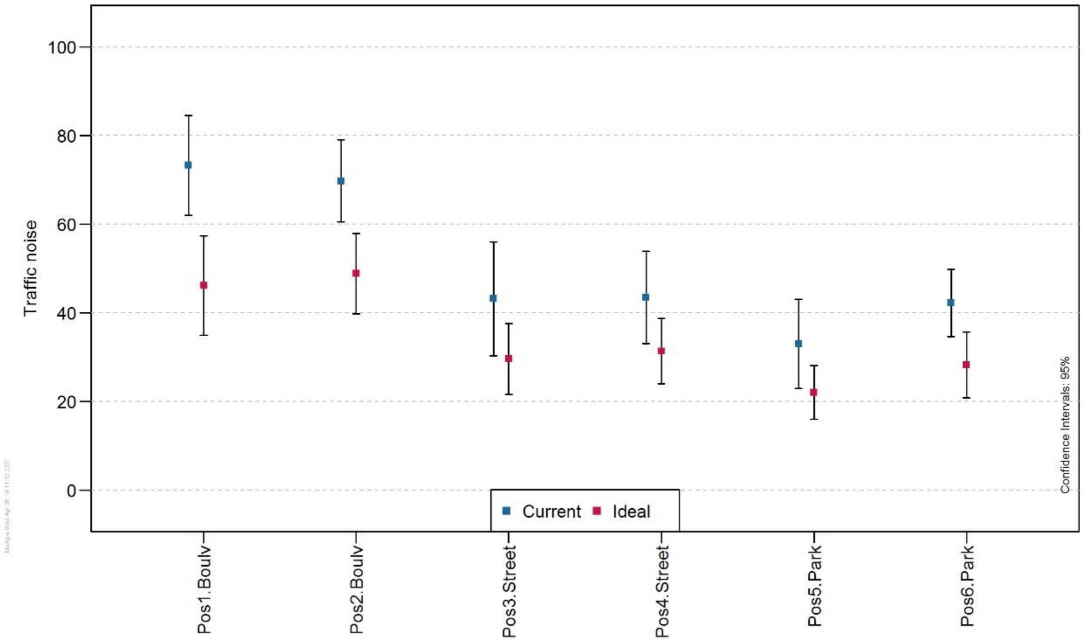


Figure 88: Traffic noise. The mean assessments and 95 % confidence intervals in each position.

The pattern from Loudness and Traffic noise is also seen for Stressful and annoyance in Figure 89 and Figure 90 and also for Intrusive in Figure 91.

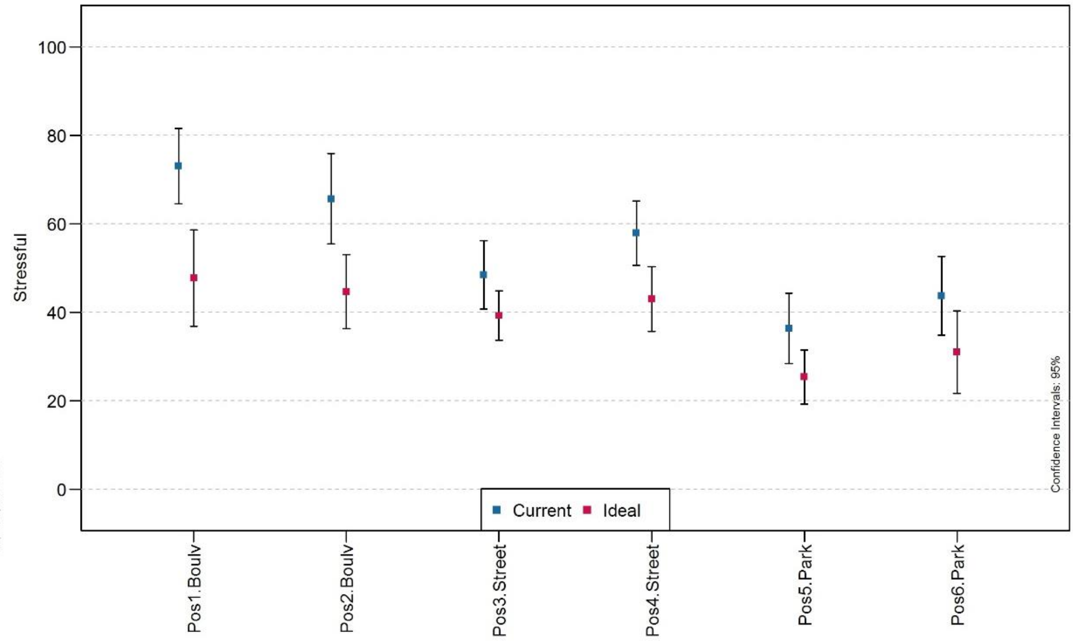


Figure 89: Stressful. The mean assessments and 95 % confidence intervals in each position.

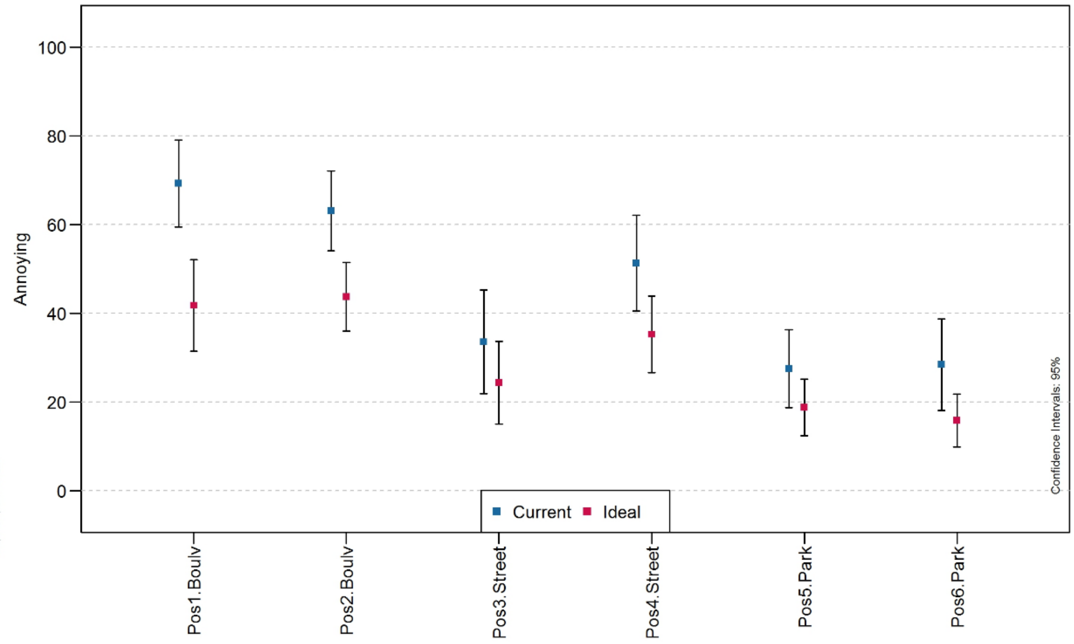


Figure 90: Annoyance. The mean assessments and 95 % confidence intervals in each position.

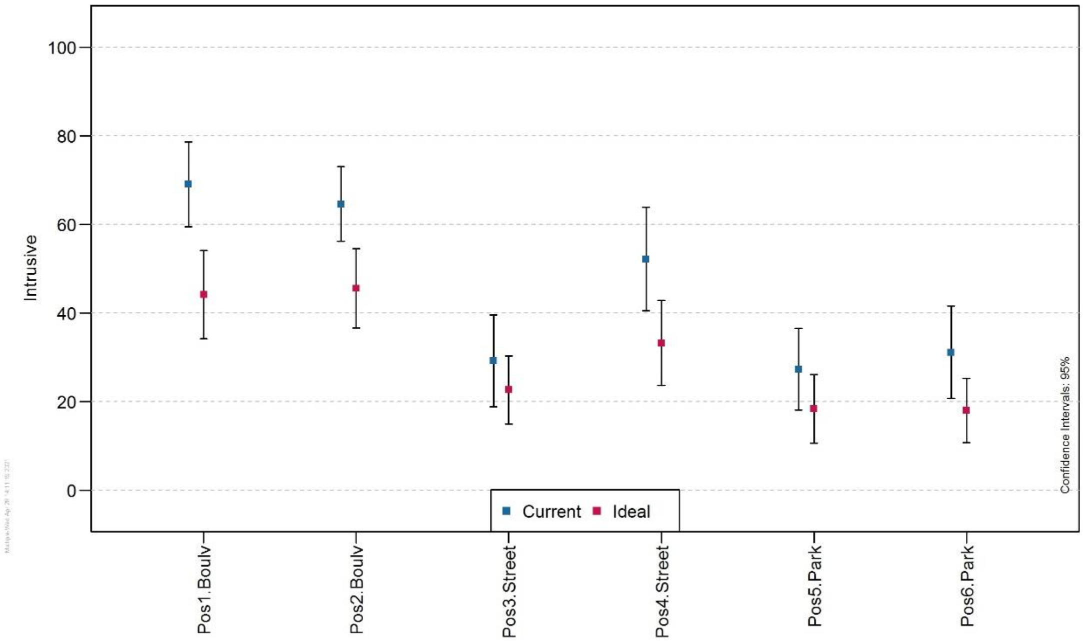


Figure 91: Intrusive. The mean assessments and 95 % confidence intervals in each position.

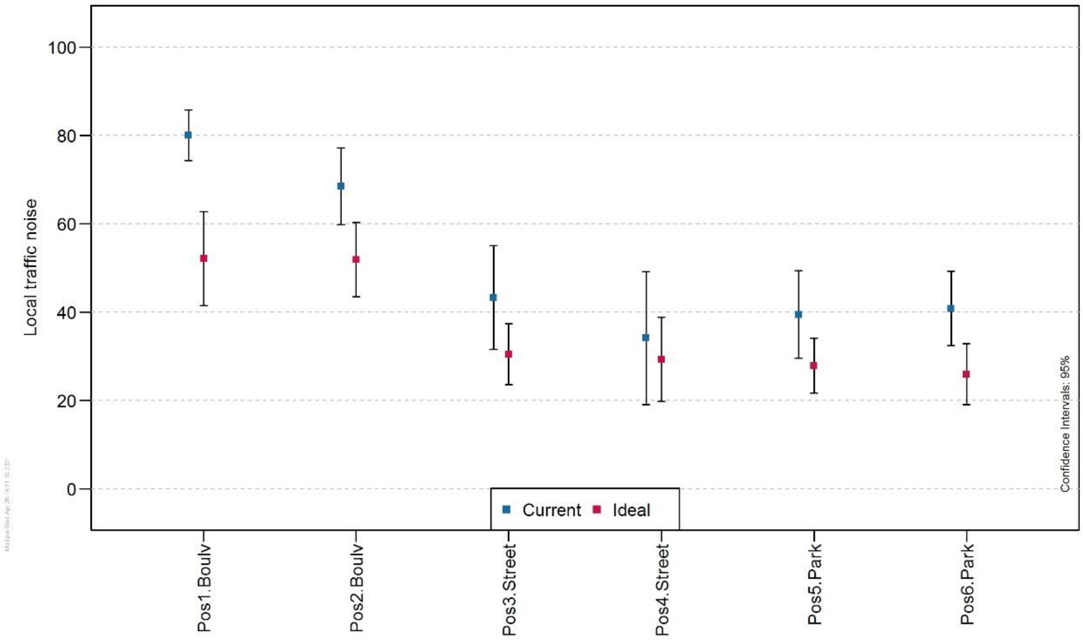


Figure 92: Local traffic noise. The mean assessments and 95 % confidence intervals in each position.

In Figure 92 it is seen that in position 3 the perception of the actual Local traffic noise is almost the same as the actual.

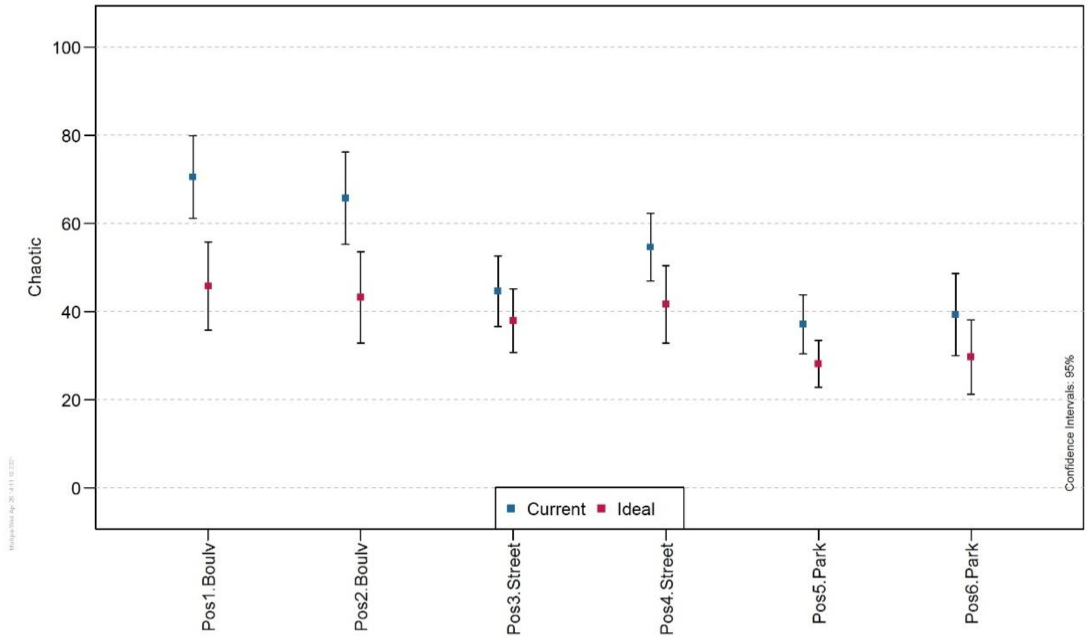


Figure 93: Chaotic. The mean assessments and 95 % confidence intervals in each position.

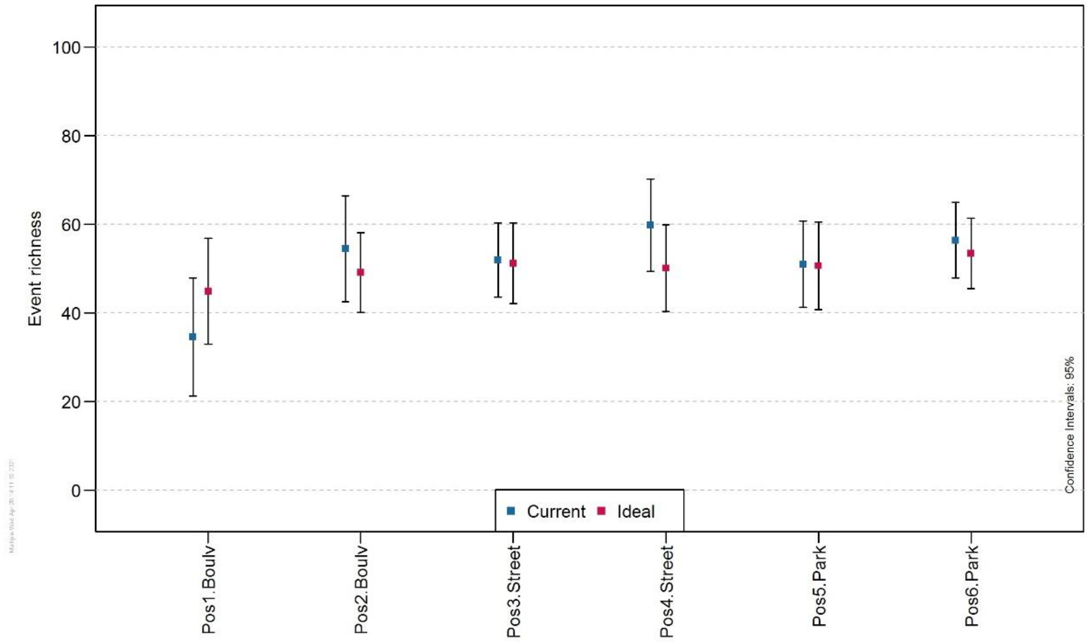


Figure 94: Event richness. The mean assessments and 95 % confidence intervals in each position.

In Figure 94 it is seen that almost all assessments of actual and ideal Event richness are in the middle of the scale. Only position 1 is lower and position 4 is higher.

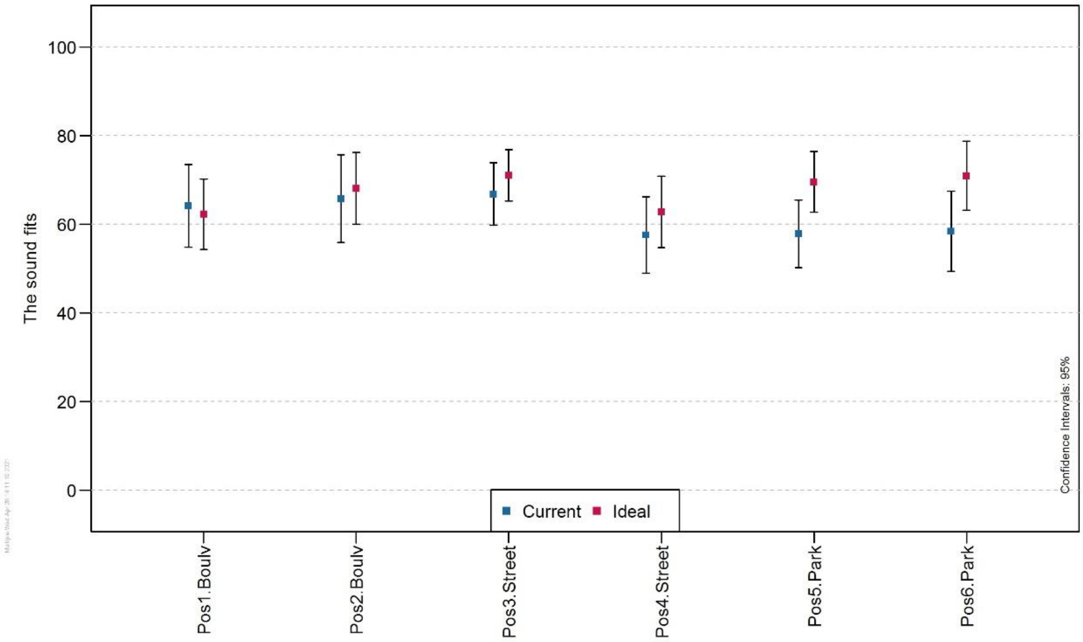


Figure 95: The sound fits the location. The mean assessments and 95 % confidence intervals

The assessment of the sound fits the location in Figure 95 seem to say that it sounds as expected. The ideal point is a bit hard to interpret for this attribute.

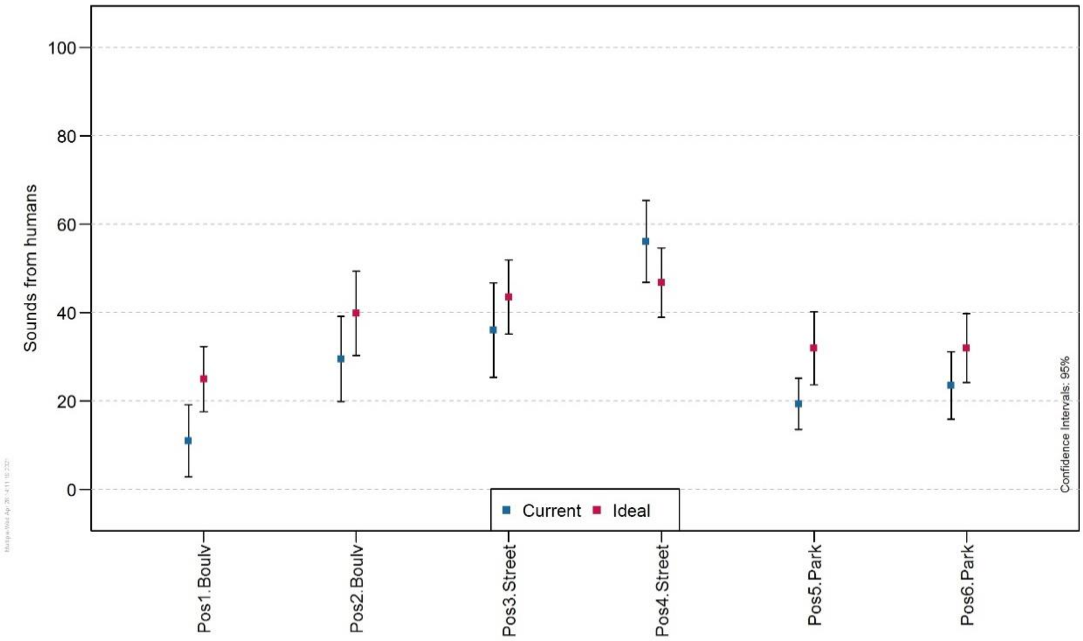


Figure 96: Sounds from humans. The mean assessments and 95 % confidence intervals in each position.

From Figure 96 it is seen that Sounds from humans are most pronounced in position 4, where the ideal point is below the assessment of the actual sound. For the other positions, more sounds from humans are wanted.

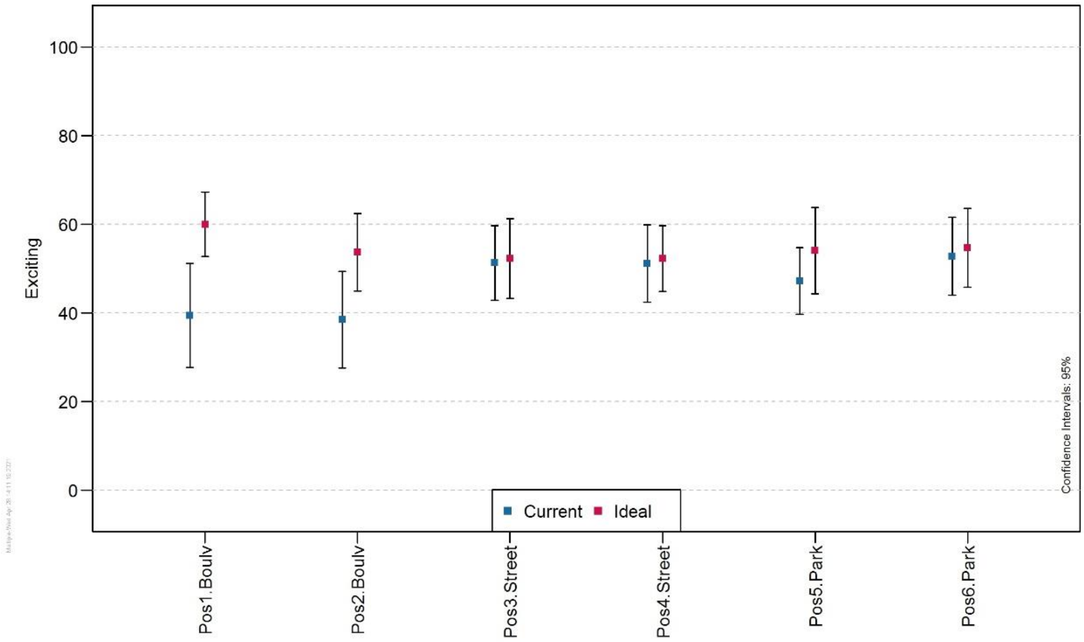


Figure 97: Exciting. The mean assessments and 95 % confidence intervals in each position.

Except for positions 1 and 2 all assessments and ideal points of Exciting are in the middle of the scale (see Figure 97). The sound in positions 1 and 2 should be more exciting according to the ideal points.

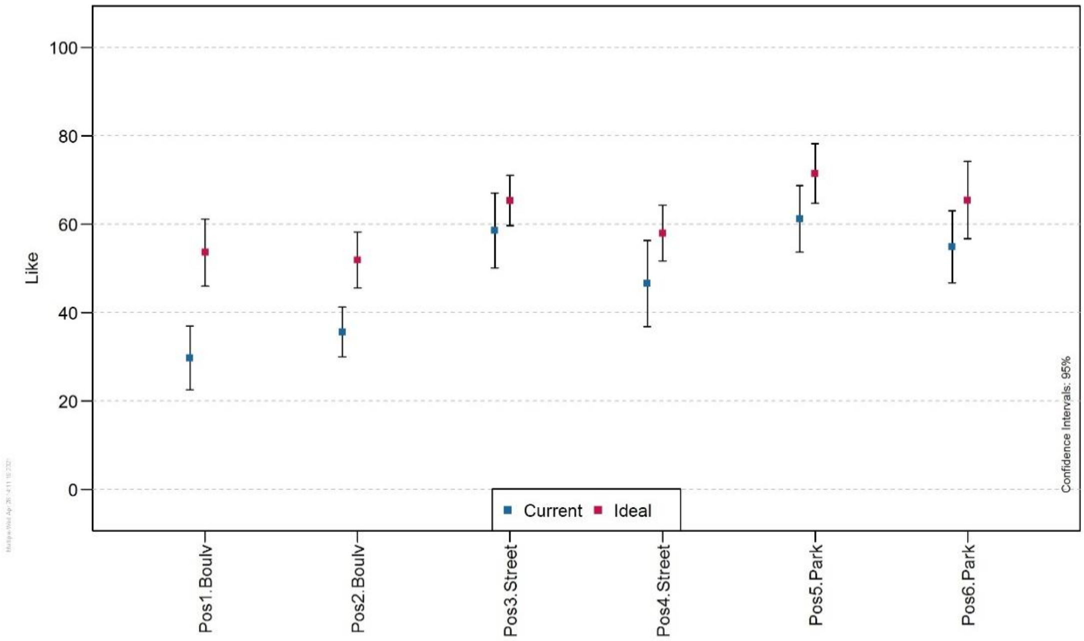


Figure 98: Like. The mean assessments and 95% confidence intervals in each position.

From Figure 98 it is seen that the best liked soundscapes are the ones in positions 3, 5 and 6. The same holds for Pleasantness in Figure 99.

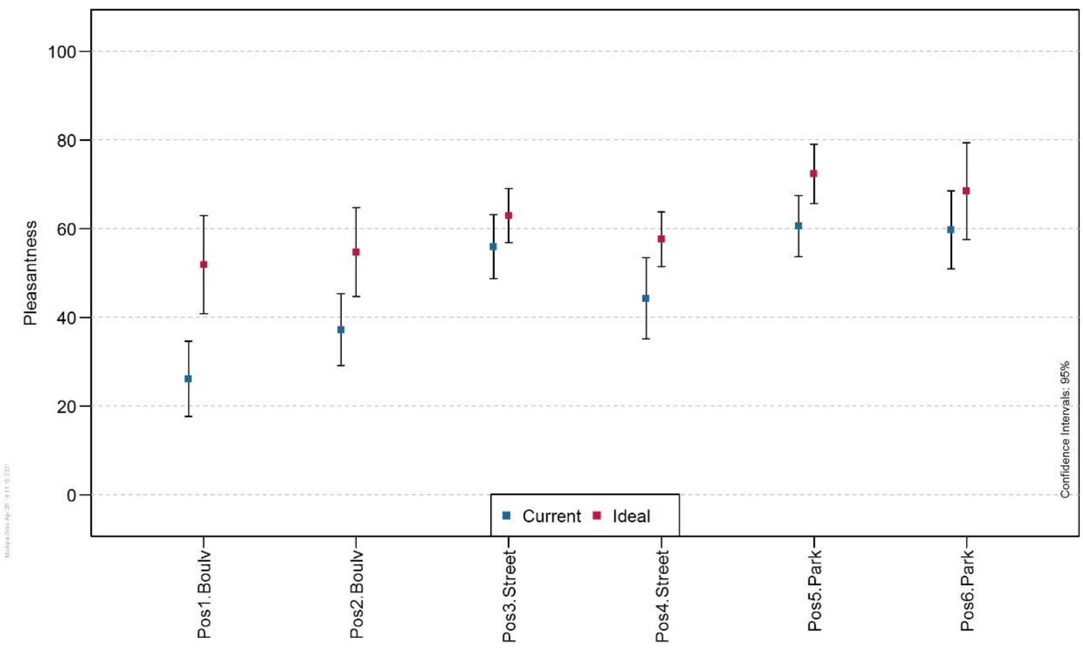


Figure 99: Pleasantness. The mean assessments and 95% confidence intervals in each position.

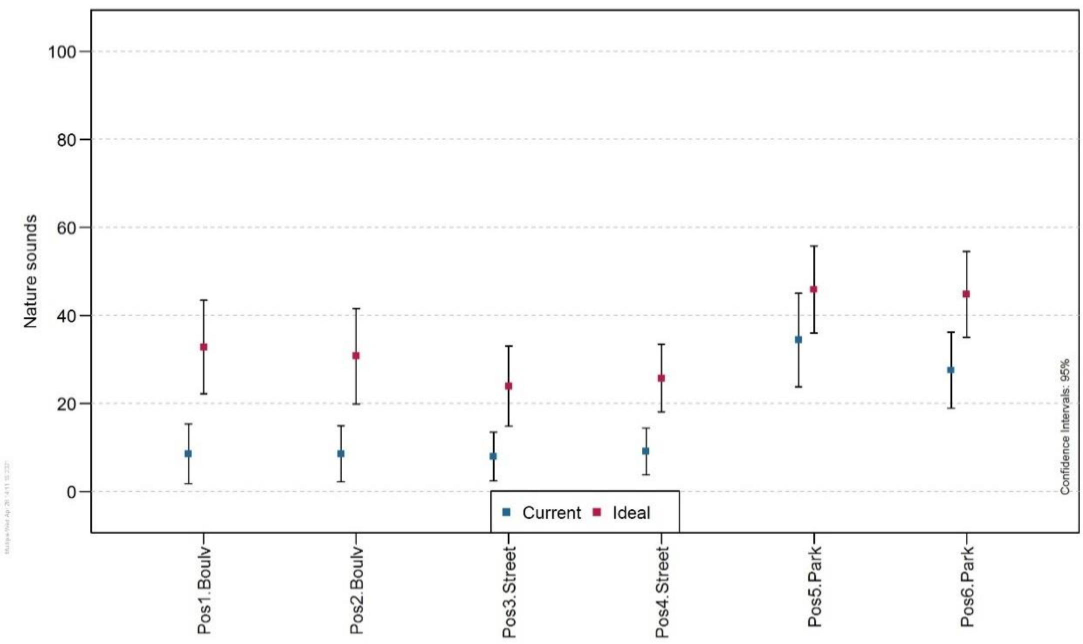


Figure 100: Nature sounds. The mean assessments and 95 % confidence intervals in each position.

The pattern for the assessments of Nature sounds in Figure 100 deviates from other assessments. The assessments are very low for positions 1-4 and essentially and significantly lower that the ideal points in these positions.

Although a correlation analysis[10] has not been made, it is easily seen from the graphs above that there is a high correlation among attributes with negative connotations (like Annoying, Stressful,

[10] Correlation is a term for the relationship between two quantitative variables. This is when one variable increases while the other increases and vice versa.

Intrusive…) and a high correlation among attributes with positive connotations (like Pleasantness, Nature sounds and Like).

From the graphs in Figure 87 to Figure 100 it can be concluded (the remarks shall be seen as trends as they are not all statistically significant):

- For position 1 compared to position 2: It is seen that the assessments of Loudness, Traffic noise, Stressful, Annoying, and Intrusive are slightly less in position 2. The assessments of “The sound fits” and the ideal points are equal for the two positions, so the sounds seem to be as one could expect at such locations.
- For position 3 compared to position 4: The assessments of Loudness, Stressful, Annoying, Intrusive and Chaotic are higher in position 4 although the Traffic noise is assessed equal. The assessments of “The sound fits” and the ideal points are equal for the two positions, so the sounds seem to be as one could expect for the activities seen at these locations. The ideal point for the Event richness is the same as the assessment in position 3 but is higher than the assessment in position 4. Less activity seems to be preferred in position 4.
- For position 5 compared to position 6: The assessments of Loudness, Traffic noise, Stressful, Intrusive and Chaotic are slightly higher in position 6 although the Annoyance is assessed almost equal. For “The sound fits” the ideal points seem to deviate significantly from the assessments in both these positions. This is not the case for positions 1-4. This could be interpreted as there are more traffic noise than expected in a green park where the traffic is only partly or not visible at all.

The differences between the assessments of the actual and the ideal situations are summarised in the soundscape index, see Figure 103.

Principal component analysis

While the 14 attributes have been found to contribute with valuable information in general, some might contribute with similar information in one particular sound walk. This makes it of interest to understand the relationship between ratings of the attributes, which may also help understand the mechanisms of how to improve the soundscapes investigated.

A principal component analysis, PCA, is a tool to get an overview over the many assessments of the attributes for the actual situation. PCA, is a dimensionality-reduction method that is often used to reduce the dimensionality of large data sets by transforming a large set of variables into a smaller one that still contains most of the information in the large set. The idea of the PCA is to reduce the number of mathematical dimensions. Basically, all the results from the test can be thought of as a multidimensional space spanned out by the 14 attributes. The data will form a cloud of points. Think of only three dimensions and fly around this cloud until you find the direction where the cloud has the largest dimension, we could call it the length (Dimension 1). Next find the direction perpendicular to the length where the cloud has the largest dimension, we could call it the width (Dimension 2). We do not know if these dimensions have any meaning (yet), but they are the directions with the largest variations in the data. This also means that they are the most important dimensions in relation to explaining the variations we see.

If all attribute ratings were completely independent (uncorrelated) we would have 14 perpendicular dimensions, but due to correlations between some and others that are rated the same across all listening positions, the number of mathematical important independent dimensions are always smaller.

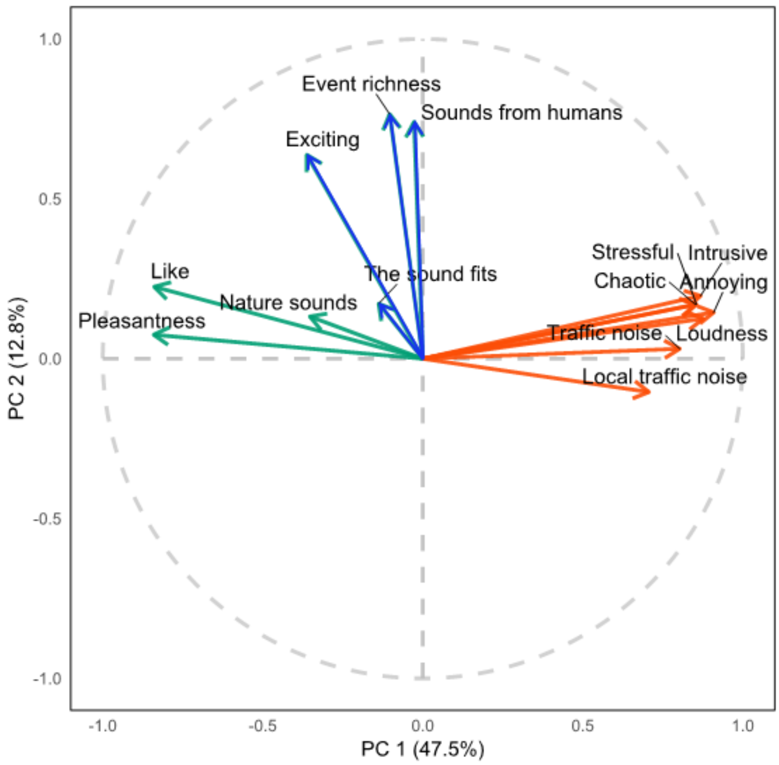


Figure 101: PCA loadings from a principal component analysis (PCA) of the actual situation that indicates the relationship between the various attributes.

A result from the PCA is the “loadings” of the attributes shown in Figure 101. It shows the correlation of the attributes in the plane of dimension 1 and 2. If the vectors representing the attributes are close together, then the attributes are correlated (e.g. Loudness and Annoying). If a vector is long (e.g. Annoying), its variation is explained mainly by these two first dimensions. If a vector is short (e.g. The sound fits), it is mainly explained by a third or other dimension.

It is seen that the attributes Pleasantness, Nature sounds and Like (green arrows) are in the same direction. In the opposite direction is Loudness, Traffic noise, Stressful, Annoyance, Intrusive, Local traffic noise and Chaotic (orange arrows). It is quite meaningful that these two groups are in opposite directions. We can conclude that dimension 1 is related to Annoyance with the largest annoyance to the right and the least (Liking) to the left. The attributes Event richness, The sound fits, Sounds from humans and Exciting (blue arrows) have a special meaning as they are more or less perpendicular to the direction of the two first mentioned groups, dimension 1. Dimension 2 is related to how exiting the sound is in terms of Event richness and Sounds from humans. Dimension 1 explains 47.5 % of the variation in data, dimension 2 explains 12.8 %. In total the two dimensions explain 60.3 % of the variation in the data.

The PCA loadings plot may also suggest that increasing the audibility of nature sounds may increase pleasantness and reduced annoyance.

Relations between the positions

From the assessments of the attributes some information about the six positions can be deduced.

From a principal component analysis, PCA analysis, of the attributes a systems factor map is shown in Figure 102. To understand this figure, you can imagine seeing the beforementioned cloud of points from a direction where you see the maximum length (dimension 1 on the x-axis) and the maximum width (dimension 2 on the y-axis). The Blue square is then the position of the mean value for all points belonging to position 1 and the blue ellipse is indicating the 95% confidence area of this mean value and so forth for the other five positions.

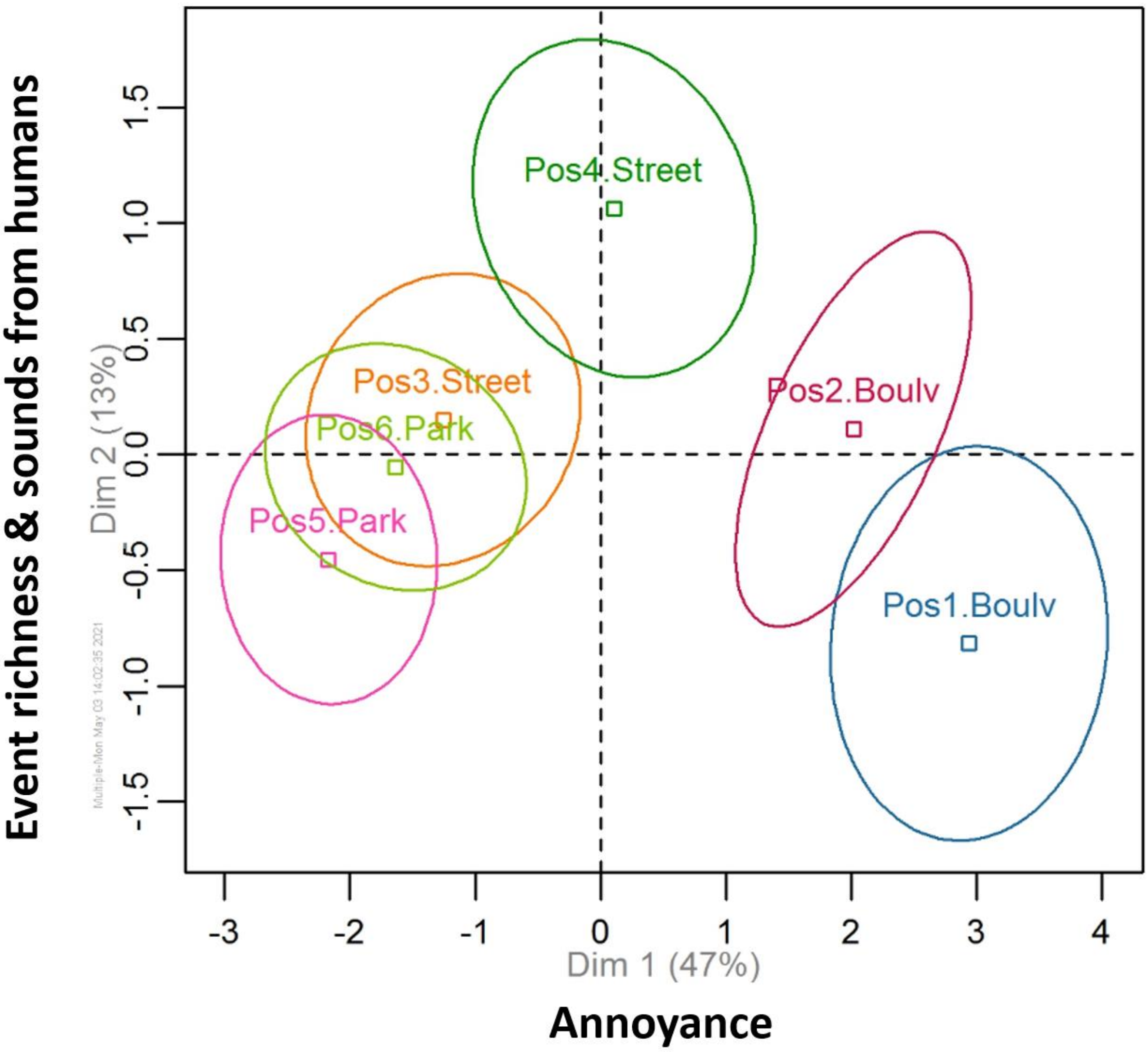


Figure 102:A systems factor map from a principal component analysis (PCA) that shows the mean values and confidence ellipses for the measuring positions in the first two dimensions of the space consisting of the attribute assessments.

When dimension 1 is related to annoyance, and dimension 2 is related to Event richness and Sounds from humans, Figure 102 can be interpreted as follows: Position 1 by the road with high traffic volume is the most annoying, position 5 in the park is the least annoying. As position 6 is included in the confidence ellipse of position 5, the two park positions are probably not significantly different. Positions 1 and 5 have the least Event richness and Sounds from humans while position 4 is clearly the one with the maximum of these attributes.

From Table 5 it can be seen that position 3 has almost the same L_{Aeq} as position 4. Anyway, the impression of position 3 is that it is a silent street with a few cars passing by now and then. In that sense it is more in line with positions 5 and 6 as the figure shows while there was a lot of activity in position 4 (schools and some building activity).

The soundscape index

FORCE Technology has constructed a soundscape index which can be calculated from the differences between the assessments of the actual and the ideal situation for each attribute evaluated.

An overview of the results is given in Figure 103. Each curve shows the deviation from the ideal point for all attributes for a measuring position. The assessment of the ideal has been given the value 0 and is here marked as a black line. What you want less of is above 0, and what you want more of is below 0.

The deviations from the ideal must be seen in the light of the fact that the uncertainty (95 % confidence intervals) is on average around 10 units on the y-axis.

Based on the total deviations, a sound landscape index has been calculated which is shown in Figure 103. It is a number between 0 and 10 that indicates the quality of the soundscape. 0 is lowest and 10 is highest quality.

The soundscape index SI is calculated as:

(4) $$SI = \frac{100 - 1{,}5 * M}{10}$$

Where M is the average deviation from the ideal point for all attributes.

The soundscape index SI can be seen as an overall expression of the quality of the soundscape at a specific location based on the evaluation of 14 different attributes related to soundscape (see Table 6). The soundscape index SI can be used to compare the soundscape quality at different locations.

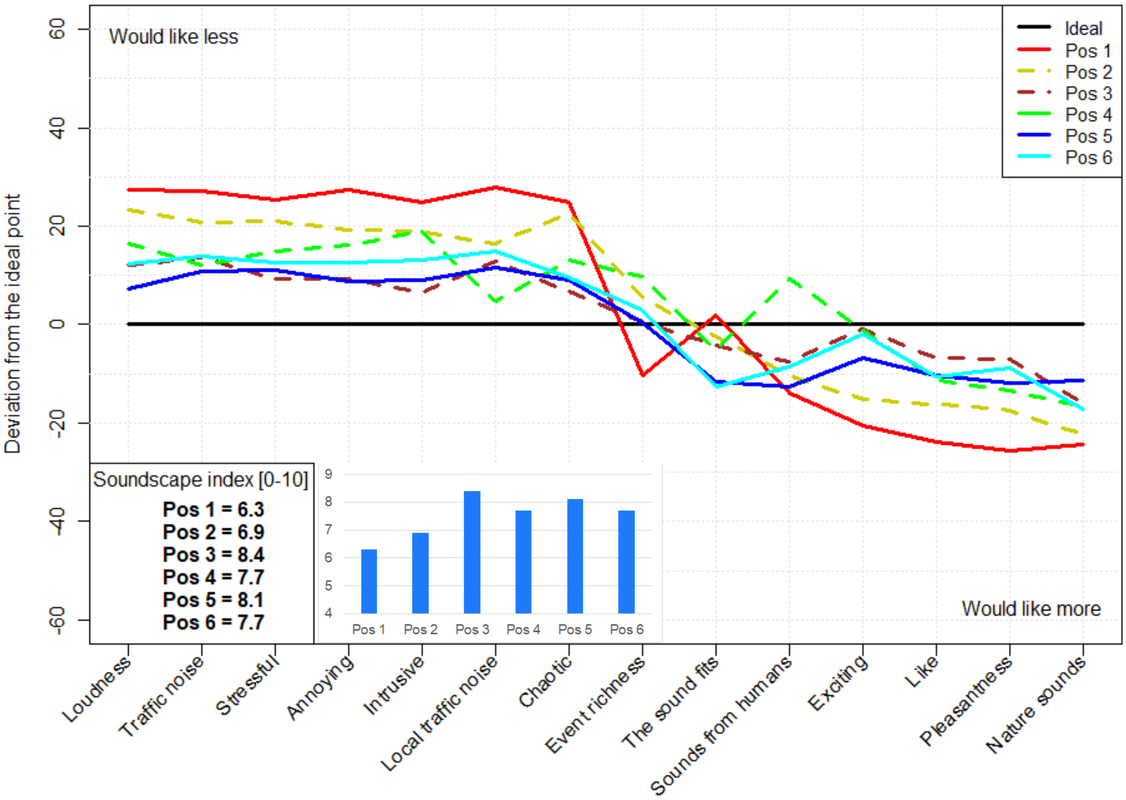


Figure 103: Soundscape index for each of the 6 measurement positions. Each curve shows the deviation from the ideal point for all attributes for a measuring position. The ideal point is marked with the black line. The soundscape index for each position is shown in the lower left corner of the graph.

It is seen that positions 1 and 2 have the lowest soundscape index indicating that these positions are the most unpleasant to be situated in. On the other hand, positions 3 and 5 have the highest ratings soundscape index indicating that these positions are the most pleasant to be situated in. It is remarkable that position 3 is rated higher than positions 5 and 6 in the park. The explanation may be that the traffic noise was more prominent than one would expect in the park while position 3 was perceived as a rather silent street.

6.3.5. Models for annoyance – dose-response curves

The relation between the annoyance reaction and the noise exposure can be described with dose-response curves. Most often these curves represent the annoyance response as function of the noise exposure, L_{den} where the annoyance responses are averaged over all context, social and personal variables.

The responses are normally obtained from socio-acoustic surveys where hundreds to thousands of respondents are asked to assess the annoyance within the last year when they are at home (see as an example [41]). The annoyance assessment is meant to be the average over time and over the many situations where the annoyance is felt at home.

Although the annoyance measured during the sound walks uses the same annoyance scale, the situation is quite different. It is a short time assessment where the traffic is present and where the focus is at the traffic and the annoyance felt in the actual situation “answering questions on a sound walk”.

Nevertheless, there may be similarities between the dose-response reactions and the non-acoustic factors that modify the dose response curves.

With the purpose of finding the dose-response curves for the annoyance from traffic noise during sound walks, models of the annoyance measured as a variable in the sound walks as function of the corresponding L_{Aeq} levels have been tested. The curve in Figure 104 shows a model with a logistic fit (see Section 5.1.2) to the measured data.

It should be noted that normally the results from socio-acoustic surveys are given as curves showing the percentage of highly annoyed. For the sound walks we have chosen to show the results for the annoyance in each position as the average annoyance response for all participants on the 0-10 scale.

The logistic curve is defined by only two constants, the slope, s, and the fifty percent value of the exposure, f (see Section 5.1.2).

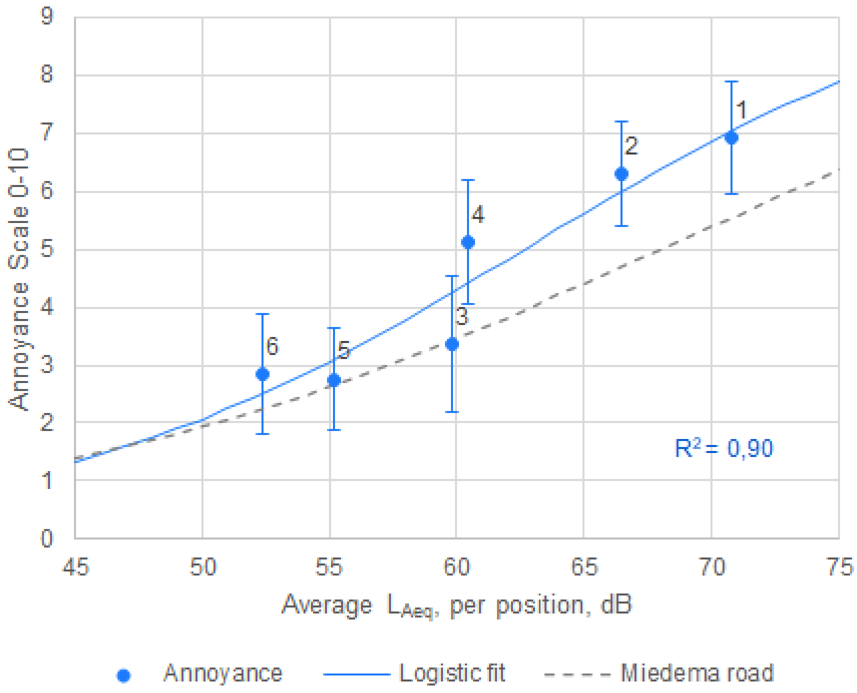


Figure 104: Average annoyance response during the sound walks in each of the measuring positions 1-6. The vertical bars represent the 95 % confidence intervals for each measurement position. The blue curve can be described by s = 0,1064 and f = 62,7, see the text. The grey dotted curve here called "Miedema road") (s = 0,0795, f = 70,4) is the average annoyance score deduced from [47] according to [48]. For this curve L_{den} is converted to L_{day} (~ L_{Aeq}) by adding 2,4 dB according to [53].

The model in Figure 104 gives good fit (R^2 = 0,9) to the data. So, it can be concluded that it is possible to find a dose-response curve from a sound walk when there is sufficient variation in the noise levels, in this case a 20 dB range of L_{Aeq} values from 52-71 dB.

The "official" EU curve (here called the Miedema curve) is also shown. (The curve is corrected from L_{den} to L_{Aeq}). Compared to the corresponding curve from the Miedema data (showing the annoyance score and not the percentage of highly annoyed as usually used), it is seen that the annoyance response is higher from the sound walks and with a steeper slope. This is to be expected because the Miedema survey data is the average over all situations at home where the focus is not at the traffic noise as in the sound walks.

The next relevant topic is to see if the influence of non-acoustic factors can be modelled. In this case it was planned to model the influence of greenery and the visibility of the traffic.

The input data for this (L_{Aeq}, amount of greenery and visibility of the traffic) is found in Table 5 and a logistic regression is made with a model including L_{Aeq}, % greenery and % traffic visible (the dotted red curves in Figure 105).

In the analysis it turns out that only the influence of L_{Aeq} is statistically significant. Anyway, for illustration purposes only the tendency for the effect of greenery on the dose-response curves is shown in Figure 105. The annoyance equivalent change in L_{Aeq} for 0-100 % greenery is seen to be approx. 3 dB. Meaning that in a situation with 100 % greenery, the annoyance response is lower than in a similar situation but without greenery. The reduced annoyance corresponds to 3 dB.

The non-significant effect of the visibility of the traffic is of the same magnitude.

As the confidence intervals for the size of both effects include both positive and negative changes, no reliable data for the influence of these moderators can be deduced from the sound walk results.

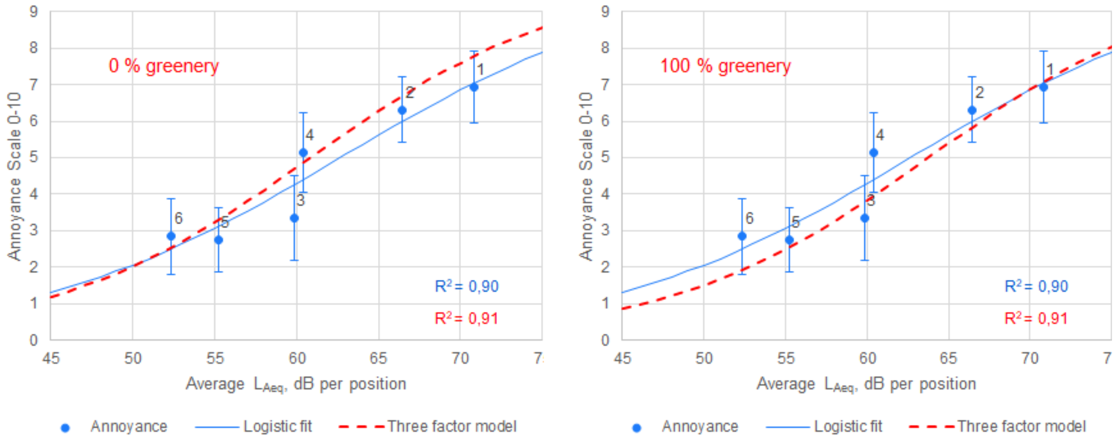


Figure 105: The (non-significant) effect of greenery on the dose response curve. The dotted red line represents 0 % greenery in the left graph and 100 % greenery in the right. The blue curves show the average annoyance response during the sound walks in each of the measuring positions 1-6 as seen in Figure 104,

It may be a bit disappointing that the effect of greenery and visible traffic is not significant in this investigation. But on the other hand, the input data shows little variation in the moderator greenery and the high values correlate with low noise levels so there is not much left for this variable to explain. The same holds for traffic visibility where the two data points without 100 % visibility have the lowest noise levels.

It may be possible to investigate the effect of the variable's greenery and visible traffic by the means of sound walks. In that case more measuring points would be needed and with more and independent variations of the variables L_{Aeq}, greenery and visible traffic.

6.3.6. Conclusions of the sound walks

The sound walks were successful in the sense that they gave a good representation of the sound sources in a sound source hierarchy (sound source taxonomy). The diversity of sound sources was dominated by sounds from human activity, especially traffic noise. According to the participants bad sounds were dominating except in the two positions in the park. Results with acceptable uncertainty (95 % confidence intervals) were obtained for the 14 soundscape attributes (soundscape descriptors) used to describe the soundscape and the annoyance. The results gave detailed characteristics of the six measuring positions. A principal component analysis revealed that the results could mainly be represented in an annoyance-like dimension and a dimension describing Event richness and Sounds from humans. From these results a "systems factor map" could be constructed, which gave a clear picture of the relations between the six measuring positions, and why they differed.

Furthermore, it was possible to calculate the soundscape indices for the six positions which gave a clear discrimination between the positions in terms of soundscape quality.

Sound level measurements were made during the sound walks and annotated level recordings helped the understanding of the soundscape assessments.

By combining the assessments of annoyance from the sound walks with the measured noise levels it was possible to make a model (dose-response curve) for the annoyance as function of the noise level (L_{Aeq}) with a good fit (R^2 = 0,9). The results for greenery and the visibility of the traffic are summarized as part of the hypothesis testing.

The investigation has showed that sound walks can give valuable and quantifiable information about the soundscapes in the various positions.

6.4. Conclusion on hypothesis testing

In comparison of the first findings in the literature analysis (see Chapter 3) and the surveys conducted within the FAMOS project, the following results can be obtained:

Listening tests

The influence of the moderators greenery and visibility of traffic on annoyance is significant but opposite findings in practice and in the literature. The hypothesis is that this is caused by disappointed expectations of the assessors performing the listening tests from what is seen on the videos.

According to the analysis of the listening tests, the annoyance increased with increasing percentage of greenery, which is in contradiction to findings in practice and in the literature. Furthermore, the annoyance decreased with increasing visibility of the traffic. This is also in contradiction with other findings where the annoyance decreases when the traffic is not visible.

In general, we found that the annoyance increased with decreasing values of "The sound fits" the actual environment. So, our hypothesis is, that if you expect a rather silent environment and are exposed to higher noise levels than expected, the noise is perceived as more annoying. This could also be seen as, when the expectations are not fulfilled, the annoyance increases.

There were other differences in the positions than greenery and visible traffic, e.g. different speed of the traffic, traffic flow, road type, screen type and distance to the road. It is unknown whether that did influence the assessments of annoyance.

Some of the results deviated from findings elsewhere and it was concluded that it is important that the assessors have a full understanding of the context, e.g. by a short introductory video tour showing the road and its surroundings or by using virtual reality to enhance the assessors envelopment in the scenario.

Mini surveys

For visibility of the traffic and greenery, results showed a tendency towards a lower annoyance with blocked views. The effect is small but still visible for a blocked view by greenery. Visibility of traffic will increase the annoyance especially when traffic is visible from the sleeping room or multiple rooms. A quantification on the effect, i.e. changes in noise level, in CTL or similar, cannot be derived due to the low size of the data collected.

A major influence on annoyance was also identified by expectations and expectations met. For noise level changes, a noise level reduction of less than 10 dB led to a relevant number of respondents that perceived expectations that were not met regarding noise reduction.

The surveys carried out have a high uncertainty regarding the noise levels as the exact location of each dwelling is unknown. Uncertainty would be lower with a higher number of respondents, alternatively a face-to-face interview in the survey area could have a higher reliability on locations and thus noise levels, but limit the number of responses.

Sound walks

The influence of greenery and the visibility of the traffic was sought to be modelled. Due to insufficient variations and correlation with the traffic noise levels, the modelled influence of these moderators was not significant. A trend was found that the effect of presence of greenery reduced the annoyance equivalent level with around 3 dB, but the uncertainty was large.

Summary

In general, the mini surveys and the sound walks showed tendencies to support the findings of literature analysis. However, results have some uncertainty mainly because of limits in the data sets. Possibilities were limited within the framework of the FAMOS project. The situation with the Corona virus also influenced the test, especially the mini surveys (interviews were planned). The listening tests showed opposite findings which could be explained by unmet expectations on the silence of an environment.

6.5. Usage of testing methods and comparison

The analysis of three different ways to obtain data for analysis regarding annoyance showed different suitability given a real situation:

Listening tests

Audio-visual listening test may be used to quantify the effect of noise characteristics and moderators. It is important that good practice for such tests is followed to avoid bias in the results, see e.g. [43].

By following good practice, it is relatively easy to get reliable results in listening tests with objective and well-defined attributes.

When making listening tests on subjective attributes such as annoyance, the following factors should be taken into account:

- Preferable more than 20 assessors should participate
- The assessors should be representative for “normal (untrained) citizens” preferable living in residences under similar conditions as simulated in the test.

- For assessment of annoyance the context is important. Make the test surrounding as realistic/"home-like" as possible. Avoid laboratory like setups as much as possible and hide them behind curtains if necessary.
- Give a realistic visual presentation (pictures/video/Virtual Reality) as possible
- Make sure that the assessors understand and imagines the scenario when they make the assessments.
- Use standardized scales and scale labels
- If the effect of more than one moderator is tested, then stimuli should include independent variations in each of the moderators

Mini surveys

The results from the mini surveys suggest that mini survey may a useful tool for investigating relevant moderators that contribute to annoyance from traffic noise. The survey carried out showed that postal mailings can give a good control on coverage and could address more people than via electronic mailing (for which the addresses of possible respondents must be known beforehand).

However, it is suggested to just send out invitations to the survey itself which will be carried out electronically. If so, the costs for the questionnaire itself are negligible. A mailed survey needs an extensive mailing as well as the possibility of returning the results. If paper is to be returned, the postal fees have to be considered.

As one of the biggest disadvantages, the exact assessment of the location of a dwelling showed a big uncertainty in determination of noise levels related to the dwelling. Focus on a survey design should be a good way for respondents to give information on location of their residency, but also taking privacy reasons and concerns into account. A higher reliability for the location could also be achieved in face-to-face interviews in the survey areas.

The mini survey itself showed that a survey itself is applicable for different aims. These can as well be focused locally ("expectations to be considered," like importance greenery) as give a general overview on attitudes towards noise (as towards authorities etc.). For future comparison, a common set of questions should be used.

To summarise, mini survey…

- are suitable for areas, analysing e.g. expectations on noise and the general development (need for greenery, improvement of neighbourhood),
- may also be suitable to ascertain general factors when summarizing results from different areas, as attitudes towards authorities, annoyance from different types of roads, effects of greenery and visibility etc.,
- are best based on an unchanged "common set of questions" throughout different surveys,
- quantification with acceptable uncertainty is possible if the number of respondents is 300 or more (compare Section 5.2.1, Section 6.2 and Chapter 7),
- for correct calculations of noise levels, the addresses of the respondents should be known.

Sound walks

The results also suggest that soundscape measurements may be a useful tool for investigating the annoyance from traffic noise and the effect of non-acoustic variables, e.g. greenery and visible traffic. For this to be successful some details should be considered.

As the holistic situations at the places of interest may differ for other reasons than the differences in the variables under investigation, a higher number of positions is needed so unwanted bias can be corrected for or averaged out. Alternatively, special care should be taken that the main differences only or primarily are caused by differences in the variables of interest.

There shall also be sufficient and independent variation in the variables under investigation in the chosen measuring positions. As an example: Greenery may be related to lower noise levels e.g. if measurements are made in a park away from the traffic. If so, both other “green” positions with high noise levels should be found and also no-green positions with low noise levels.

Based on the sparse experience from this investigation: As a rule of thumb we would recommend having four times as many measuring positions as the number of variables of interest. So, if we want to investigate the influence of noise level, greenery, and the visibility of the traffic, this means 12 measuring positions. For construction of a dose-response curves we will recommend at least 6 measuring positions where the main variable is the noise level of the traffic with a level range of 15-20 dB or more.

At least 20 persons (e.g. in groups of 5-7 persons) shall participate in making the assessments. If not the same group of persons is assessing all positions, more persons and some experimental design is needed to ensure that differences in results are caused by the positions and not the difference between the groups of assessors. With the current questionnaire the assessment time is 5-10 minutes in each position. Larger numbers of participants could result in a sigher statistical confidence.

To summarise, sound walks…

- may be a useful tool for investigating the annoyance from traffic noise and the effect of non-acoustic variables, e.g. greenery and visible traffic,
- should be limited in the numbers of variables (moderators) analysed,
- measuring positions with independent variation in the moderators under investigation should be selected/included
- may need a high degree of participation, at least 20 persons (e.g. in groups of 5-7 persons)
- cannot directly adopted at new/planned locations (presence of different places of interest; prediction of future changes / situation after a construction etc.). Similar places elsewhere may serve as substitute

7. Modelling

The overall objective of FAMOS is to quantify how different factors modify people's subjective reactions to road traffic noise. Therefore, the purpose was to establish models for the effect of moderators expressed as dose-response curves for the moderators in various context and use case situations. The aim was to describe the models in practical terms, which use cases they are applicable for and which context variables to control or specify as input and to get reliable output estimates of the moderator effect with a specified uncertainty.

Supplementing the findings of the former work packages 1 and 2 (see Chapters 3 and 4), additional modelling should in work package 3 concentrate on the most relevant moderators already retrieved (see Chapter 3). This modelling work is documented in the report “Modelling noise annoyance moderators. Deliverable D3.1” of the FAMOS project [54]. Here more technical statistical terms used in the following are presented.

The model is based on input in the form of raw data from two Danish questionnaire surveys. Within the project work has been done to collect data from other sources, but it turned out that it is not at all easy-to-get access to raw data from former questionnaire surveys from other countries. Within the framework of the FAMOS project and in cooperation with the Programme Executive Board (PEB) of the FAMOS project it has therefore only been possible to obtain raw data from comprehensive Danish surveys.

Based on input from two large questionnaire surveys on perceived noise annoyance, the model can demonstrate the effect of various moderators. The result within the project will not be ready-to-use piece of software with user interface for general use. It will anyway be possible to use the model for input data from more surveys at a later stage after the termination of the FAMOS project.

7.1. Background and purpose

A modelling methodology is developed and suggested for analysing the influence of moderators of annoyance from road traffic. The methodology is exemplified through the modelling of two datasets from the Danish Road Directorate that has been made available for the FAMOS project. The literature review (see Section 5.1) showed a significant portion of previous studies looking into only a few potential moderators per study, which might overestimate each moderator’s influence on annoyance. A more complete model is needed looking at a wide range of potential moderators. The previous studies provide a good basis for selecting relevant moderators. The two Danish studies included comprehensive questionnaires with many of the moderators suggested in the literature and therefore makes an ideal test case for investigation of the potential benefit of making a more comprehensive statistical regression model, enabling NRA’s to predict annoyance from several alternative changes to an environment with neighbours affected by road traffic noise and make choices on an improved informed basis for applying tools to reduce the perceived noise annoyance.

The two Danish studies [41], [55], [40], [56] are of excellent quality both in terms of included questions, questionnaire design, high number of participants, and data quality as well as the methodological approach that follows the current ISO standard for such investigations [45]. The results must be considered valid for Denmark as well as similar north European countries/regions and they can be considered a first good step towards a model valid for the whole of Europe, but they are not a sufficient data basis for making a road traffic annoyance model that can provide accurate predictions for all of Europe. While getting data from a representative part of Europe as originally intended, sharing of personal data from questionnaires between research partners is a major challenge. Even more so with the introduction of the General Data Protection Regulation (GDPR) in May 2018. Especially since part of the relevant data for annoyance studies can include personal medical data.

The contribution of this modelling is also to further investigate the potential of including more moderators and more interactions between moderators in a multiple regression model and further qualify the list of questions of importance to collect in future studies allowing the future creation of a valuable tool for working with annoyance moderators in practical road and noise planning

7.1.1. Data for the modelling

As already mentioned, the raw data from two major Danish socio-acoustic surveys were made available for modelling in this project by permission from the Danish Road Directorate:

1. Noise annoyance from motorways and urbans roads, [41] and [55]
2. Community response to noise reducing pavements, [40] and [56].

The study on noise annoyance from motorways and urbans roads (performed in 2014) was made with the purpose to find out whether the noise annoyance experienced by residents along motorways is larger than the noise annoyance experienced by residents along urban roads, at the same noise levels. The motorways include sections of a total length of 200 km (10 % of the Danish motorway network) that affect residential areas by noise in large cities (Aalborg, Odense, and Copenhagen), and affect both urban communities and dwellings in rural areas throughout Denmark. The urban roads include 20 sections in the three large cities in Denmark (Copenhagen, Aarhus, and Odense). The sections in cities are both urban roads with little traffic, shopping streets and large, busy through roads. The questionnaire contained 30 questions. The national road administrations mainly have the responsibility for motorways and other main roads. To reflect this, it has therefore been decided only to analyse the subset of data on motorways.

The study on community response to noise reducing pavements were performed before (in 2007) and after (in 2008) the pavement on two major roads (Frederikssundsvej including some neighbouring roads and Kastrupvej) in Copenhagen was renewed with noise reducing thin layer asphalt. The questionnaire contained 40 questions (see [54]) and the methodology used for the survey was similar to the motorway study.

The road surfaces in the before situation were 8 years old asphalt concrete having 11 mm maximum aggregate size. In the after situation the pavements were new noise reducing thin asphalt layers. At the repaved roads, an average noise reduction of 4 dB was measured.

The number of respondents in the studies can be found in Table 8.

Table 8: Number of respondents in the studies which is the data basis for the modelling. Data from the red shaded cells (6316 respondent) are included in the modelling.

Study	Year	Number of respondents		Total
Noise annoyance from motorways and urban roads	2014	Motorways: 3446	Urban roads: 3315	6761
Noise reducing pavements (Copenhagen dataset)	2007 and 2008	Before: 1330	After: 1540	2870

A total of 6316 respondents are included in the analysis of the two datasets included in this analysis. This is a very high number of respondents and much higher than what is seen in many other international annoyance surveys [1]. Note, that in the remaining sections of this chapter, the "Noise annoyance from motorways and urban roads" is referred to as the "motorway" dataset (as only the motorway responses were included) and the "Community response to noise reducing pavement" is referred to as the "Copenhagen dataset".

7.1.2. Questionnaire content and Common questions

Both questionnaires in the two studies have the questions divided into sections with headings describing their topics, which gives a nice overview, as shown here.

Table 9: The types of questions in the Motorway and the Copenhagen dataset. The question topics and their numbering used for the Copenhagen dataset can be seen in the appendix in [54].

Noise annoyance from motorways	Copenhagen dataset
Questions about different type of annoyance from traffic (Q1-Q2)	Questions about different type of annoyance from traffic (Q1-Q2)
Questions about noise (Q3-Q17)	Questions about noise (Q3-Q10)
	Questions about what to do to reduce traffic noise (Q11-Q14)
Questions about the residence (Q18-Q23)	Questions about the residence (Q15-Q24)
Questions about yourself (Q24-Q30)	Questions about yourself (Q25-Q40)

Generally, the "motorway" study has questions in a broader range of topics, such as visual influence and types of vehicles, while the "Copenhagen" study have many questions about the difference between indoor and outdoor and also include more questions on the health of respondents. The two studies have 13-15 questions in common (some a similar, but not identical), which is of interest with regards to the comparison of modelling output of the two later in this chapter. These common questions are listed in Table 10.

For the questions being in both surveys, the response options are not always identical, either because the first study indicated that a certain option was missing (based on comments in the 'Other' response free text field) or for other reasons unknown.

Table 10: Common questions in the motorway study and in the Copenhagen dataset.

Topic of Question	Motorway (question number)	Copenhagen dataset (question number)
Overall road annoyance	1	1
Causes to annoyance by road traffic	2	2
12-month Road traffic noise annoyance	3	3
Behaviour changes due to road noise + Activities affected from road traffic	9+11	7
Other frequent sources of noise	6	10
Type of outdoor areas (motorway) / Access to own garden (Copenhagen)	13	23
Activities affected from road traffic when outside	16	9
Acceptance of road noise at home	17	4
Type of bedroom windows	22	20
Type of living room windows	23	17
Birth year	24	25
Gender	25	26
Years in current dwelling	26	27
Noise sensitivity	28	33
Hearing acuity	27	35

7.1.3. Data reduction and imputation

Data reduction

For the two studies, data has been converted and reduced from the original dataset. The main task in the data reduction consisted of reducing response options to improve the modelling potential. The data reduction was done in two ways:

1. By removing response options that led to no additional information.
2. By grouping options.

As an example of this process is a question (8a) on the cause of annoyance: Vehicle type, see Figure 106. The question had 11 response options. Option 10 (Other) and 11 (Don't know) was removed (set to NA) because these options would not help understand the causes of annoyance. Furthermore, four options were grouped into a "Heavy vehicle" category and three other options into an "intrusive vehicles" category, as illustrated in Figure 1. This reduced the number of possible interactions and helped with interpretation of the model outcome. The process is described in more detail in [54].

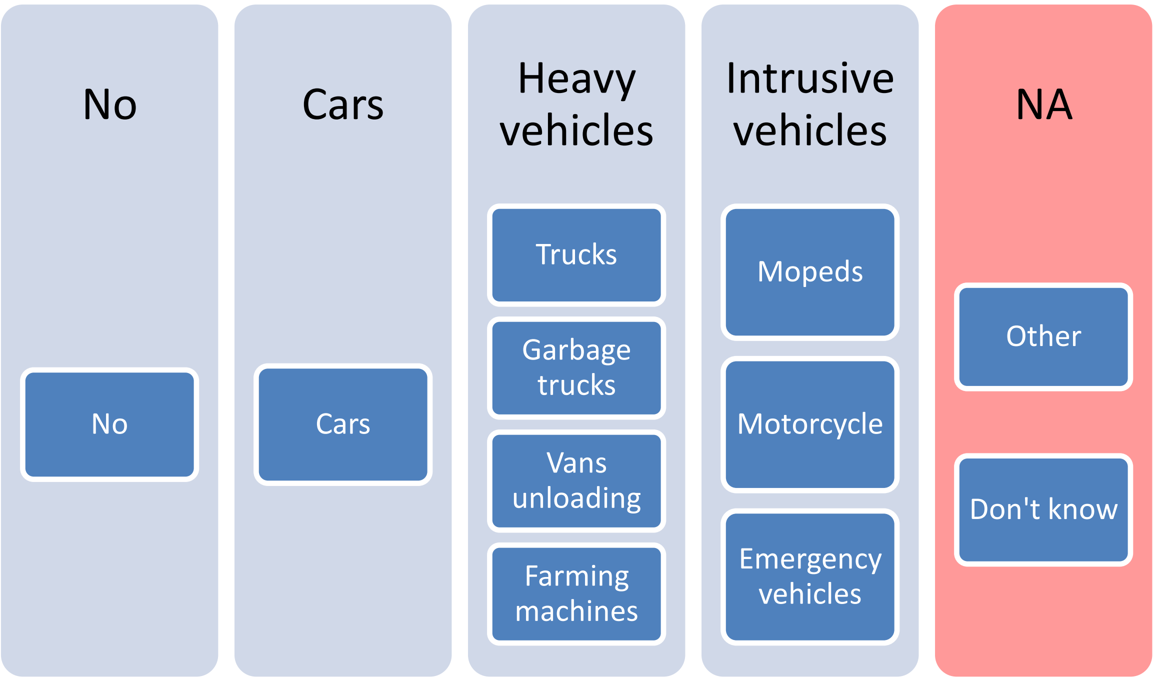


Figure 106: Example of reducing response options for the question on the vehicle type as cause of annoyance. Here reduced from 11 options to 4 options. Darker blue boxes are the original options, and the light blue are the reduced set of options. The light red box is the original options that was recoded as missing response.

Data imputation

In some cases, the person answering a questionnaire has not given answers to all the questions included. This results in missing data in some cases. For the Copenhagen dataset, missing data was observed to a degree where the number of responses was reduced from 2564 to 1731 (-32%) when removing rows having one or more columns with a missing value (“NA”), as is done automatically by the statistical software **R**, when calculating a regression model. This would be a waste of valuable data to throw away. In the motorway dataset, a few questions/columns also had too many missing data. These columns were removed, as the value of them in the model would be limited or even risk becoming biased if imputation was performed. This is a suited approach if the missing values are limited to a few columns in the dataset, but if they are spread across many columns, another approach is needed: *Imputation*. This technique inputs data according to a chosen strategy of which many exists.

The imputed data (ideally) adds no information but ensures that all rows are kept as the data basis for the model. For numerical data it is for instance common practice to replace missing values with the mean of the column (having responses to the same question). This, however, changes the distribution of the data, which can become problematic if too many values are missing. Another approach, used in this project, is to replace a missing value with a randomly sampled value from the same column. This approach has the advantage of being simple and working for both numerical (continuous and discrete) and categorical (multiple choice) data. More advanced methods exist but requires separate handling of each data type as well as each question’s response options. These methods are suited for datasets with a large proportion of missing data.

By applying this data imputation process, it has been possible to include nearly all responses, also the ones with missing data, in the analysis and modelling work performed.

7.1.4. Modelling type and process

Dose response curves and logistic transformations

The results from the surveys used may be described as dose-response curves between the self-reported noise annoyance, and L_{den}. The dose-response curves can be using logistic regression (see Section 3.1.2).

A constructed example of a dose response curve for the average annoyance according to logit transformation is shown in Figure 107.

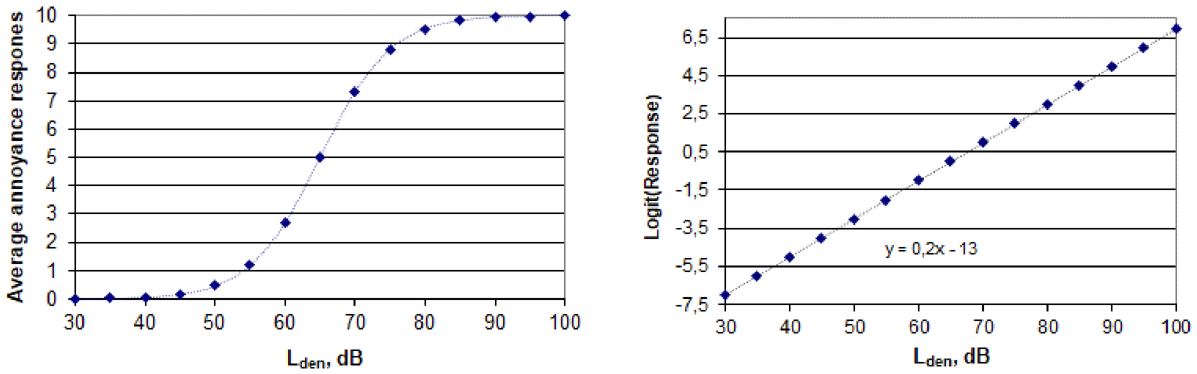


Figure 107: An ideal constructed example (with averaged annoyance on the 0 to 10 scale in 5 dB classes). To the left the average response as function of L_{den}.. To the right the same data, but the response is transformed with the logit transformation.

By transforming the annoyance response with the logit function (see below), the dose response curve can be linearized, which makes it easy to find the constants for the curve.

The model used in this analysis is a general multiple regression model with a logit-transformation of the raw data for the response variable, i.e. the answers to the 12-month average noise annoyance at home according to ISO TS 15 666 [45] as used in the questionnaires. For this question respondents stated their answer on a 11-point numerical scale ranging from 0 to 10 and on a 5-point verbal scale ranging from “Not at all annoyed” to “extremely annoyed”. Only the 11-point data was used here, having the highest resolution of annoyance.

The model is based directly on the raw data for the annoyance responses, which requires some considerations and choices that are not needed when operating on the averaged responses.

The logit-function limits predictions to a fixed range, such that predictions cannot exceed the minimum or maximum annoyance (for further details see [54]).

Regression model

The model consists of a number of terms that describe the effect of variables that affects the annoyance response. A more detailed description of the model and the expressions used can be seen in [54]. Initially the model included all questions from the questionnaire and was then optimized by removing terms. This was done to obtain a model which only have relevant terms that can explain the systematic variation in the data and remove terms with no or only spurious contributions. In this project, the reduction was done in two steps:

1. The number of terms was reduced using the AIC criterion (Akaike Information Criterion) to only include terms, which statistically improve the degree of explained variance.
2. Secondly, all two-way interaction terms of the surviving terms were added and again the AIC criterion used to reduce the model to one having terms and interactions that contributes significantly to the degree of explained variance.

The interactions terms are of especially importance as they are rarely reported in the literature and allows estimation of the combined influence of moderators for a given situation (effect sizes from different moderators cannot simply be added together).

The results from the model are related to the average response on the 0-10 annoyance scale. Often the results from surveys are presented as e.g. the percentage of highly annoyed (%HA), i.e. the percentage of respondents that have answered in the categories 8, 9 and 10 on the annoyance scale.

In the appendix of [54], the relations between the average annoyance response on the 0-10 scale and the percentage of Highly Annoyed (%HA), Annoyed (%A) and Little Annoyed (%LA) can be found. It can be seen that e.g. an average annoyance response of 3 corresponds to around 10% Highly annoyed.

In the following two sections general linear regression models were made on the basis of one dataset per model. This approach was chosen, rather making one model on a combination of the two datasets, as it allows an evaluation of the appropriateness of the method and the datasets. Assuming that the surveys are both general in nature, the resulting models will be similar, if the method is stable. All common factors in the two models can be considered more general and possibly suited for a broader context than that of the individual datasets. This comparison of the models is the topic of Section 5.4.

7.2. Result from the Danish Motorway dataset

The obtained regression model after removing insignificant terms has a high degree of explained variance (adjusted R^2 = 77%) and fulfils all modelling assumptions i.e., the model can be trusted both regarding noise annoyance predictions and degree of influence from moderators. Although it is still not able to fully describe the causes of variance in response.

In Figure 109 the correspondence between annoyance responses ("Annoyance") and annoyance predicted by the model ("Predicted annoyance") is shown. Since the annoyance responses were discrete while the predictions are continuous, model predictions were added as a new column to the dataset, then the dataset was split into subset for each annoyance response, and finally the mean estimate and 95% confidence intervals were calculated on the annoyance predictions within each subset.

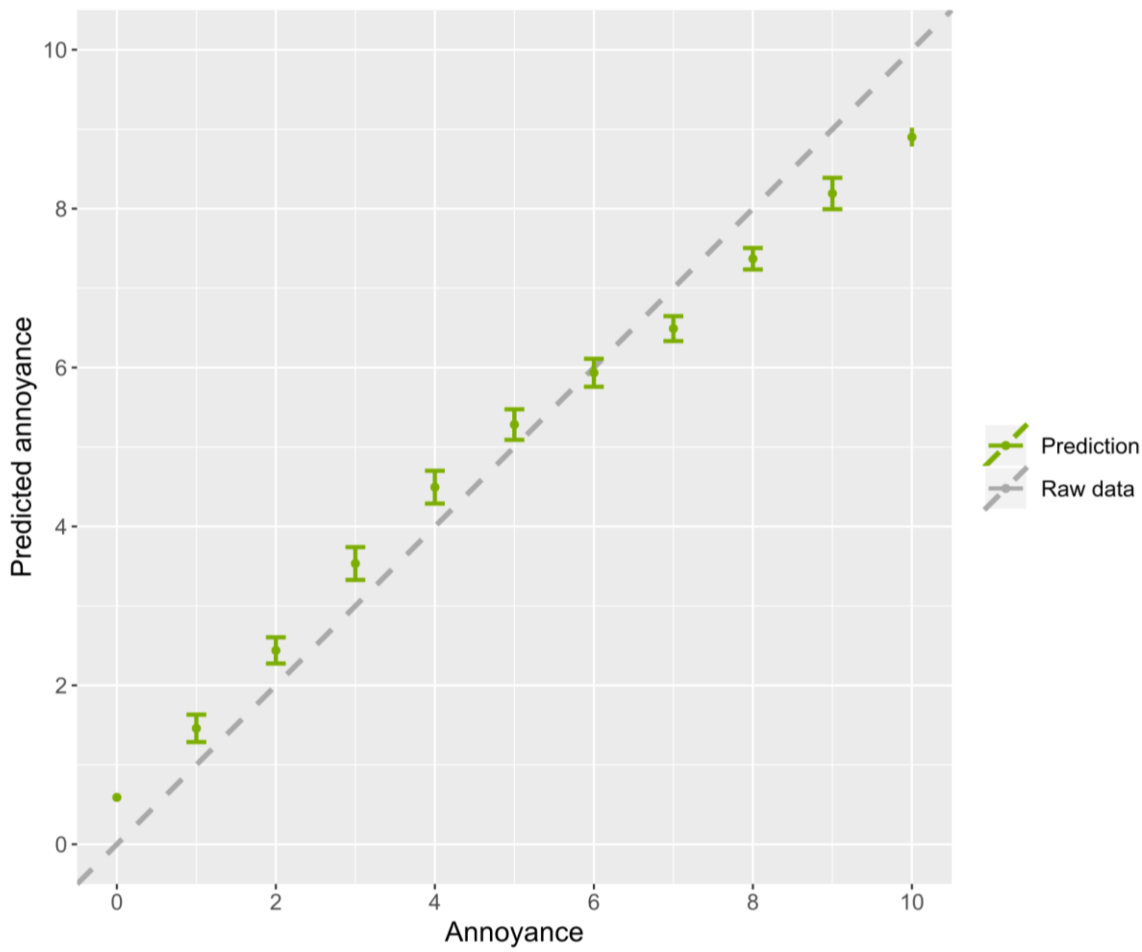


Figure 108: Annoyance (raw data) vs. Predicted annoyance. Mean value estimates with 95% confidence intervals. For the Motorway dataset subset.

The figure generally shows a good correspondence, but also a curvature causing a slight over-estimating at lower annoyance levels and a slight under-estimation at higher annoyance levels.

The model contains 15 main moderators as well as 11 interaction terms between combined variables. They are listed in Table 11 and Table 12 respectively. Among the main moderators are both identified moderators found in the FAMOS literature study [2] as well as other moderators.

For a linear regression model, the coefficients of the model (i.e., the multipliers that describe the influence of the moderators), would be linearly linked to the response variable, annoyance, but for a model with a non-linear transformation, they are not. Consequently, it is simple to report the relative importance of terms, but more complicated to report the influence as e.g. absolute change in annoyance or equivalent L_{den} shift. To simplify the task, here, the F-value is reported (see Table 11 and Table 12), which estimates the relative variance accounted for by the variables, i.e., the systematic variation. The F-value is tested for significance in an F-test (Wald test) against a model with only the intercept. Furthermore, some examples are given, which quantifies the effect for the given context. A higher F-value corresponds to a larger proportion of variance described by the term. First, the relative influence is discussed.

Surprisingly, the responses to the question *Acceptance of road noise level at home*, has the highest contribution with an F-value of 5.400, i.e., more than twice that of the second largest term, L_{den}, with 2.439. The fourth most important variable, *Causes of annoyance by road traffic*, is the first moderator which road authorities can influence. The reduced response options from this question (see detail in [54]) includes:

- Feeling unsafe in traffic

- Noise from traffic
- Vibration from traffic
- Air pollution or odour

Among the remaining moderators, which might be influenced by road authorities, is *Annoyance cause: Vehicle type* from the example Figure 106, where the types of vehicles might be restricted, as well as *Time of day with peak annoyance*.

While the interactions are relatively small compared with the largest main effects, sorted by F-value, interactions, are in place 9, 11, 15, 17, 19-22, 24-26, among the full list of terms (again see Table 11 and Table 12). Meaning that 7 main effects are smaller than the largest interaction effect: *Acceptance of road noise at home x Access to a quiet side*. This interaction predicts that if a participant answers “No” or “Don’t know”, their annoyance level will be higher than if they answer “Yes”.

The largest main moderator, Acceptance of road noise level at home, also has multiple significant interactions. Specifically, with Access to a quiet side, Causes of annoyance by road traffic, Types of outdoor areas available, and Annoyance cause: Vehicle type, all of which seems like logical interactions.

Another interesting set of interactions is the two interactions with L_{den}, *Types of outdoor areas available* and *Orientation of outdoor areas*, which can be seen as correction factors in the cases where L_{den} is not an accurate predictor, namely when outside.

Note: Besides the main question on noise annoyance also Q2 “*Causes of annoyance by road*” contains a question on whether noise is a source of annoyance. This is the main driver of the results in Q2 so an alternative analysis to the one shown in Table 12 but without Q2 has been made. In this analysis the question “*Motorway visible*” appears to be significant with an F-value of 253, i.e. a larger impact than access to a quiet side.

Table 11: Motorway dataset. Regression model main effects. Sorted by F-value.

Question ID	Main variables	DF	Sum Sq	Mean Sq	F-value	p-value	Significance
17	Acceptance of road noise at home	1	2491.8	2491.8	5400.0	0.000	***
L_{den}	L_{den}	1	1125.3	1125.3	2438.7	0.000	***
18	Access to a quiet side	2	211.5	105.8	229.2	0.000	***
2	Causes of annoyance by road traffic	15	1014.9	67.7	146.6	0.000	***
7	Time of day with peak annoyance	7	461.7	66.0	142.9	0.000	***
28	Noise sensitivity	1	45.9	45.9	99.6	0.000	***
9	Behaviour change due to road noise	4	107.6	26.9	58.3	0.000	***
16b	Behaviour change due to road noise, when outside	1	14.5	14.5	31.3	0.000	***
8a	Annoyance cause: Vehicle type	8	87.1	10.9	23.6	0.000	***
16a	Activities affected from road traffic when outside	7	40.2	5.7	12.5	0.000	***
13	Types of outdoor areas available	1	5.4	5.4	11.7	0.001	***
11	Indoor activities affected from road traffic	7	36.5	5.2	11.3	0.000	***
14	Orientation of outdoor areas	3	10.1	3.4	7.3	0.000	***
6	Other frequent sources of noise	1	3.3	3.3	7.2	0.007	**
22	Type of bedroom windows	1	1.5	1.5	3.2	0.075	.

Table 12: Motorway dataset. Regression model interaction effects. Sorted by F-value. The notation xx:yy in the far left column describes the interaction term between xx and yy.

Question ID	Interaction effect IDs	DF	Sum Sq	Mean Sq	F-value	p-value	Significance
17:18	Acceptance of road noise at home Access to a quiet side	2	26.9	13.4	29.1	0.000	***
12:22	Main road noise source visual Type of bedroom windows	1	9.7	9.7	21.1	0.000	***
L_{den}: 13	L_{den} Types of outdoor areas available	1	3.5	3.5	7.5	0.006	**
17:2	Acceptance of road noise at home Causes of annoyance by road traffic (Scale)	13	43.5	3.3	7.3	0.000	***
17:13	Acceptance of road noise at home Types of outdoor areas available	1	2.3	2.3	5.0	0.026	*
18:13	Access to a quiet side Types of outdoor areas available	2	4.5	2.3	4.9	0.007	**
17:8a	Acceptance of road noise at home Annoyance cause: Vehicle type	8	18.1	2.3	4.9	0.000	***
6:7	Other frequent sources of noise Time of day with peak annoyance	7	14.9	2.1	4.6	0.000	***
18:22	Access to a quiet side Type of bedroom windows	2	2.6	1.3	2.8	0.058	.
7:8a	Time of day with peak annoyance Annoyance cause: Vehicle type	53	69.3	1.3	2.8	0.000	***
Lden: 14	L_{den} Orientation of outdoor areas	3	3.5	1.2	2.5	0.055	.

7.2.1. Main effect dose-response curves (Motorway dataset)

All plots in this section have the response variable, 12-month average road traffic annoyance on the 0-10 scale, on the y-axis and a main effect on the x-axis, e.g. L_{den}. The plots show the estimated mean with 95%-confidence intervals of the raw responses ("Raw data") in the motorway dataset and the model prediction ("Prediction"), with 95%-confidence intervals. At all points on the curve where the confidence intervals of the averaged raw data and the prediction overlaps, the model estimates the effect as well as can be done with the uncertainty of the data. Note, that this type of plot can only be made for the few moderators with a numerical response type and plots were made purely for moderators contributing to the model (i.e. being in Table 11 and Table 12).

Figure 109 shows the influence of the moderator *acceptance of road noise level at home* on annoyance. The prediction is based on the same dataset, as the prediction model, which implies that the curve might look different for different datasets, with different distributions and combinations of the 16 moderators included in the model[11]. The figure shows a large shift in the predicted annoyance from approx. 1 at high acceptance to approx. 8.3 at low acceptance (1.5) in relation to the acceptance of road noise at home. Interactions terms including this moderator (such as 17:18 in Table 12) might, however, reduce the effect for the individual.

One may wonder whether the L_{den} is the main driver behind the acceptance, i.e. that persons living at low noise levels have a higher score on the acceptance scale. In [54] it can be seen that, that is not the case.

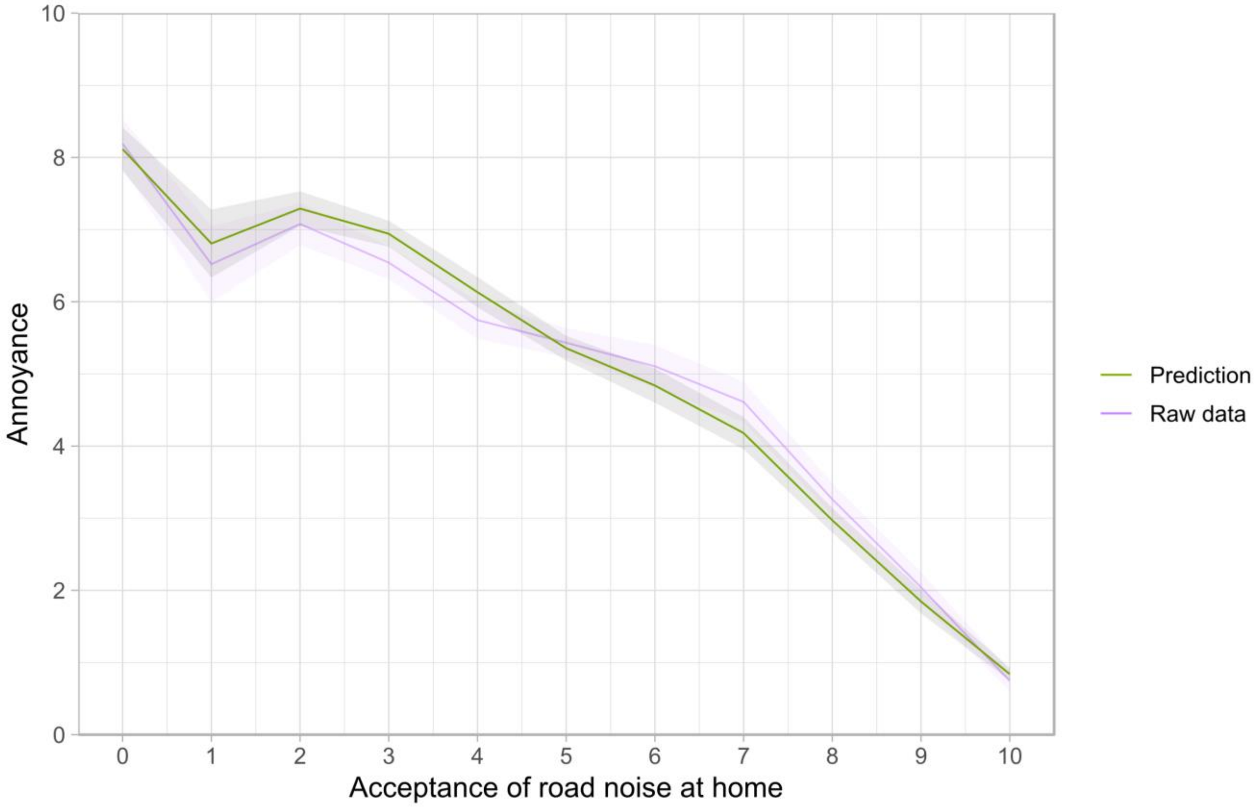


Figure 109: Prediction of annoyance from acceptance of road noise level. Main effect. With 95% confidence intervals. From the Motorway dataset.

[11] *Main road noise source visual* is included as an interaction effect only, but not a main effect, which is why the number of moderators (16) is larger than the number of main effects (15) in the model.

For Figure 110, the effect of the variable, L_{den}, on annoyance spans the range 2.8 to 8.1, increasing with the noise level as expected. The assumed s-shaped nature of the dose-response curve has an almost linear relationship within L_{den} range 53-67 dB. The original dataset spans the range from 48 to 77 dB, and the prediction was kept within a similar interval to avoid extrapolation outside the valid range of the model.

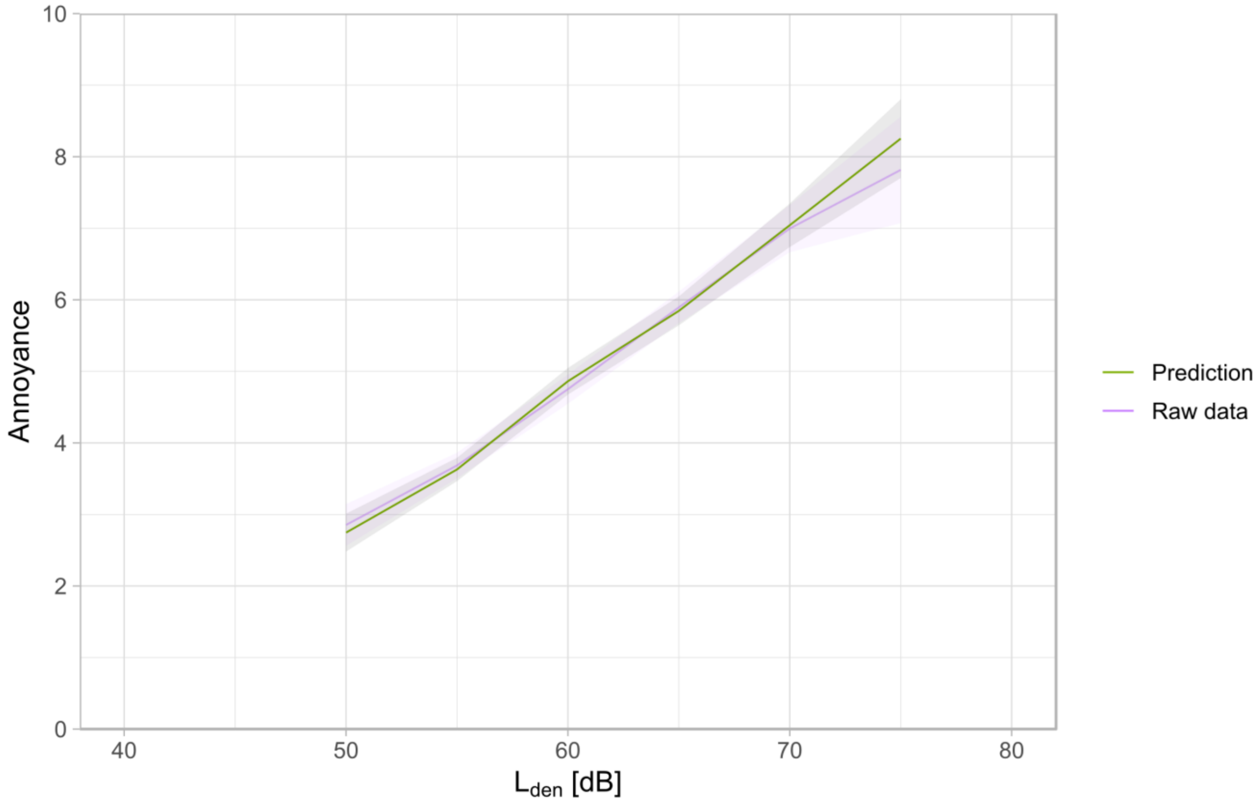


Figure 110: Prediction of annoyance from L_{den}. Main effect. With 95% confidence intervals. From the Motorway dataset.

7.2.2. Relation to FAMOS literature study

The literature study, documented in Chapter 5, led to four non-acoustic moderators of main focus listed in the columns of Figure 111. These were selected partly because they had a large effect on annoyance: up to 6 dB (Access to quiet side), 10 dB (Visual/greenery), and 15 dB (Attitudes) in annoyance equivalent noise level shift respectively for the first three columns. While it is currently unknown how large the effect is of the neighbourhood soundscape, the effect has been reported, and might be a moderator that road authorities and municipalities can influence. The smaller boxes in Figure 111 indicate the moderators included in the present dataset, with blue indicating a moderator included in the regression model and red indication that the moderator was excluded from the model, either because it was insignificant or had a too small effect size (F-value). The up to 15 dB reported for "*Attitude towards authorities and road owners*", were based on direct questions on this subject, while "*Acceptance of road noise level at home*" is only assumed indirectly related here. In all likelihood many underlying moderators (objective and subject) may influence acceptance of road noise level at home, but general trust in- or attitude towards authorities may be one of these.

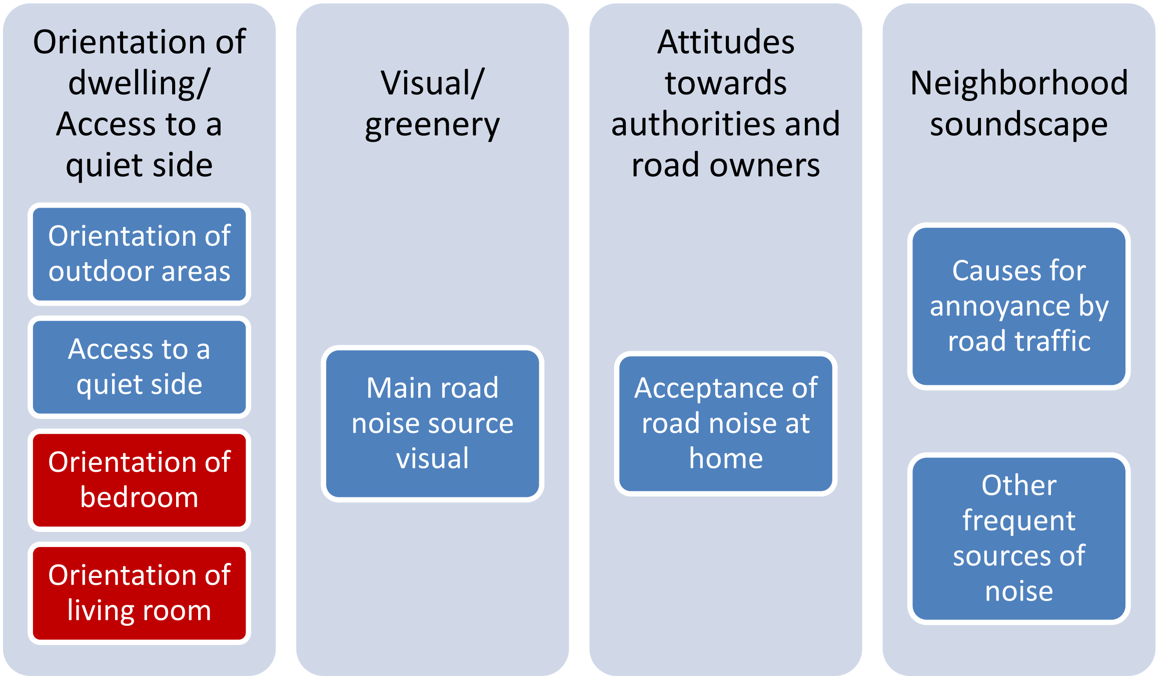


Figure 111: The moderators of focus in the literature study in the light blue columns with boxes of questions from the Motorway dataset. Blue boxes are questions included in the model, and red boxes are questions excluded from the model.

In the following three subsections, the influence of these moderators (*attitude towards authorities… excluded*[12]) are exemplified. The plots are based on the full prediction model influence all main- and interaction terms. Predictions are based on the original dataset, which is then split up in groups based on the moderator options in question and subgroups of 5-dB L_{den} bins. Notice that differences between options, will include all differences between these groups and subgroups in the dataset. The assumption is thus, that subgroups are balanced on all other factors to a degree where the moderator under investigation will be the main driver of the differences.

Notice that if a subset of data for a given combination of the 5-dB L_{den} bin and the moderator did not have more than 20 observations in the dataset, which the prediction was based on, the prediction was removed from the plots in these subsections. This was done to avoid predictions based on too few observations that would not be representative of the general population and could lead to confusing in interpretation of the plots.

Effect size of Orientation of dwelling / Access to a quiet side

In Figure 112, the predicted influence of orientation of outdoor areas in relation to road traffic annoyance (Question 14) as a function of L_{den} is shown. Focusing on the green and purple lines first, the effect of having access to an outdoor area away from the motorway noise sources is predicted to reduce annoyance with approximately two steps on the annoyance scale in the range from 50 dB to 70 dB. Looking at the case, where a citizen has both an outdoor area facing towards the main noise source and away from one (turquoise line), this reduction is (surprisingly) completely gone.

[12] Plot of the influence of "*Acceptance of road noise at home*" excluded as response rating were on a 0-10 scale, i.e., having too many levels to illustrate trends in plot in a meaningful way due to too few datapoints.

In Figure 114, the predicted influence of access to a quiet side (Question 18) in relation to the road traffic annoyance as a function of L_{den} is shown. Access to a quiet side is also predicted to reduce annoyance by approx. 2 on the annoyance scale independent of the L_{den} noise level.

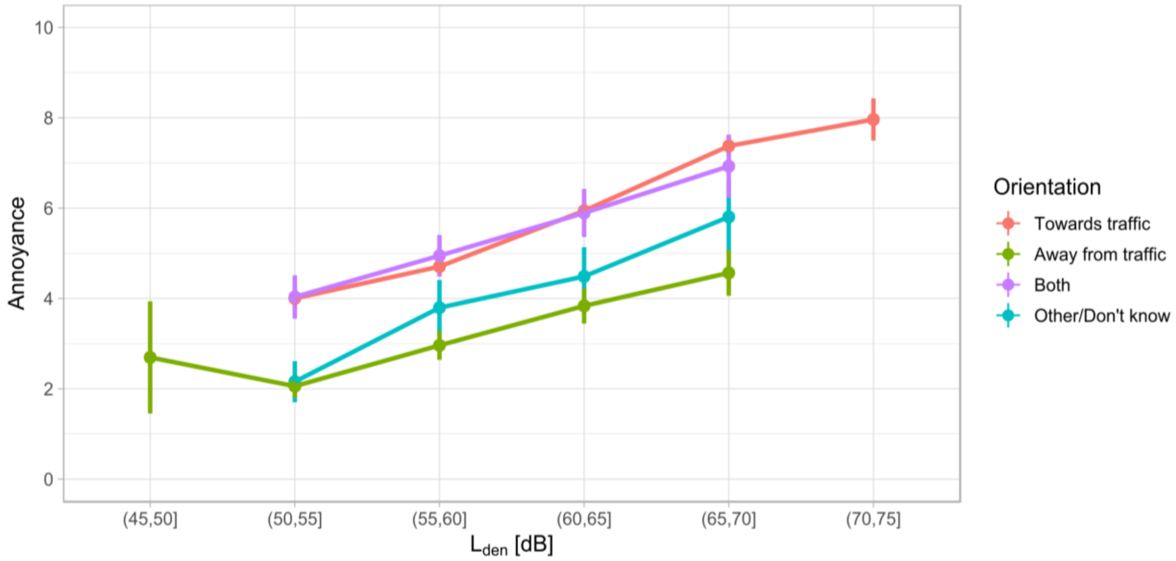


*Figure 112: Prediction of Annoyance as a function of L_{den} split into groups of response options of the moderator **Orientation of outdoor areas** . Vertical lines are 95% confidence intervals. Notice that the question covered garden, courtyard, and balcony, which is why participants can answer outdoor areas both pointing towards the main road noise source and away from it.*

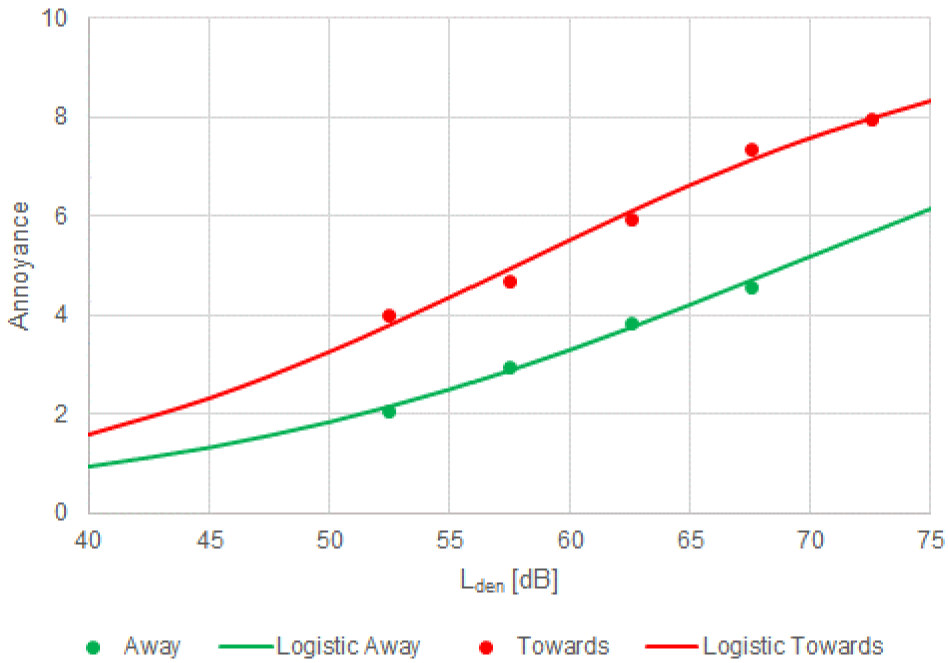


Figure 113: Outdoor areas away from or towards the road. Prediction of Annoyance as a function of L_{den} for persons with outdoor areas away from the road (green) and towards the road (red). The points are based on data from the model/Figure 112. The curves are logistic fits to the data.

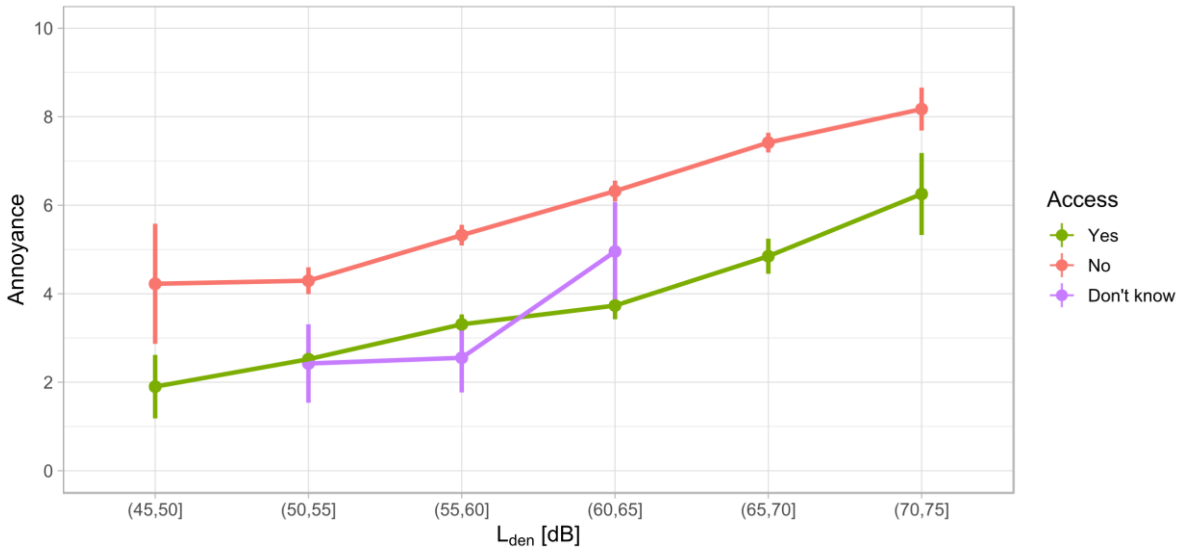


*Figure 114: Prediction of Annoyance as a function of L_{den} split into groups of response options of the moderator **Access to a quiet side**. Vertical lines are 95% confidence intervals.*

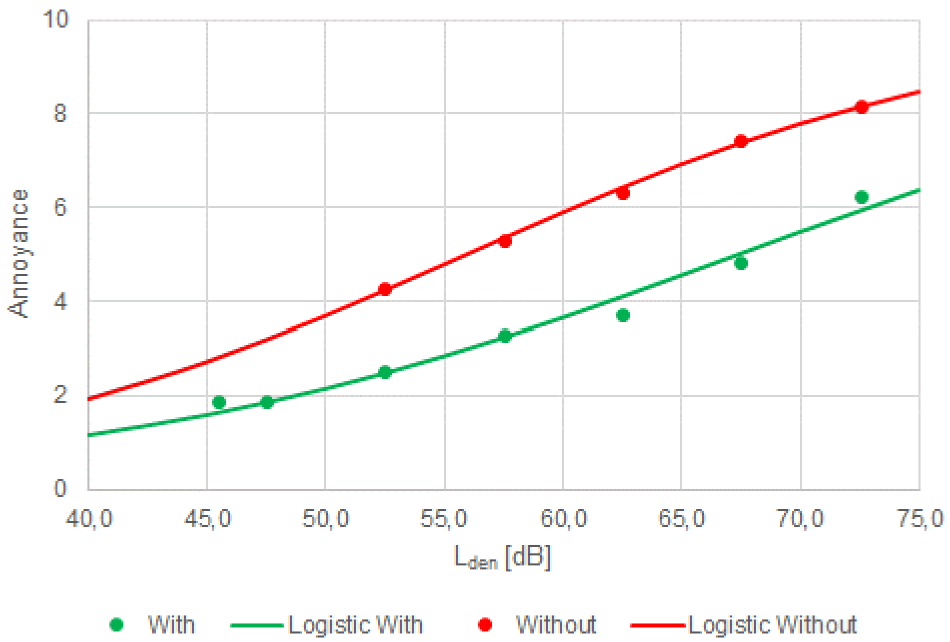


Figure 115: With or without a quiet side. Prediction of Annoyance as a function of L_{den} for persons with access to a quiet side (green) and persons without access to a quiet side (red). The points are based on data from the model/Figure 114. The curves are logistic fits to the data.

Effect size of Visual road

In Figure 116, is a prediction of the interaction between being able to see the road being the primary noise source and having special windows installed in the bedroom; An interaction found significant in the model, where the visual effect in this analysis was not significant on its own (see Table 12 and the note below). The figure can be trusted between 50 and 75 dB. The trend is that seeing the road increases annoyance by 1 to 2 points on the annoyance scale and that having special windows increasing annoyance further. Both effects are too small on their own to be significant, but combined, the effect of seeing the road / noise source while having special windows with better insolation increasing annoyance sufficiently (0.5-2 points on the annoyance scale) becomes a significant effect compared to the opposite situation. It seems counterintuitive that special windows with better sound insolation increased annoyance, but this has been found in other studies as well (see Figure 11). One might speculate as to whether the extra insulation in (expensive) special windows is disappointing/unsatisfactory. However, not many people having special windows participated in the study (292 with, 3349 without), which increases the uncertainty of this hypothesis.

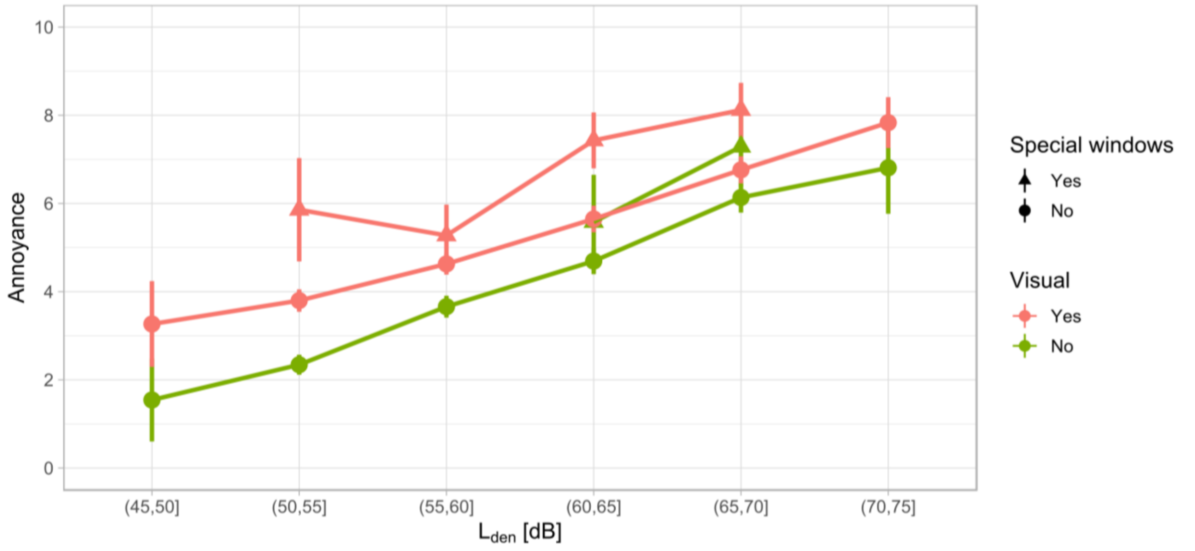


Figure 116: Prediction of Annoyance as a function of L_{den} split into groups of response options of the interaction ***Main road noise source visual*** *and* ***Special bedroom windows*** *. Vertical lines are 95% confidence intervals.*

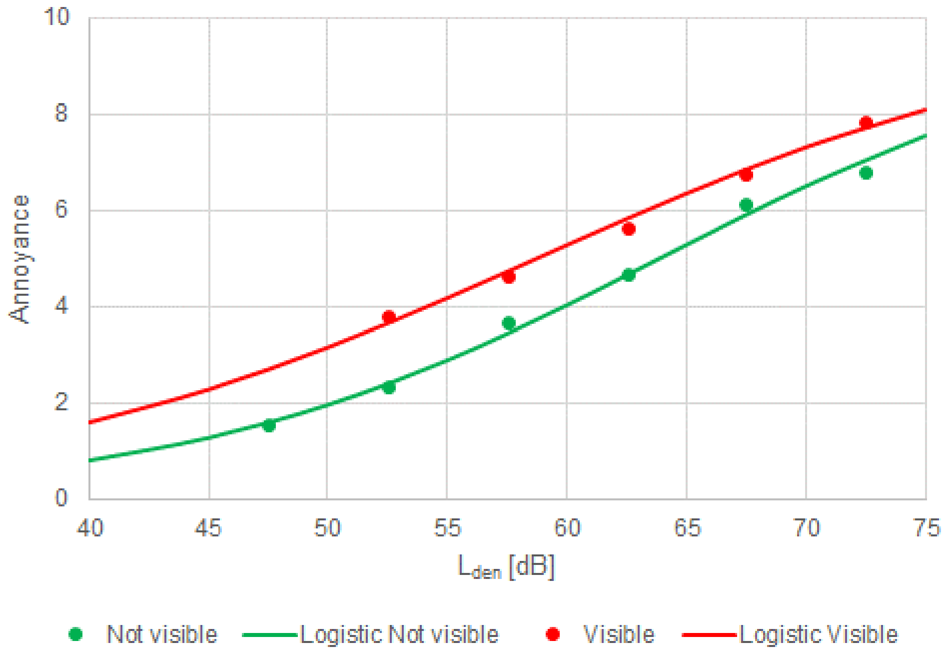


Figure 117: Road not visible or visible from home. Prediction of Annoyance as a function of L_{den} for persons where the road is not visible from their home (green) and persons where the road is visible (red). The points are based on data from the model/Figure 116. Datapoints with less than 20 respondents are omitted. The curves are logistic fits to the data.

Effect size of Neighbourhood soundscape

In Figure 118 the influence of the moderator on causes of annoyance from road traffic is predicted in the local neighbourhood. The coded option list included: Feeling unsafe in traffic, Noise from traffic, Vibration from traffic, and Air pollution or odour, which leads to 16 combinations in total, but in Figure 118, four of these are plotted: 1) No specific causes, 2) feeling unsafe, 3) noise, 4) feeling unsafe and noise. Most noticeable, the feeling of being unsafe leads to a predicted small increase in annoyance (1-1.5 points on the annoyance scale), while noise in the local neighbourhood leads to a very significant increase (3.5-5 points on the annoyance scale) and dominates if both are listed as reasons. Note, that this change is likely too big to be caused by this moderator and its interactions alone. It is likely that the prediction basis in unbalanced in terms of other moderators, exaggerating the increase.

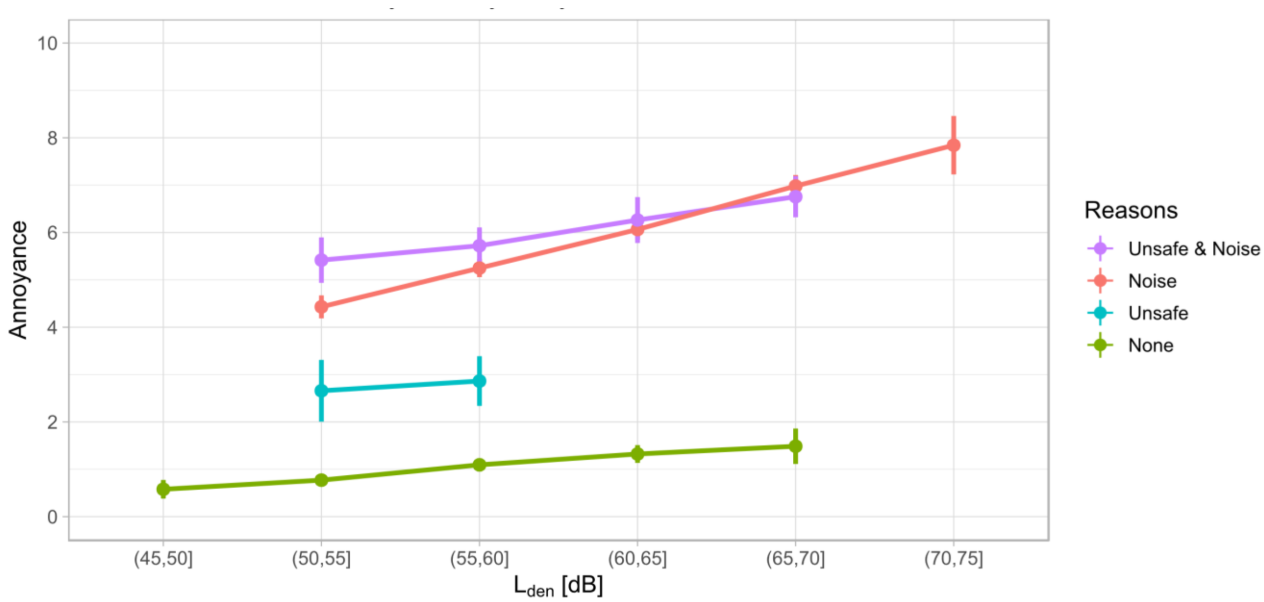


*Figure 118: Prediction of Annoyance as a function of L_{den} split into groups of response options of the moderator **Causes of annoyance by traffic** . Vertical lines are 95% confidence intervals.*

Annoyance equivalent noise levels shifts

Looking at the curve of Annoyance vs. L_{den} in Figure 110 at the range 55-65 dB, the shift in the predicted annoyance response is 2.37. This can be used as an approximate slope for estimating annoyance equivalent level shifts for each moderator. This is done in Table 13 below. The shift of average annoyance is the difference in mean values depending on the moderator in question. Since the difference change with L_{den}, the difference is described with an interval. These values can be estimated by looking at the figures in the previous pages. Note, that these equivalent noise level shifts are not additive, i.e. cannot be summed. Please keep in mind that this table inherits the assumption of the original plots, namely that subgroups are balanced on all other factors to a degree where the moderator under investigation will be the main driver of the differences.

Table 13: Annoyance equivalent level changes for the motorway dataset.

	Moderator	**Shift of average annoyance**	**Annoyance equivalent noise level shift, dB**
Q14	Orientation of outdoor areas	2.0-2.8	8.4-11.8
Q18	Access to a quiet side	1.9-2.8	8.0-11.8
Q12 **Q22**	Main road noise source visual Special bedroom windows	1.0-3.5	4.2-14.8
Q2	Causes of annoyance by traffic	2.0-5.7	8.4-24.1

7.3. Results from the Copenhagen dataset

The obtained regression model for the Copenhagen dataset has a high degree of explained variance (adjusted R^2 = 70.8%) and fulfils all modelling assumptions [54], i.e., the model can be trusted both in terms of noise annoyance predictions and degree of influence from moderators.

In Figure 119 the correspondence between annoyance responses ("Annoyance") and annoyance predicted by the model ("Predicted annoyance") is shown. Since the annoyance responses were discrete while the predictions are continuous, model predictions were first added as a new column to the dataset, then the dataset was split into subset for each annoyance response, and finally the mean estimate and 95% confidence intervals were calculated on the annoyance predictions within each response subset.

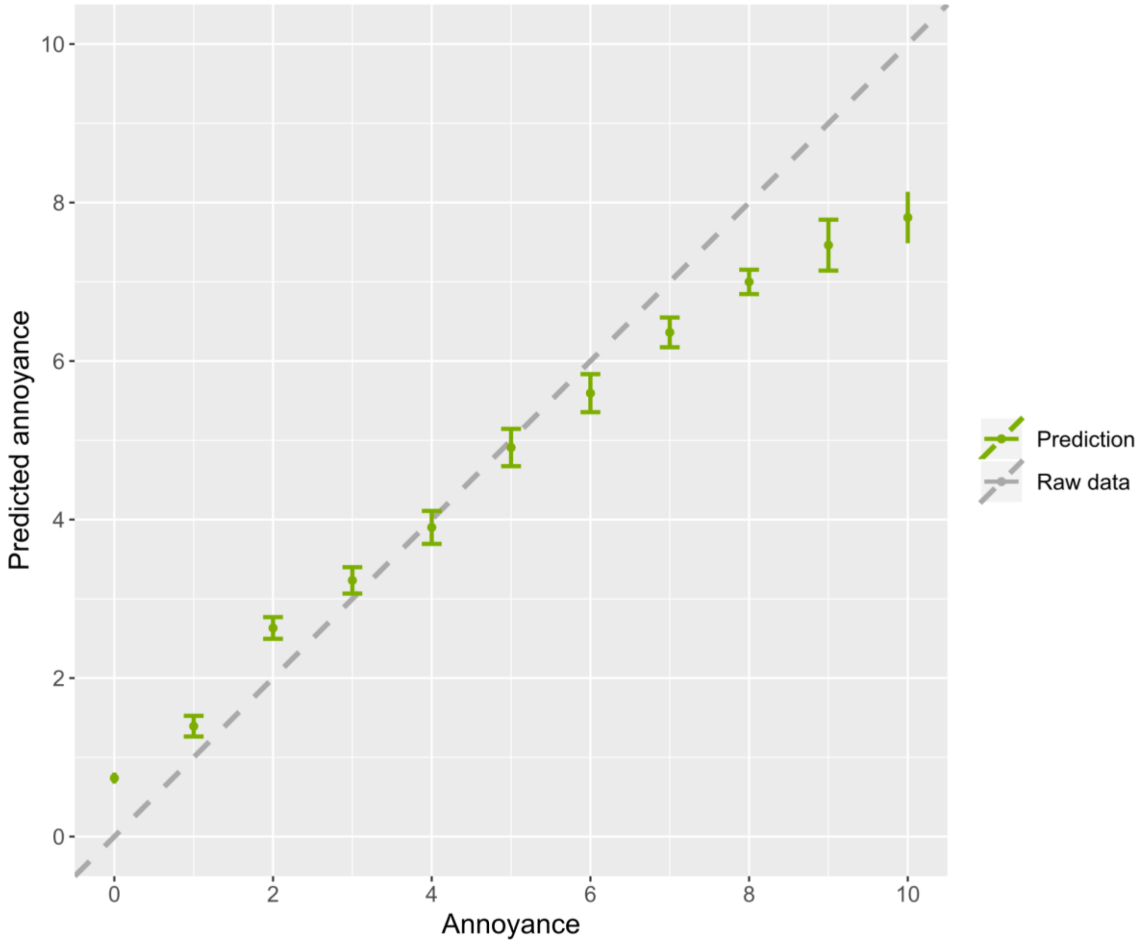


Figure 119: Annoyance (grey curve) vs. Predicted annoyance (green). Mean value estimates with 95% confidence intervals. For the Copenhagen dataset.

The figure generally shows a good correspondence, but also the same curvature as for the first model for the Motorway dataset causing a slight over-estimating at lower annoyance levels and a slight under-estimation at higher annoyance levels.

The model includes nine main variables (listed in Table 14) and five interaction effects (listed in Table 15).

Table 14: Copenhagen dataset. Regression model main effects. Sorted by F-value.

Question ID	Main variables	DF	Sum Sq	Mean Sq	F-value	p-value	Signif.
L_{den}	L_{den}	1	711.9	711.9	1571.7	$2.86e^{-267}$	***
04	Acceptance of road noise at home (Yes/No)	1	519.2	519.2	1146.2	$3.02e^{-207}$	***
02	Causes of annoyance by road traffic	13	1296.0	99.7	220.1	0	***
33	Noise sensitivity	1	73.8	73.8	163.0	$3.31e^{-36}$	***
07	Indoor activities affected from road traffic	15	111.5	7.4	16.4	$1.20e^{-41}$	***
11	Noise actions	6	35.1	5.9	12.9	$1.93e^{-14}$	***
30	Windows living room open summer	1	4.6	4.6	10.2	0.001	***
23	Access to own garden	1	4.1	4.1	9.1	0.003	**
31	Windows living room open winter	1	1.5	1.5	3.2	0.074	*

Table 15: Copenhagen dataset. Regression model interaction effects. Sorted by F-value. The notation xx:yy describes the interaction term between xx and yy.

Question ID	Main effects	DF	Sum Sq	Mean Sq	F-value	p-value	Signif.
04:33	Acceptance of road noise at home (Yes/No) Noise sensitivity	1	2.9	2.9	6.3	0.012	*
L_{den}:04	L_{den} Acceptance of road noise at home (Yes/No)	1	2.7	2.7	6.0	0.014	*
29:33	Household young kids Noise sensitivity	1	2.5	2.5	5.6	0.018	*
L_{den}:29	L_{den} Household young kids	1	1.3	1.3	2.9	0.091	.
02:33	Causes of annoyance by road traffic Noise sensitivity	12	15.4	1.3	2.8	0.001	***

7.3.1. Main effect dose-response curves

All plots in this section have the response variable, 12-month average road traffic annoyance on the 0-10 scale, on the y-axis and a main effect on the x-axis, e.g., L_{den}. The plots show the estimated mean with 95%-confidence intervals of the raw responses (“Raw data”) in the Copenhagen dataset and the model prediction (“Prediction”), with 95%-confidence intervals. At all points on the curve where the confidence intervals of the averaged raw data and the confidence intervals of the prediction overlaps, the model estimates the effect as good as possible with the uncertainty of the data. Note, that this type of plot can only be made for the few moderators with a numerical response type and plots were made purely for moderators contributing to the model (i.e. being in Table 14 or Table 15).

The relationship between the variable L_{den} and annoyance is plotted in Figure 120. The shaded areas are 95% confidence intervals calculated for each 5-dB bin starting with the 40 dB bin being an average of the range 37.5-42.5. The effect of the variable, L_{den}, on annoyance spans the range 1.4 to 5.9, increasing with the noise level as expected. The original dataset spans the range from 38 to 73 dB, and the prediction was kept within a similar interval to avoid extrapolation outside the valid range of the model. The expansion of the confidence intervals at 40 dB at 75 dB is a consequence of the dataset including a limited number of datapoints within these two 5-dB bins.

It can be seen that the slope of the linear part of the curve is 0.2 meaning that one step on the annoyance scale corresponds to a noise level difference of 5 dB.

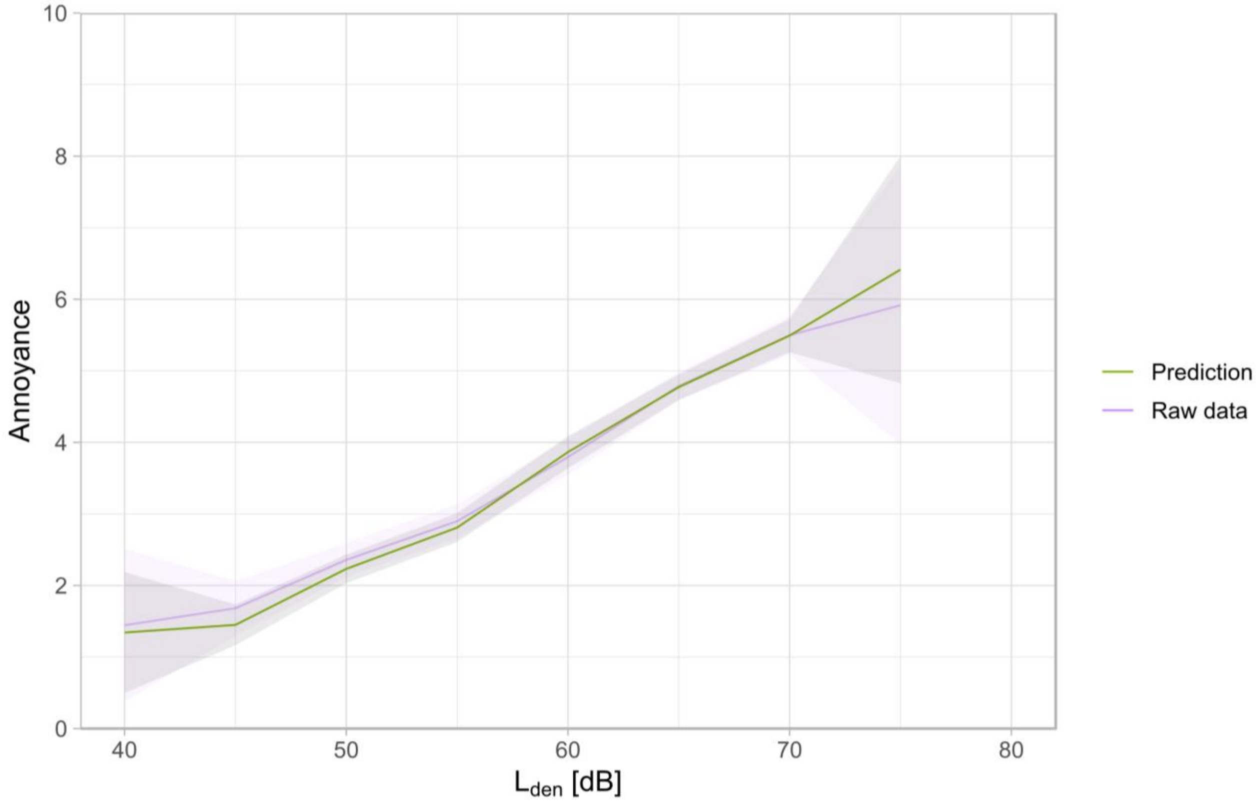


Figure 120: Prediction of annoyance from ***L_{den}*** *in 5-dB bins. Main effect. With 95% confidence intervals. From the Copenhagen dataset.*

By comparison with Figure 110 it can be seen that the annoyance from motorways is 1 higher on the annoyance scale than the annoyance for urban roads. This corresponds to an annoyance equivalent noise level shift of 5 dB. According to this comparison people living along motorways are more annoyed by the same noise level than people living along urban roads. The same result was found in [57].

The relationship between the moderator Noise sensitivity and annoyance is plotted in Figure 121. The shaded areas are 95% confidence intervals calculated for each step on the sensitivity scale with the 1 bin being an average of the range -0.5 to +0.5. The effect of the moderator, Noise sensitivity, on annoyance spans the range 1.5 to 7.3, the annoyance increasing with noise sensitivity as expected. The original dataset spans the full-scale range. The expansion of the confidence intervals above 6 on the noise sensitivity scale is a consequence of the dataset including a decreasing number of datapoints at higher noise sensitivity levels.

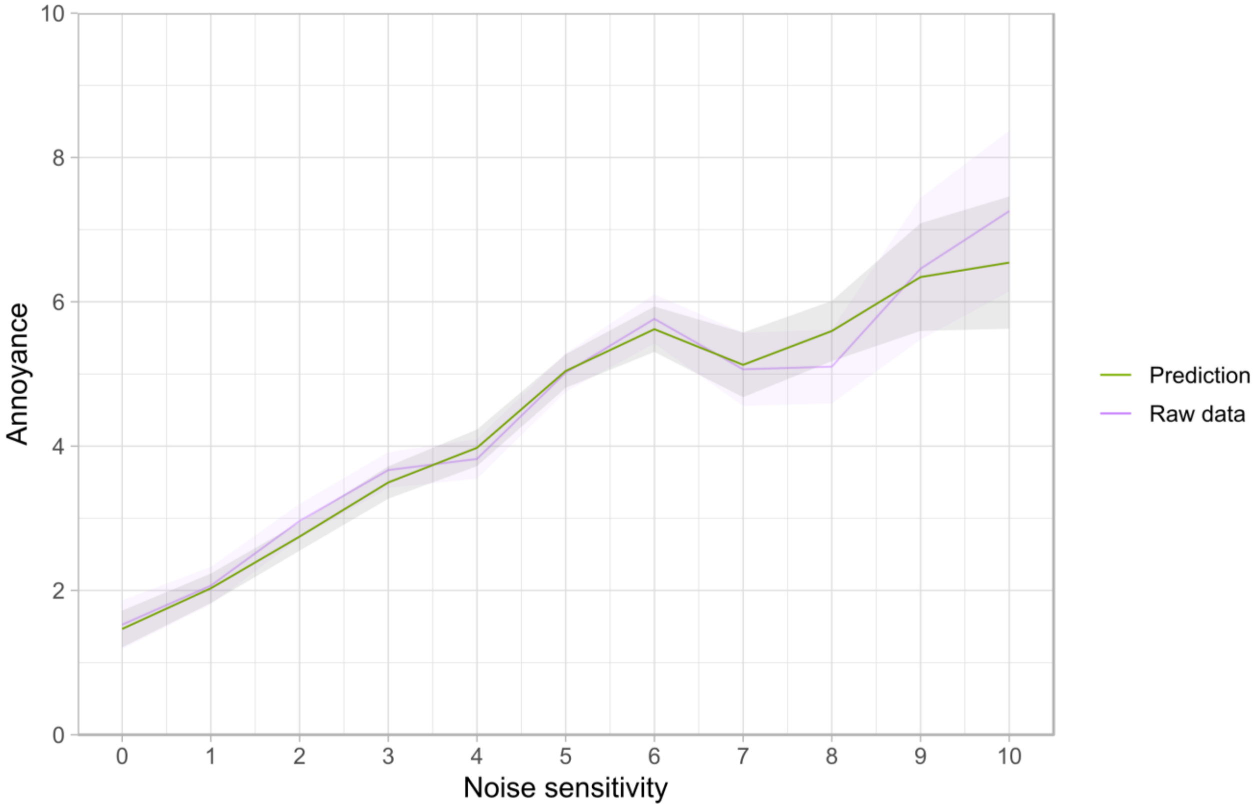


*Figure 121: Prediction of annoyance from **Noise sensitivity**. Main effect. With 95% confidence intervals. From the Copenhagen dataset.*

One may wonder whether the L_{den} is the main driver behind the noise sensitivity, i.e. that persons living at high noise levels have a higher score on the noise sensitivity scale. In [54] it can be seen that this is not the case.

7.3.2. Relation to FAMOS literature study

Similar to the analysis in Section 7.2.2, the FAMOS moderators in focus have been investigated in more detail for the model developed on the Copenhagen dataset. An overview is shown in Figure 122. The influence of the two moderators (blue boxes in Figure 122) included in the model are discussed in the next two subsections.

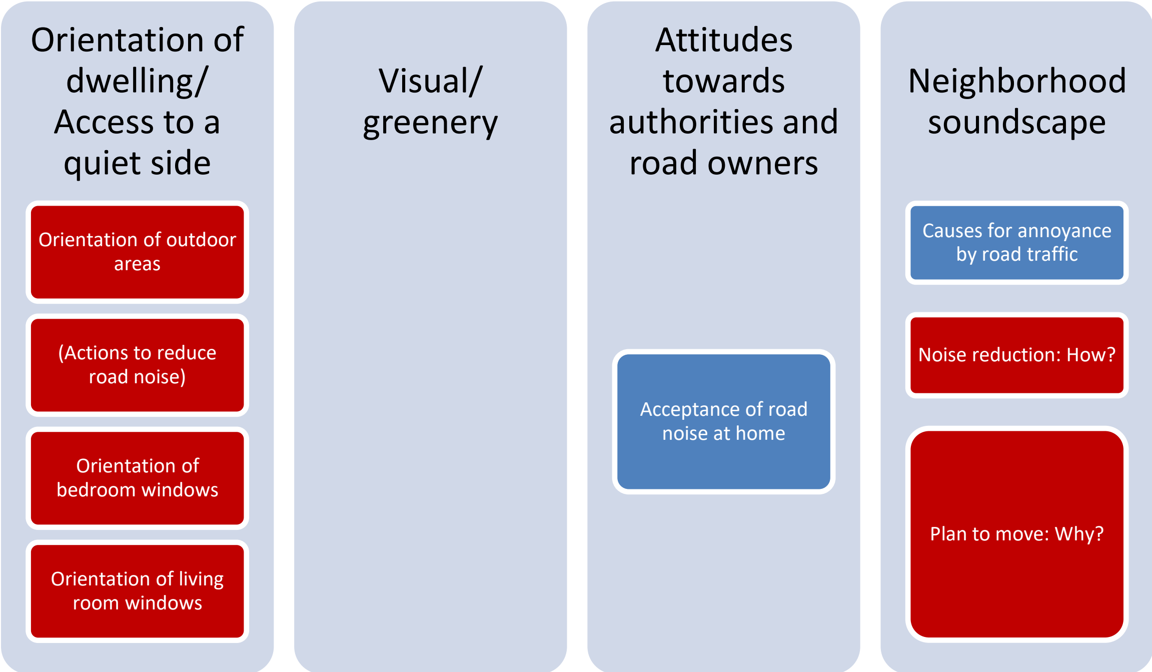


Figure 122: The moderators of focus in the FAMOS literature study in the light blue columns with boxes of questions from the Copenhagen dataset. Blue boxes are questions included in the model, and red boxes are questions excluded from the model.

Effect size of Acceptance of road traffic noise

The relationship between acceptance of road traffic noise, L_{den}, and Annoyance is depicted in Figure 123. It shows an increase of about 4 on the annoyance scale independent of the L_{den} level, which is a very large change. Even larger than the influence of L_{den}, which increases with about 3 for the "No" subset and 1.5 for the "Yes" subset.

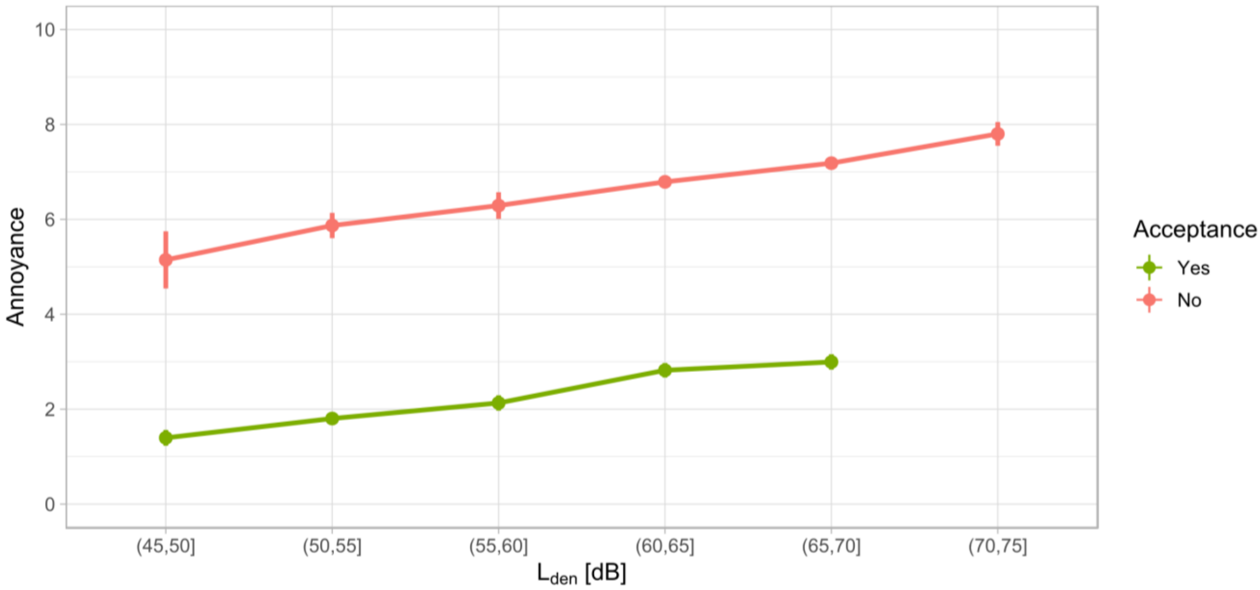


Figure 123: Prediction of Annoyance as a function of L_{den} in 5 dB intervals split into groups of response options of the interaction ***Acceptance of road traffic noise*** *(. Vertical lines are 95% confidence intervals. From the Copenhagen dataset.*

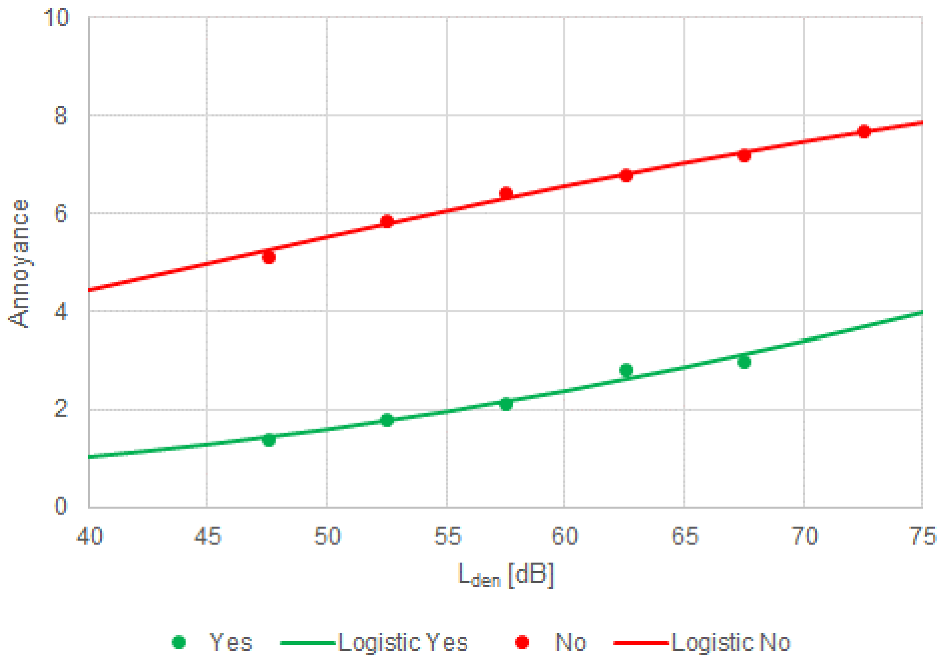


Figure 124: Acceptance of road traffic noise. Prediction of Annoyance as a function of L_{den} for persons finds road traffic noise acceptable (green) and persons that do not find the noise acceptable (red). The points are based on data from the model/Figure 123. The curves are logistic fits to the data.

Effect size of Causes of annoyance by road traffic

The causes of annoyance from road traffic in the local neighbourhood as a function of L_{den} and Annoyance is depicted in Figure 125. Note that only a subset is shown. Participants could select multiple causes of annoyance, e.g., both "Feeling unsafe" and "Noise/vibration", but here only predictions of the *single cause* cases are plotted for simplicity and because not every combination had sufficient data to make good predictions. In total nine logical[13] combinations are possible.

[A] An illogical combination would be "Not annoyed" ***and*** any of other options.

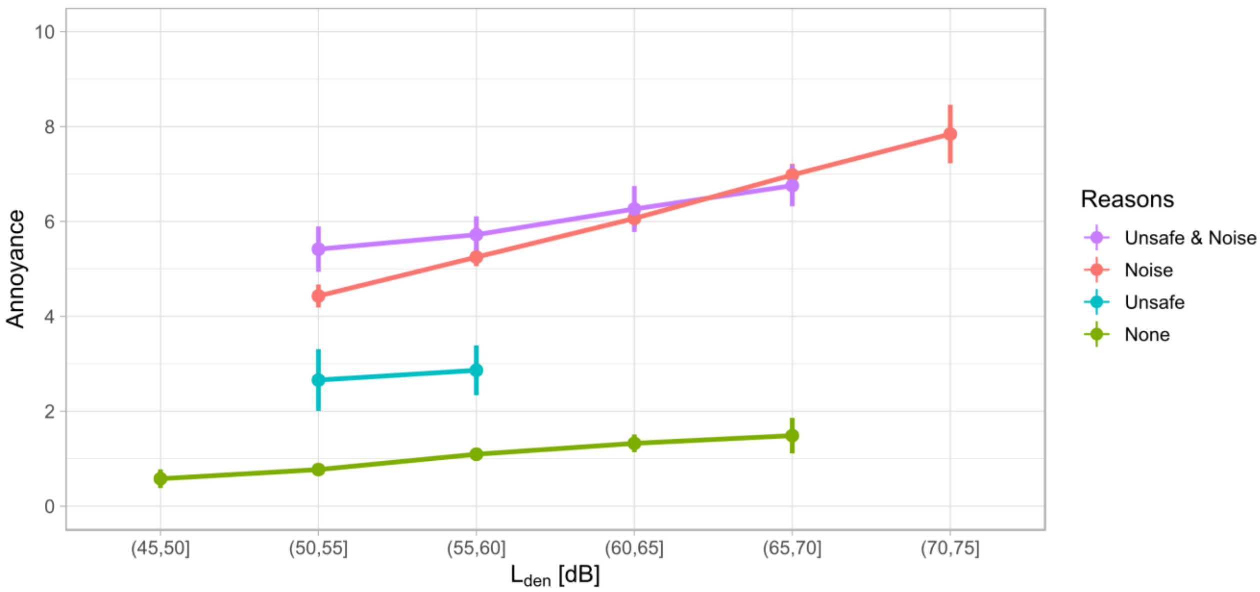


*Figure 125: Prediction of Annoyance as a function of L_{den} split into groups of response options of the interaction **Ways/causes of annoyed by road traffic** . Vertical lines are 95% confidence intervals. From the Copenhagen dataset.*

From the figure it is seen that Feeling unsafe account for 1 on the annoyance scale which according to Figure 120 corresponds to an annoyance equivalent noise level shift of 5 dB.

It is also seen that the effect of noise and vibration is increasing with the noise level.

Annoyance equivalent noise levels shifts

Looking at the curve of Annoyance vs. L_{den} in Figure 120 at the range 55-65 dB, the shift in annoyance is 1.9 dB. This can be used as an approximate slope for estimating annoyance equivalent level shifts for each moderator. This is done in Table 16. Once again, the shift of average annoyance is the difference in mean values depending on the moderator in question. Since the difference change with L_{den}, the difference is described with an interval. These values can be estimated by looking at the figures in the previous subsections of Section 7.2.2. Note, that these equivalent noise level shifts are not additive, i.e. cannot be summed. Again, keep in mind that this table inherits the assuming of the original plots, namely that subgroups are balanced on all other factors to a degree where the moderator under investigation will be the main driver of the differences.

Table 16: Annoyance equivalent level changes for the Copenhagen dataset.

	Moderator	**Shift of average annoyance**	**Equivalent noise level shift [dB]**
Q4	Acceptance of road traffic noise	3.8-4.3	19.1-21.6
Q2	Causes of annoyance by road traffic	2.3-4.6	11.6-23.1

7.4. Comparison between models for the two datasets

Out of the 15 common questions in the two datasets,

- one was the annoyance variable, i.e. the 12-month average traffic noise annoyance,
- one was excluded (a second annoyance question)
- and 13 were included in the input for the model calculations.

Among the 13, six moderators were found significant in both models. Two of these questions, however, have different response options. In “Acceptance of road noise at home”, the first dataset had an ordinal response type (0, 1, …, 10), while the response was reduced to “Yes” or “No” options in the second. The question on “Behaviour changes due to road noise + Activities affected from road traffic” includes the same options, but the Copenhagen dataset also has additional options related to sleep disturbance. Furthermore, the question on “Type of outdoor area” in the motorway dataset is broader than “Access to own garden” in the Copenhagen dataset.

The six common variables are summarised in Table 17. Having these moderators in both models suggest that their influence on annoyance is of a general nature and that their effect may exist beyond the context of these two datasets.

One secondary observation is, that in neither model, the basic demographics of gender and age are included, i.e., they were not found to significantly improve the model. Possibly suggesting that the more specific questions make the demographic questions less relevant or even irrelevant.

The two models share no interaction terms among the 11 interactions in the motorway model and 5 interactions in the Copenhagen model. This shows that the interactions are not stable across datasets and thus not suited for making general recommendations.

Overall, the model on the motorway dataset, might be a more general model due to the type of questions included, where the Copenhagen dataset model was more focused leading to it being less useful to explain the general moderators of annoyance, which is also apparent from the difference in the percentage of explained variance, 77% vs. 70%, in the two models.

Table 17: Common variables in the two models. All six variables are main effects.

TOPIC OF TERM/QUESTION
Acceptance of road noise at home
L_{den}
Causes of annoyance by road traffic
Noise sensitivity
Behaviour changes due to road noise + Activities affected from road traffic
Type of outdoor areas (motorway dataset) Access to own garden (Copenhagen dataset)

7.5. Discussion and Conclusions on the modelling

The model finds -not surprisingly- that the annoyance increases with L_{den}. There is good compliance between the model prediction and the data it is built on, which is a good validity check on the math and statistical principles for the model. The model results are also compliant to the results found in the original simpler models for the same data reported earlier. It can be concluded that the models are trustworthy and representative for the input data.

The models show a large shift in the predicted annoyance from approx. 1 at high acceptance to approx. 8.3 at low acceptance in relation to the acceptance of road noise at home. If one assumes that the acceptance of road noise is related to trust in authorities (i.e. that they have done what is possible to reduce the noise), then this result illustrates that trust to the authorities is a very important moderator.

The up to 15 dB reported in the literature survey in Section 5.2.7 for “Attitude towards authorities and road owners”, were based on direct questions on this subject, while “Acceptance of road noise level at home” is only assumed indirectly related here. In all likelihood many underlying moderators (objective and subject) may influence acceptance of road noise level at home, but general trust in- or attitude towards authorities may be one of these.

The model shows that the annoyance is increasing with noise sensitivity as expected. For a span of noise sensitivity on 0-10 the resulting span on the annoyance 0-10 scale is five steps.

Furthermore, it is found that the annoyance from motorways is 1 higher on the annoyance scale than the annoyance for urban roads. This corresponds to an annoyance equivalent noise level shift of 5 dB, which is in line with earlier findings.

The impact of specific moderators can be expressed in "annoyance equivalent noise level shifts" so that the presence or absence of certain moderators is expressed as a corresponding perceived increase or decrease in the noise level, L_{den}.

From the model the following "annoyance equivalent noise level shifts" are found:

Motorway dataset:

- Orientation of outdoor areas: 10 dB (8.4-11.8 dB)
- Access to a quiet side: 10 dB (8.0-11.8 dB)
- Special bedroom windows: 10 dB (4.2-14.8 dB)
- Causes to annoyance by traffic[14]: 16 dB (8.4-24.1 dB)
- Motorway visible 4 dB (2-6 dB)

Annoyance equivalent noise level shifts, Copenhagen dataset:

- Acceptance of road traffic noise: 20 dB (19.1-21.6 dB)
- Causes of annoyance by traffic: 17 dB (11.6-23.1 dB)

Feeling unsafe corresponds to an annoyance equivalent noise level shift of 5 dB.

Based on input from the two large Danish questionnaire surveys on perceived noise annoyance, the model can demonstrate the effect of various moderators. The result within the project is not ready-to-use piece of software with user interface for general use, but with the model, the effect of further moderators and interactions than illustrated in this chapter, can be estimated.

It will also be possible input data from more surveys after the termination of the FAMOS project and thereby obtain a more general validity.

A total of the answers from 6316 respondents are used in the analysis of the two datasets included in this analysis. This is a very high number of respondents and much higher than what is seen in many other international annoyance surveys.

[14] This is a general question including: Feeling unsafe at the roads and surroundings, unsafe for children, noise, vibrations, air pollution and dust from the traffic

The results must be considered valid for Denmark as well as for similar north European countries/regions and they can be considered a first good step towards a model valid for the whole of Europe. At the present stage this may not be a sufficient data basis for making a road traffic annoyance model that can provide representative predictions for all of Europe.

So, even if the models may not be considered representative for all citizens of Europe, they provide strong evidence for the effect of the moderators that are found significant in this study. While the data basis of only two studies may not be sufficient, the Danish studies had a very high quality and covered a broad range of questions many of which were identified in the literature as relevant. The models based on Danish raw data confirms the findings in the literature study [2] to a very large extent. The models provide strong evidence for the effect of the moderators that are found significant in this study.

The contribution of the modelling documented in this chapter is also to further investigate the potential of including more moderators and more interactions between moderators in a multiple regression model and further qualify the list of “questions of importance” to collect in future studies. As mentioned, the model is built to make predictions of the average annoyance response on the 0-10 annoyance scale from ISO 15 666. It may be enhanced to calculate e.g., the percentage of highly annoyed (%HA) from the model findings. Inclusion of data from more surveys could improve the models and their validity. An important factor for this will be the use of uniform questionnaires or at least a larger part of standardized questions covering relevant topics (see Section 6.2).

8. Synthesis on moderators of noise annoyance

After the steps of literature analysis, contact to researchers, own surveys and tests as well as modelling the results will in the following be compared, discussed, and compiled into a whole. The -for practical use- most relevant results for the effect of the moderators will be reviewed with respect to validity and uncertainty.

The moderators effect on the annoyance will be refined, simplified and will in practical terms describe for which cases they are applicable. The results of the synthesis will be optimized in relation to the practical applications for the NRA's. The results presented in this chapter of synthesis will be the main input to a practical formulated guidebook (the deliverable D.4.5 of the FAMOS project).

8.1. Summary of possible moderators

Based on the moderators shown in Table 1 (see page 16) and the results of literature analysis (see Section 5.1) and information from external researchers (see Section 5.3), a first list of moderators was assembled. They were amended and/or revised by further investigation done within the project (see Chapters 6 and 7).

The final moderators will be described, and illustrative examples will be shown. The results give an overview on possible effects with a general order of magnitude. However, it has to be considered that the effect size (the annoyance equivalent noise level shift, see Chapter 4, page 13) itself may depend on other moderators not controllable. Details on possible interactions will be given in Section 8.2.

8.1.1. Moderators pertaining to attitudes and public relations

Attitudes towards authorities and road owners

Many annoyance surveys indicate that the relationship between the authorities (source owners) and the neighbourhood is an important non-acoustical factor. People that have a high trust in the authorities and believe that a road is being constructed to impose a minimum impact on the neighbourhood and society are less annoyed than people with a low trust and people that feel alien to the road work and having a feeling of not being treated fairly.

Overall, trust and acceptance can yield in an annoyance equivalent noise level shift of about 20 dB from highest trust to lowest trust. This effect can be taken into account “two way” based on an “average trust”, i.e. resulting in a possible shift of 10 dB towards “less annoyance” for good trust and a shift of 10 dB towards “higher annoyance” for mistrust (see Section 5.2.7).

Figure 126: Open discussion between road authorities and residents.

Note: The FAMOS project did not investigate how this moderator changes/evolves. Trust and acceptance are likely no steady constant that will remain at a certain value over a longer period of time. It may change due to changes in residents (residents leaving the area, new residents moving in) or by external influence (e.g. from other projects in other areas). However, events influencing trust and acceptance (both positive and negative) may just fade after a longer time, making the influence on annoyance smaller.

Expectations / public relations

In the aviation industry a "high-rate change airport" (HRC) is characterized by large and abrupt changes in the operation pattern (but not necessary changes in the noise exposure level). If plans for future changes are launched, and especially if these plans are controversial and not rooted properly in the community, the airport may also be characterized as an HRC airport. Likewise, negative media attention may lead to an HRC characteristic. It is quite likely that a similar situation may be found for road traffic. In the aviation industry the average difference between a typical airport and an HRC airport is equivalent to an annoyance equivalent noise level shift of about 9 dB.

Attention is needed if plans for future changes are launched, especially if these plans are controversial and not rooted properly in the community. This is especially the case when large and abrupt changes occur.

An unfortunate presentation of plans of noise mitigation can trigger adverse actions in the community and thus can completely reverse the expected positive effects. The effect of expectations and expectations met can result in a shift of about 5-10 dB (see Sections 5.2.3, 5.2.8 and 6.2.3). This is about the same shift that can be expected from the erection of a typical noise barrier or extensive noise mitigation measures of the local traffic situation in an existing community.

Figure 127: Listening examples (calibrated auralisations) at a public meeting about a road project for better correspondence of the neighbours' expectations and results.

8.1.2. Controllable factors pertaining to the road

Traffic volume

The traffic volume, *i.e.* the number of vehicles, affects the annoyance response. As the number of passing vehicles increases, the noise exposure level will increase and consequently the prevalence of noise annoyed residents will increase. However, the annoyance increases more rapidly than would be expected from the noise level itself. At equal noise levels, a high number of vehicles appear to be more annoying than a small number. The annoyance equivalent noise level shift has been reported to about 1.5 dB per doubling of the number of vehicles (increase in CTL value, see Section 5.2.2).

Figure 128: Similar road types (motorway) with low traffic (above) and high traffic (below)

Safety expectation

People may feel unsafe about both local and national roads in their neighbourhood. For local roads, typically belonging to the municipalities, improvements could be affected e.g. by reduced speed, humps, chicanes, bike lanes, pedestrian crossings, traffic light regulation, removing heavy traffic to other routes etc. NRA could help the municipality with technical advice and also money to do the improvements. For national roads, the perceived safety can also be influenced by the proximity of traffic to residential usage and the presence or absence of guardrails. The effect corresponds to an annoyance equivalent noise level shift of about 5 dB (see Sections 5.2.9, 7.2.2 and 7.3.2).

Figure 129: Guard rails, enforcement of speed limits.

Figure 130: Improving safety on local roads, e.g. with speed reductions

Vegetation and greenery influencing the visual appearance of the surroundings

The visual appearance of the road and its immediate surroundings have a significant impact on the annoyance response. Visual greenery in the form of single trees or bushes, strips of grass, etc. have no effect as a noise-reducing element, but never-the-less such elements may cause a reduction in the annoyance equivalent noise level of as much as 10 dB (see Section 5.2.4 and high expectation of greenery in Section 6.2.3).

However, studies from the Netherlands indicate that trees close to a noise barrier can affect the noise reduction of the barrier itself when higher than the barrier. This should be considered as a possible negative effect [59]. The effect might be caused by an influence on the diffraction on the top of the noise barrier or when leaves are on the trees reflections of the road noise will occur from the treetops.

Regarding the effect of vegetation, a decrease in vegetation and greenery can offten occur after trimming of bushes and cutting of trees as part of maintenance that is carried out every couple of years. This should be considered as it may have a major influence on noise annoyance (increase due to reduced vegetation/greenery), maybe even leading to loss of trust/acceptance (see also examples in Section 8.3.4).

Figure 131: Greenery surrounding a motorway and covering the view to the noise barrier.

Noise barriers (expectations and visual appearance)

Noise barriers are often used as a means to reduce the noise from a major road. Different constructions and different materials are being used; earth berms, solid walls made of concrete or wood, transparent walls made of glass, etc. The walls may be acoustic reflective or fitted with absorption on the side facing the road. The screening effect of a noise barrier is primarily defined by the effective height, dependent on as well the distance to the road as to the receiver. A barrier introduces an insertion loss of 5-6 dB when the direct line of sight from the source to the receiver is just barely broken. An effective height of 3-4 meters will provide an insertion loss of up to about 15 dB. A typical noise barrier will provide an insertion loss of about 10-12 dB, but the subjective effect, *i.e.* the corresponding reduction in the annoyance equivalent noise level is dependent on a number of other factors:

- Did the effect of the barrier meet the expectations of the residents?
- Were they involved in the visual design or were they left alien to the design process?

The physical effect, *i.e.* the reduction in noise level, may often be offset by an opposite shift in the annoyance response. This is partially due to expectations (see “Expectations / public participation” and Sections 5.2.3, 5.2.8 and 6.2.3) which can result in a shift of 5-10 dB.

Regarding the visual appearance, the influence of the design itself is mostly unclear (see Section 5.2.3), but most likely lower with about 2 dB.

Greenery and vegetation may result in a higher shift (see section on “vegetation and greenery” on the previous pages).

Figure 132: Embankment covering the view to a motorway (not visible on the left), also improved with greenery.

Figure 133: Wooden noise barrier adapting to the surroundings.

Figure 134: Greenery covering the lower part of a high noise barrier.

8.1.3. Factors pertaining to the neighbourhood

Locations and orientation of residences / access to a quiet side

The noise response is per definition presented as a function of the most noise-exposed façade of the residence. The house itself can act as an effective noise barrier and it has been observed that it may be advantageous to locate noise-sensitive rooms of the residence away from the noise source. Living room and especially bedroom windows should not be facing the roadside. Likewise, balconies, terraces and similar outdoor areas should preferably be located on the quiet side of the house.

Various studies report having access to a quiet side of the residence will reduce the annoyance equivalent noise level by about 10 dB (see Sections 5.2.5 and 7.2.2).

Figure 135: Improving the ambience quality with local noise barriers to protect terraces.

Figure 136: One facade facing the noise from the 6-lane motorway in the front, with chance to a quiet side on the far side. Typical two-room apartments, balconies suggesting living rooms on the loud side, giving a quiet side for bedrooms.

Neighbourhood soundscape

It has been shown that the annoyance reported by a resident is not only dependent on the noise level at the (most exposed) façade of the residence, but also depends on the soundscape qualities of the neighbourhood, i.e. the outdoor area around the dwelling.

Neighbourhoods characterized by general high levels of road traffic noise are assessed as being more annoying than a quieter neighbourhood even if the residence is not directly exposed to this noise. It may therefore be worthwhile to re-direct the neighbourhood traffic and divide the traffic in local streets and through-streets according to origin and destination. This may even increase the noise in some areas, but the net effect may be a reduction in the overall community annoyance.

Based on observations from Oslo (Figure 19) we estimate that the annoyance equivalent noise level shift may be up to 10 dB.

Figure 137: Reducing local traffic, improving outdoor qualities, and reducing the noise in the local neighbourhood.

8.1.4. Non-controllable personal and demographic variables

One of the objectives of the FAMOS project is to identify and quantify non-acoustical factors that have an influence on peoples' annoyance reactions to road traffic noise. A number of such factors that to a greater or lesser extent can be controlled by the road owner, have been discussed. Control is a matter of necessity if the objective is to use a certain factor actively in road planning and traffic control.

However, there are also many personal and demographical factors that may or may not be important for annoyance assessment. Such factors are for instance age, gender, dependency of road transportation, house ownership, social status, income, education, etc.

Information about these may be important when assessing the results from annoyance surveys. Some of these factors have been discussed in Section 5.2.1.

8.2. Overview of effect sizes, uncertainties, and combination of moderators

Evidence was found that a wide range of moderators affects the noise annoyance. Regarding the “direction” of the effect size, it depends on the situation itself: when implementing a “favourable moderator”, like improving greenery, the effect size works towards “lower annoyance”. Whenever a moderator is removed (like greenery) or changed towards a less favourable situation (like increase in neighbourhood noise), the same effect might occur towards “higher annoyance”.

The selected moderators and their order of magnitude can be seen in

Moderator	Effect size
Trust / acceptance	±10 dB
Expectations met	5 to 10 dB
Access to silent side	6 to 9 dB
Low/no visibility of the road	2 to 10 dB
Increased traffic volume	~1.5 dB per doubling
Neighbourhood noise	up to 10 dB
Orientation of outdoor areas	8 to 12 dB
Traffic safety expectations	5 to 8 dB
Vegetation and greenery	6 to 10 dB
Visual appearance of the barrier	2 dB

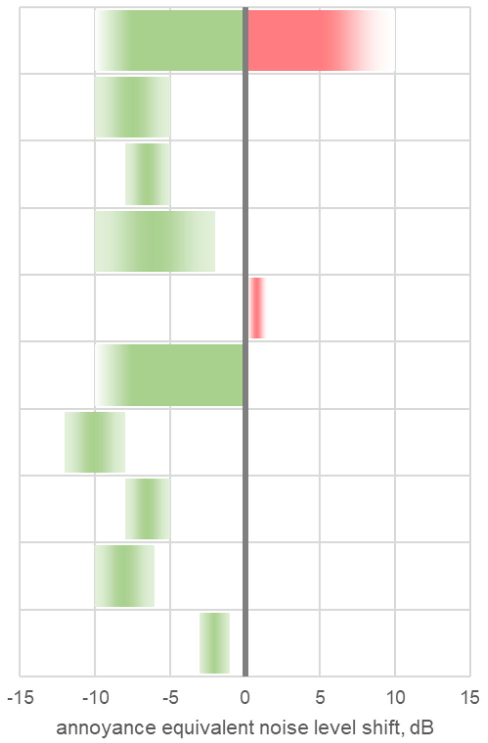


Figure 138. Except “trust/ acceptance” and “increased traffic volume”, only the “positive effect” is plotted. This depicts the possible gain that is achievable by NRAs for each moderator, based on a situation “without positive influence of a moderator”. For “trust/acceptance”, the possible effect size of ± 10 dB shows that this moderator might in most cases have an “average” from which a change is possible in both directions. So even without further influence or consideration, the annoyance might increase.

Moderator	Effect size	
Trust / acceptance	±10 dB	
Expectations met	5 to 10 dB	
Access to silent side	6 to 9 dB	
Low/no visibility of the road	2 to 10 dB	

Increased traffic volume	~1.5 dB per doubling
Neighbourhood noise	up to 10 dB
Orientation of outdoor areas	8 to 12 dB
Traffic safety expectations	5 to 8 dB
Vegetation and greenery	6 to 10 dB
Visual appearance of the barrier	2 dB

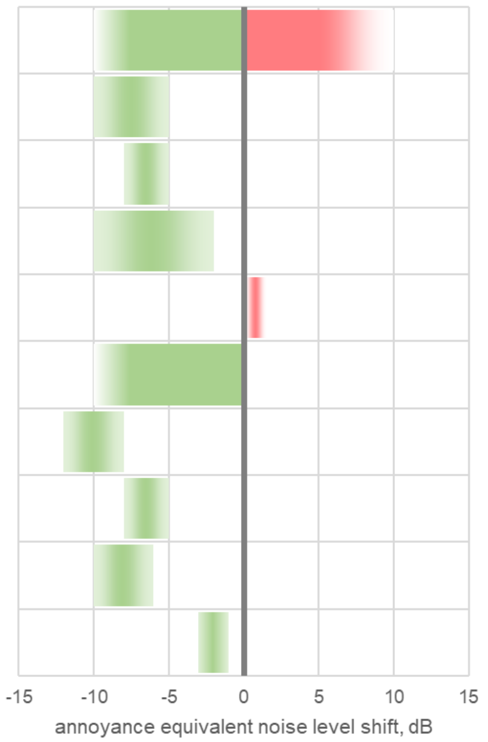


Figure 138: Overview on effect sizes

The spread shown is already simplified to the most likely effect size. Regarding uncertainties, the literature analysis (Section 5.2) shows a high variance in the annoyance equivalent noise level shifts for some moderators between different surveys. Results of listening tests, mini surveys and sound walks also showed a high uncertainty, mostly due to a low number of respondents.

The results of the modelling, which is based on data of 6316 responses shows differences regarding the uncertainty of the moderators (see Section 7.5):

- A relatively low variance was found e.g. for access to quiet sides and orientations of bedroom windows and the acceptance, i.e. attituded towards road noise and authorities. Both moderators show an effect within a 3 dB confidence interval.
- Higher uncertainties are found whenever several moderators were affected at once, like feeling unsafe, vibrations, smell and air (see Section 7.2.2, Figure 118 and Section 7.3.2, Figure 125). These result in a spread of about 12 dB in effects, although the effect size and thus uncertainty of single factors is much lower.

For some moderators, dependencies and interactions can be found. The effect size suggests that the effects are not simply to combine for different moderators, as they would result in a change higher than actual noise levels (e.g. ± 10 dB for trust, up to 10 dB for expectations, 10 dB for vegetation and greenery and so on).

Different moderators might have a positive or negative influence on each other. For most effects, an increase can be expected when interacting. For trust/acceptance, a poor quality of the other moderators can result in negative effects. An example of possible dependencies and interactions between moderators is shown in Figure 139.

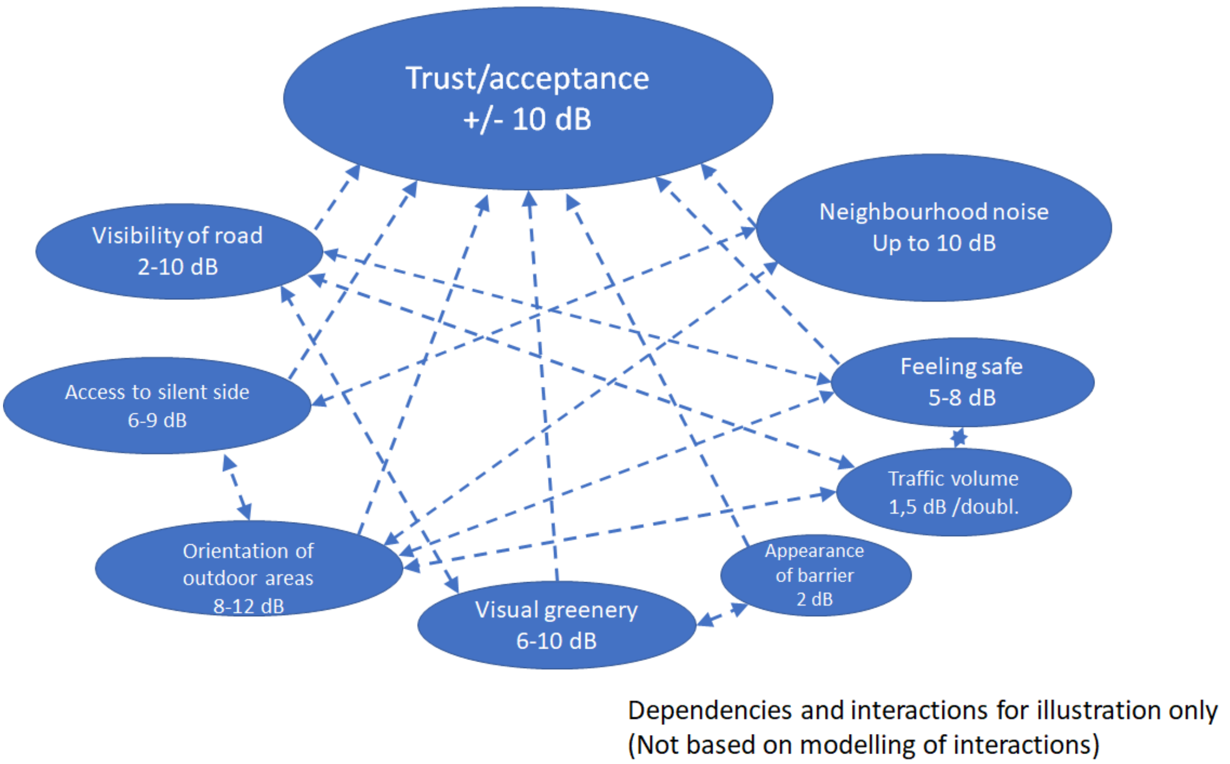


Figure 139: Possible dependencies and interactions between moderators. The effect in dB of the moderators is the average order of magnitude found in the FAMOS project.

These connections are not based on modelling of interactions but give an overview of moderators “related” to each other and having a similar influence, like visibility and greenery, appearance of the barrier and possible greenery or the influence of most moderators towards change of trust and acceptance.

Possible positive or negative influence of the different moderators might be:

- The appearance of a green noise barrier might influence the visual greenery and thus have a higher effect.
- Visual greenery might cover the view to a noise barrier and thus make the influence of the visual appearance of the barrier irrelevant.
- If the road is not visible, the perceived safety might increase.
- If access to rooms on quiet side is given, outdoor areas can be oriented there as well.
- Reduced neighbourhood noise can increase the chance of a quiet side.
- Noise mitigation measures like barriers, embankments or noise reducing pavement on a major road might not only decrease noise levels at dwellings, but also in the whole neighbourhood. In opposite, soundproof windows only decrease the noise for residents of single dwellings indoors.

Whenever multiple moderators could apply, these with the highest effect and the highest emphasis should primarily be considered. Those moderators which are just slightly addressed, like a minor change in visual greenery, could be considered with their effects to other moderators but otherwise neglected.

8.3. Examples of application and practical terms

For a better understanding, some examples shall show how the moderators apply in real life situations and how the effects can be estimated. The examples also show how some moderators can have longer lasting effects by influencing e.g. the trust in authorities or the acceptance of noise.

8.3.1. Expectations and change effect

For bigger noise mitigation measure projects, expectations might arise on the effect on noise level change. This can also be the case in situations of road enlargements where an extension could even result in a higher level of noise protection due to stricter limits that have to be met.

From an experts view, a decrease of 2-3 dB (e.g. due to noise reducing pavement) is common, mitigation of 4-10 dB (open porous asphalts or noise barriers in ideal situations) is less common. For some extensions, the noise levels after construction are planned to be equal to before although the traffic volume increases (mitigation counteracting the noise level increase), though a change of near 0 dB will be the result.

For residents, whenever noise mitigation measures are explained, expectations on a perceptible change of noise levels can arise. Although noise level changes of about 3 dB are commonly only perceptible in favouring conditions, the annoyance effects seem to be higher. A summary of different studies [58] shows that not only acoustic criteria should be considered.

However, the same effect which improves the reduction of noise annoyance can also apply when noise levels rise. One example, shown in Figure 140, shows a common situation of road construction on motorways. During construction, the traffic is shifted to one roadside. In addition, speed limits apply that are mostly lower than the regular speed limit (e.g. 60-80 km/h instead of 100-120 km/h). In the case shown, the roadside on the left side was improved first.

Figure 140: Situation during construction phase – traffic shifted to one side and speed limits.

The whole construction phases similar to that shown in the figure could result in the following noise level changes at a building at the right hand side in the picture (without noise barrier, with lower distance between buildings and road):

- Increase due to lower distance +1 dB
- Decrease due to lower speed limit -3 dB
- Noise level during phase 1 -2 dB

- Decrease due to higher distance -2 dB
- Decrease due to better road surface -2 dB
- Noise level during phase 2 -6 dB

- Increase due to distance (as before construction) +1 dB
- Increase due to higher speed limit +3 dB
- Noise level after construction (without barrier) -2 dB

For a situation with noise barrier, the decrease of noise levels could be even higher during phase 2 with the barrier taking effect.

After all, the noise level decreases, but in the final phase, the noise level increases by about 4 dB. Although the noise level is lower than before the construction process, expectations that were satisfied during that time period were counteracted due to the perceivable increase after construction. This might result in complains and unsatisfied citizens. This can to some extend be avoided by conducting a good and very informative public participation process where these changes of the noise levels during the whole construction process are explained.

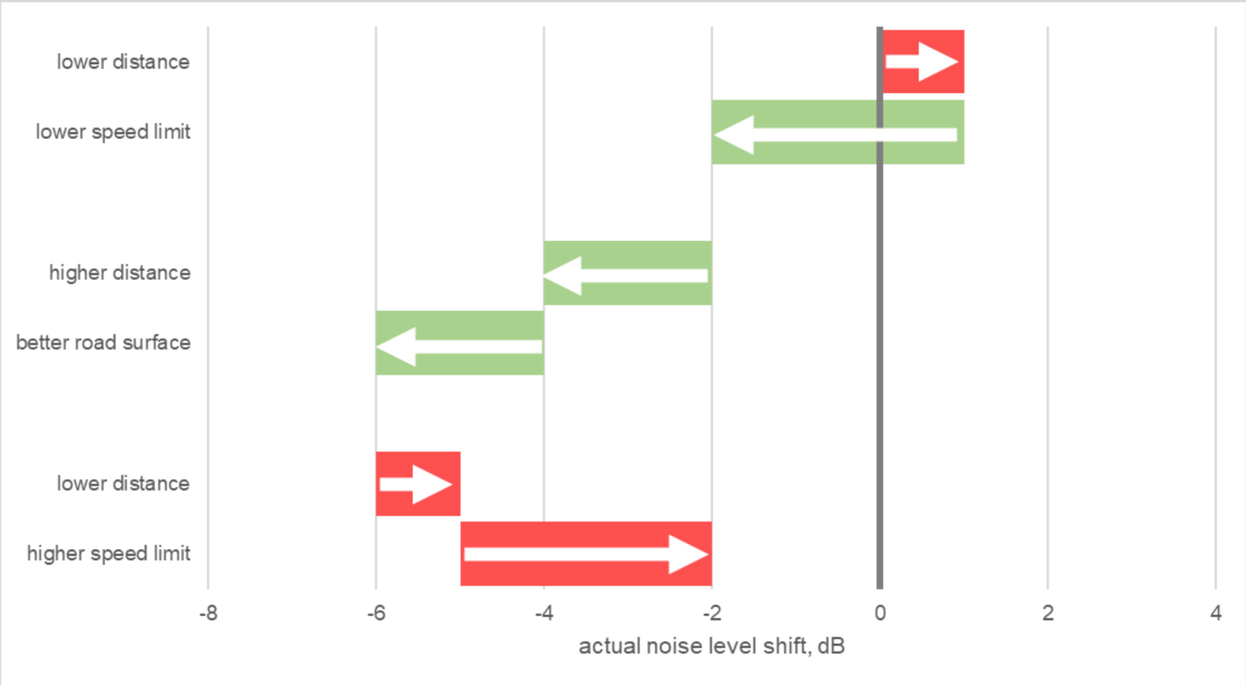


Figure 141: Changes in actual noise level over time during construction phases (red: increase, green: decrease).

Noise measurements could be carried before and after the construction phase, although these will only have documentary character. Convincing people after a negative experience (in this case: emotions vs. technical data) is expected to be harder to achieve than good public relation and good communication beforehand.

8.3.2. Construction site noise

In addition to the noise level changes of the road traffic, possible noise from the construction process might affect residents and result in annoyance: e.g. hammering down foundation, braking down old concrete, using heavy machinery etc. If the noise from the construction process is handled in an open and active process involving the citizens, negative attitudes towards the whole project can be reduced or avoided. Information on how to handle noise from road construction projects can be seen in the "ON-AIR Guidance Book on integrating Noise in Road Planning" [2] published by CEDR.

Figure 142: Construction site noise at a major motorway enlargement

To gain trust, noise monitoring during the construction process can be useful to ensure compliance of the contractors to e.g. previously agreed processes (limited usage of certain machinery, limited time of machine usage etc.) and to document fulfilment of noise limits.

Although the influence of construction site noise itself was not investigated in the FAMOS project, it is a major influence on the noise levels during a change process. Thus, it is a possible contributor to changes in noise acceptance and trust in authorities.

8.3.3. Trust in authorities

A negative effect on trust towards authorities and noise acceptance by the local citizens can result in situations with expectations that were not met, or negative changes were experienced. This can be even the case if only the annoyance is increased whereas the real noise level was not increased. The effects can lead to higher annoyance with a potential annoyance shift of up to 10 dB that counteracts the noise level reduction.

In situations like in the previous example, without further influence of other moderators such a negative effect could easily counteract the benefits of a noise barrier and noise reducing pavement, resulting in zero change of annoyance for the next years to come[15]. However, the negative effect of trust is likely to change over a longer time, resulting in "average" annoyance after some years.

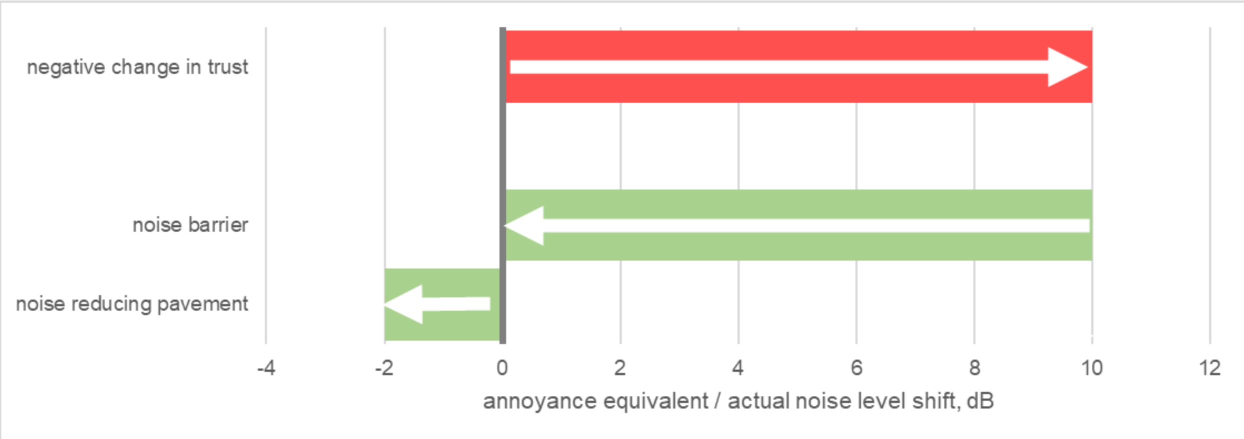


Figure 143: Increase in annoyance equivalent change (red) counteracting reduced noise levels (green)

An improvement for the example given could be achieved by good public relations work, explaining the noise level change that is to be expected and the temporary effects during construction. When including audio examples, residents will experience the realistic amount of change in noise levels to expect, which can counteract high expectations that could not be fulfilled.

15 Note: The FAMOS project did not investigate the long-term effects of trust.

8.3.4. Visibility and greenery

As part of construction processes but also due to regular roadside work, trimming and cutting of trees and bushed could be necessary. As documented before (see Section 8.1.2), visibility of the traffic and a general greenery in the surroundings can result in a shift of about 10 dB.

In one documented example (see Figure 145), extensive work was carried out roadside, cutting and trimming bushes and small trees. This resulted in an open view to the traffic (in the picture: from road to dwellings, but also vice versa). Without further announcement, this could also affect the trust in authorities, resulting in negative effects even years after the change of visibility. As for the greenery, although the bushes and trees would grow back, a negative influence on annoyance could remain.

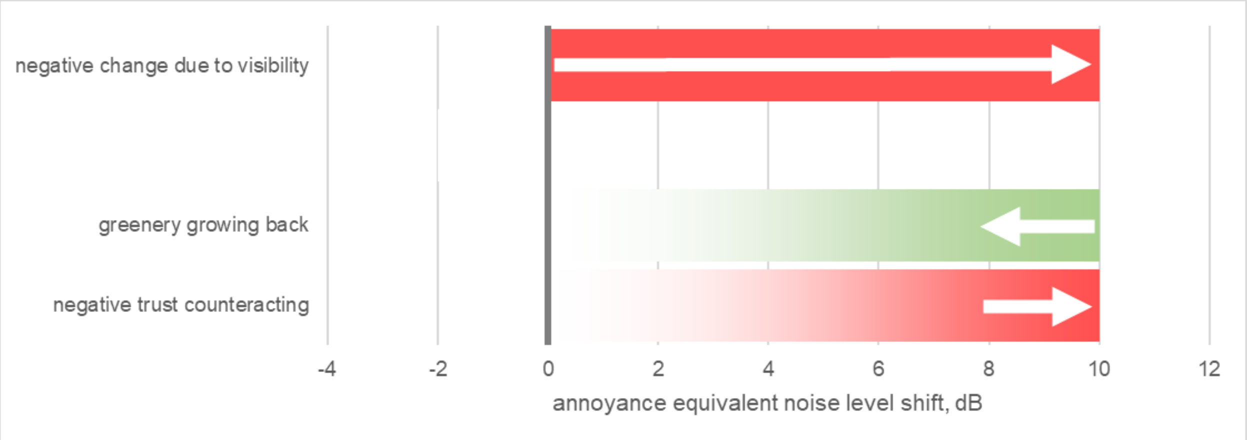


Figure 144: Negative effect by change by visibilty, effect decreasing by greenery growing back, but still negative effects due to trust possible.

An improvement for a similar situation would be to make announcements on necessary tree works before start of work and at the same time highlighting hat the trees/bushes will grow up again over the following years, resulting in the same visual appearance as before. In addition, information on the acoustic effects could be given to residents, informing on marginal effects on actual noise levels. This could lower expectations on the noise mitigating effect of greenery. However, such information could also result in lower positive change after greenery was used to reduce visibility of traffic.

Whenever changes in greenery are necessary due to road construction, timing of such work can have a possible influence. In combination with the example above, a change in greenery before start of construction could result in a higher annoyance due to change of greenery and visibility at the start and a lower trust, resulting in a higher annoyance throughout the whole construction process. If cutting trees down is carried out during or shortly after noise level reductions, the negative experience could be lower.

In addition, cutting trees in a timely manner to the construction process (i.e. cutting trees shortly before/during construction of a noise barrier, not one year or more in advance) improves the awareness of the necessity and appropriateness, counteracting possible negative effects on trust.

Figure 145: Before and after trimming of bushes and small trees; visibility of the road changes as well as visible greenery (some due to change in season between pictures)

8.3.5. Improved greenery in the surroundings

In one example, the motorway was enlarged from 2x2 lanes to 2x3 lanes. The green zone between the motorway and the dwellings was redeveloped in an open participation process with the NRA, the municipality, and residents. Although there have been no annoyance surveys carried out, conversations showed that residents are satisfied with the new situation.

Figure 146: Local situation between motorway (on the left) and residential buildings (on the right); improved greenery, landscaping and footpaths

After cutting of trees on the roadside for construction of the noise barrier, the opportunity was taken to improve the green zone between residential buildings and motorway. This area had a significant value as recreational area even before the changes.

With the noise barrier, the overall noise level could be lowered also for this area, resulting in a better outdoor quality. Changes made in the surroundings (see Figure 146) focused on improved greenery (additional trees in front of the lower, non-transparent part of the barrier), creation of new wet areas (e.g. a small natural pond) and improved spatial quality of the pedestrian network (mainly improving paths between buildings and the area). Also, five monumental trees were relocated to the area from a close by urban development project.

Regarding the moderators mentioned in Section 8.1, the following might apply:

- Participation / public relation
- Visual appearance of the noise barrier
- Visibility
- Greenery

With positive changes in those moderators, an even larger effect could result. This was not investigated within the project, but literature and own data shows effect sizes even larger than those up to -10 dB for single moderators.

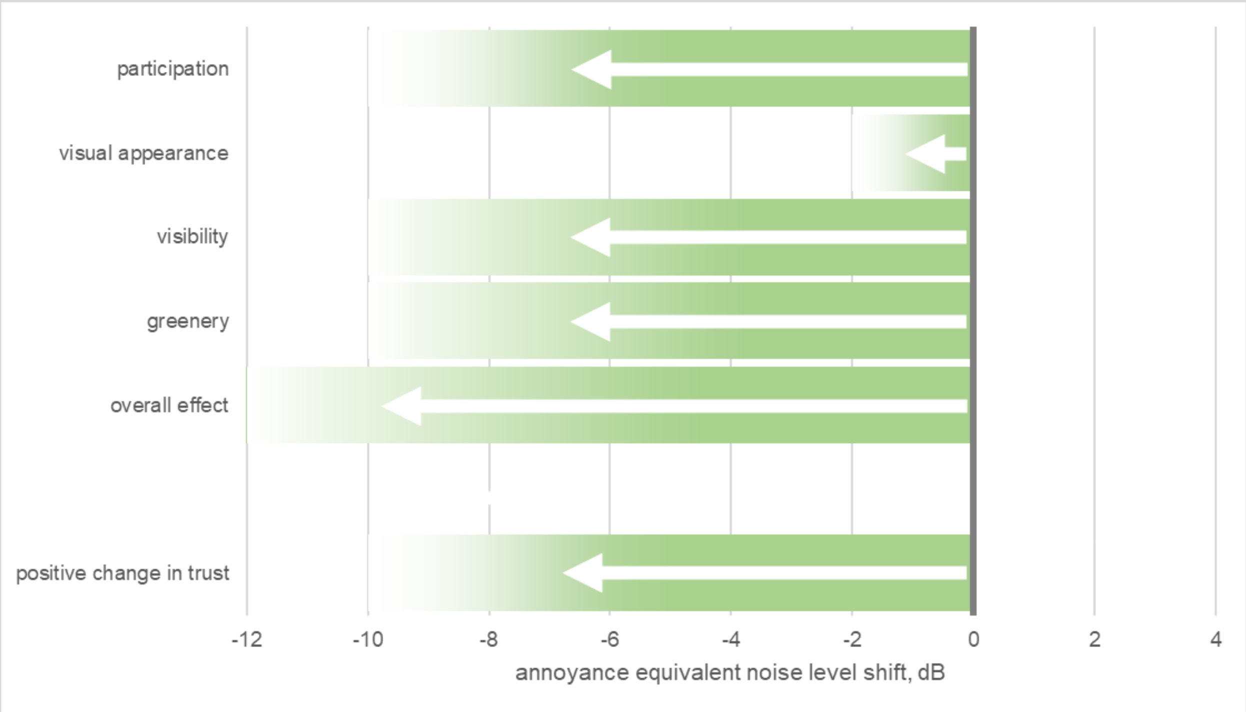


Figure 147: Combination of different moderators.

Resulting from an overall good change, the trust in authorities might improve, giving a “bonus” for a concurrent construction process or even for future changes. In the example, the improvement was finalized after completion of the construction process, so an “early bonus” in trust could not be utilised.

In this case, annoyance during road construction was not positively influenced by the changes in environment as they were carried out after the road construction. Nevertheless, a final “good change”, in this case improvement of environment, can have a final positive impression on the whole measure and thus improve acceptance.

9. Outlook

In the FAMOS project, a series of moderators was researched that can change the noise annoyance by people living in neighbourhoods exposed to road traffic noise e.g., from motorways. The effect of these moderators is present even though no measures are taken to reduce the actual noise levels. Primary research subject were acoustic moderators that could be controlled by (national) road administrations. Non-controllable factors and non-acoustical factors (such as personal factors) are not investigated.

Evidence was found that a wide range of moderators affects the noise annoyance. The selected moderators and their order of magnitude can be seen in

Moderator	**Effect size**
Trust / acceptance	±10 dB
Expectations met	5 to 10 dB
Access to silent side	6 to 9 dB
Low/no visibility of the road	2 to 10 dB
Increased traffic volume	~1.5 dB per doubling
Neighbourhood noise	up to 10 dB
Orientation of outdoor areas	8 to 12 dB
Traffic safety expectations	5 to 8 dB
Vegetation and greenery	6 to 10 dB
Visual appearance of the barrier	2 dB

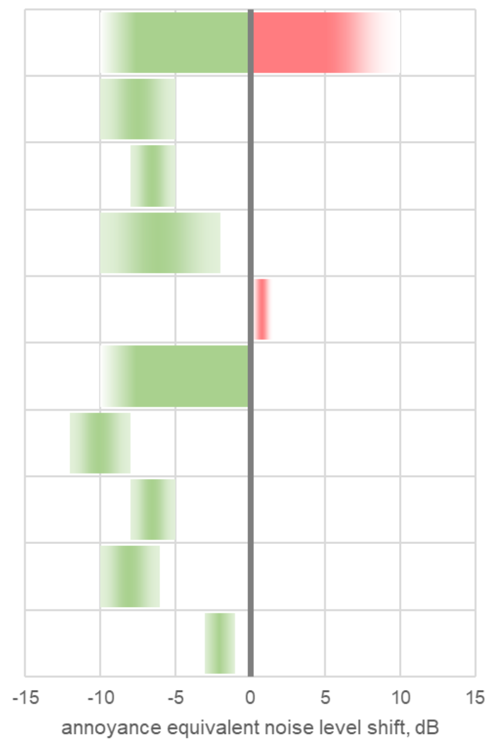


Figure 148. Except “trust/acceptance”, only the “positive effect” is plotted. This depicts the possible gain that is achievable by NRAs for each moderator, based on a situation “without positive influence of a moderator”.

Moderator	**Effect size**
Trust / acceptance	±10 dB
Expectations met	5 to 10 dB
Access to silent side	6 to 9 dB
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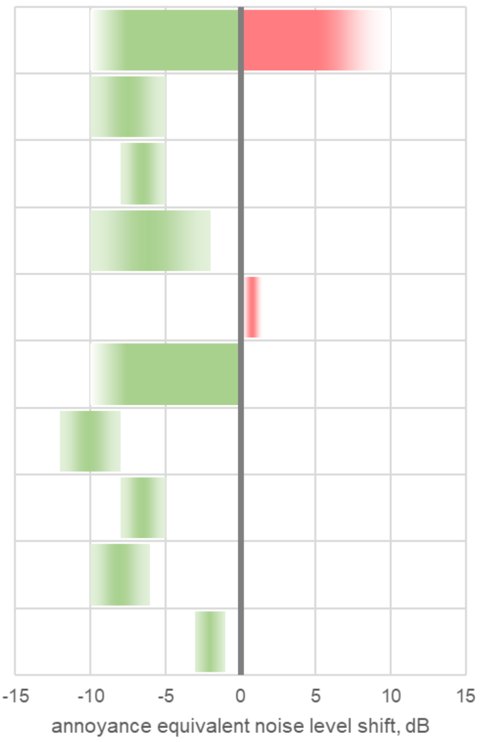

Figure 148: Overview on moderator effect sizes

This report presents the current knowledge on moderators. Even during the literature survey, new publications were published, giving further information. Some major contributions were considered (see Section 5.3), but there will always be a need to improve this knowledge in future.

Besides the controllability, the project focussed on those moderators that had the best data, i.e., several datasets with a good reliability. Although the noise surveys share common questions (like annoyance according to the ICBEN scale), not all studies include a wide range of possible moderators in their design.

To facilitate future data collection, the FAMOS project has also tested three rather simple methods to investigate the perceived annoyance of road traffic noise:

1. Mini surveys using questionnaires
2. Soundwalks in neighbourhoods
3. Listening tests performed in the laboratory

Insights on conducting those methods can help road administrations in order to investigate the effect of new road or noise abatement projects (best practice / worst practice). Valuable information includes information on number of respondents, suggestions for common questions, situations/locations for surveys etc.

Results of similar surveys can be used to derive new information about moderators and their effect on perceived annoyance. Elaboration of a common basis for questions to be used in surveys would be helpful for getting more and more reliable data on the effect of the moderators.

An advanced data foundation from surveys will make it possible to improve the models for noise annoyance including the influence of the moderators. Questions relating to the moderators should be included in the survey questions in future surveys (for inspiration find the questions used in the

Motorway and Copenhagen study which is basis for the modelling in this project and the mini survey for the Hamburg region).

In addition to this project documentation, a FAMOS guidebook (Deliverable D.4.5 of the project) is published. The knowledge found on these moderators has been used as the foundation for developing a guidebook that National Road Administrations as well as other administrations can use in planning of new roads, enlargements of existing roads as well as in noise abatement projects.

10. Literature

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11. Appendices

11.1. Appendix A1: Assessment of annoyance using the CTL method

The CTL method

The CTL (Community Tolerance Level) method is described in the international standard ISO 1996-1 (2016) [4]. The theoretical background for the method was presented by Fidell *et al.* [8] and Schomer *et al.* (2012) [59].

The CTL method is based on the observation that the annoyance response seems to be closely related to the loudness function. This observation can be traced back to Schultz (1978) [60]. For modelling purposes, it was hypothesized that the prevalence of annoyance with transportation noise should increase at the same rate as the duration-adjusted loudness of exposure. This implies that the dose-response function (annoyance vs. noise exposure) can be described by a single, fixed function, but the position of the curve relative to the noise axis will vary according to the influence of other non-dose factors. So, instead of finding a regression function based on a set of observation data where both slope and intercept must be calculated/predicted, as is done in regular univariate regression analysis, the CTL method fits the pre-determined annoyance function to the field data simply by "sliding" the function back and forth along the noise exposure axis to achieve the «best fit» according to some statistical criterion. Fidell *et al.* used a «least squared error» criterion in their first analysis. Subsequently Taraldsen *et al.* (2016) [7] showed that a «maximum likelihood estimate» would be preferable. However, in most cases both methods give very similar results.

The dose-response function for any study of prevalence of annoyance with transportation noise can thus be characterized by a single number that anchor the annoyance function to the noise axis (L_{DN} or L_{DEN}). Any arbitrary point on the effective loudness function could be used to anchor the function to the L_{DN} axis. For example, L_{DN} values corresponding to the 10% or 90% highly annoyed points could serve to describe the position of the effective loudness function along the L_{DN} axis. Since the choice is arbitrary, the midpoint of the effective loudness function—the point corresponding to a 50% annoyance prevalence rate—was selected as a convenient anchor point for present purposes. This value of L_{DN} is termed the Community Tolerance Level (CTL) (L_{ct}). CTL so defined represents a L_{DN} value at which half of the people in a community describe themselves as “highly annoyed” by the specific noise (and half do not).

The results from different surveys can be conveniently compared by simply comparing their respective CTL values. A high value indicates that the community has a high tolerance for noise and low values indicate that the community have a low tolerance for noise. The difference between two CTL values shows how much more or less noise one community will tolerate compared to another one in order to express the same degree of annoyance.

The complete dose-response function for a survey can thus be described by the following equation:

$$\%HA = 100 * e^{-\left(\frac{1}{10^{0.1(L_{dn} - L_{ct} + 5.3\ dB)}}\right)^{0.3}} \quad (5)$$

where L_{ct} is the only variable.

The results from different surveys can be combined by calculating the arithmetic average of their respective CTL values.

Comparison of different analyses

The average CTL value for a compilation of surveys on road traffic noise conducted over the past 50 years is about L_{ct} = 78 ± 5 dB. Figure 1 shows the dose-response curve corresponding to L_{ct} = 78 dB compared with the regression function derived by Miedema & Vos (1998) [6] for annoyance caused by road traffic noise. The *Miedema-curve* is currently being used as a *de facto* EU standard. Considering the rather large spread in the background data, and the wide confidence intervals, these curves may be considered equal for regulatory purposes.

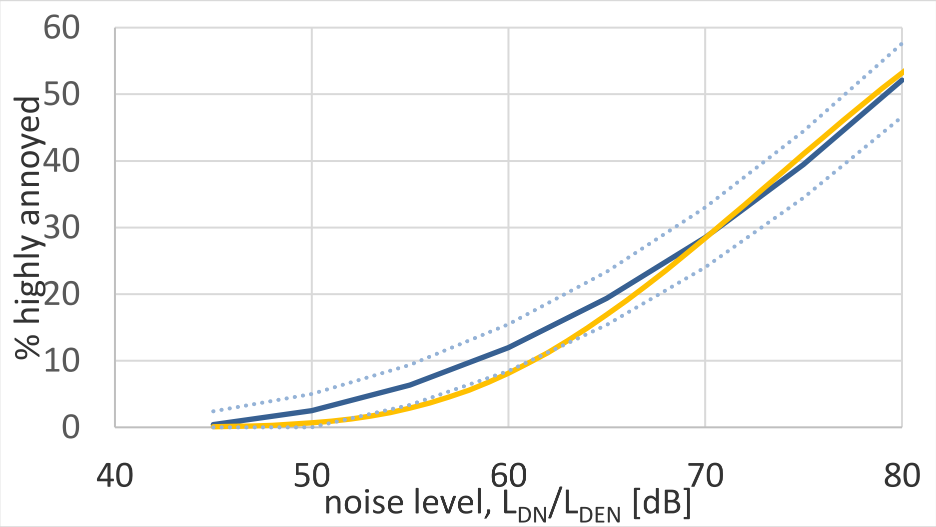

Figure 1. Dose-response curves for road traffic noise. Regression function derived by Miedema & Vos (blue line) with corresponding 95% confidence intervals (dotted lines) and curve corresponding to L_{ct} = 78 dB (yellow line)

The Danish Road Directorate has published results from a survey on annoyance from noise from different types of roads: urban roads and motorways [15]. In their report they use a logistic regression function and conclude that the dose-response curves for the two traffic situations have different slopes and different intercepts. Figure 2 shows these two regression functions compared with a CTL analysis of the same data. The two CTL curves are described by identical mathematical functions but spaced 12 dB apart on the x-axis. The CTL values are L_{ct} = 79.6 dB (urban roads) and L_{ct} = 67.6 dB (motorways) respectively. The traffic volume for the roads that are included in this study varies, but the traffic on the motorways (ADT) is typically five times higher than on the urban roads.

The Danish Road Directorate has also conducted a similar study of motorways and urban roads in or near Copenhagen [16]. The CTL values for this study are L_{ct} = 76.2 dB (urban roads) and L_{ct} = 66.9 dB (motorways). This is a difference of 9.3 dB. The traffic volume for motorway M3 is about twice as high as the motorways in the study above.

Lercher *et al.* have reported a study on annoyance from motorways and main roads in the Alpine region. They report CTL values of L_{ct} = 75.3 dB (main roads) and L_{ct} = 72.3 dB (motorways). This is a difference of only 3 dB.

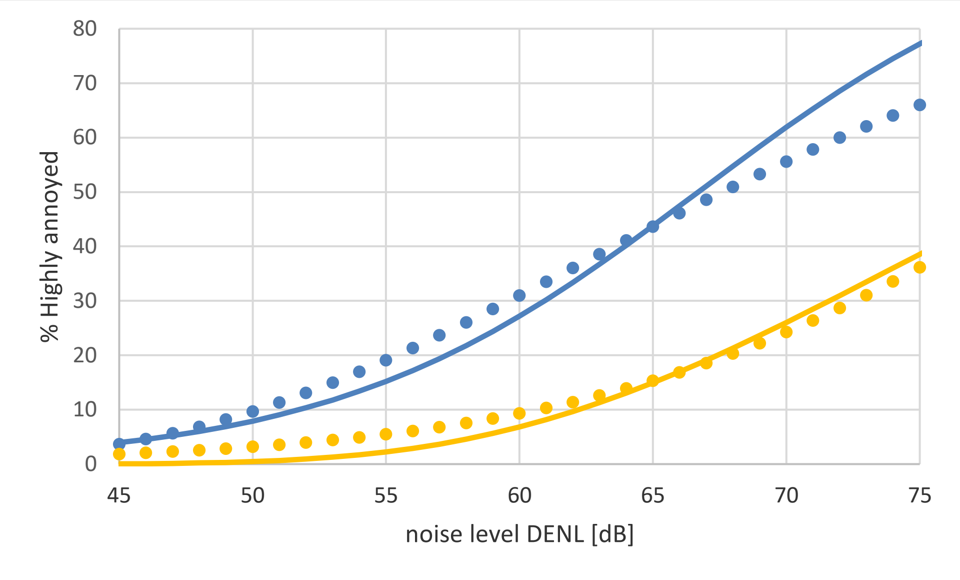

Figure 2. Dose-response curves derived from a Danish survey [15]. Solid lines show conventional logistic regression functions (motorways – blue, urban roads – yellow). The dotted lines are based on CTL analysis.

CTL for comparative studies

The results from the two Danish studies are similar with a difference in CTL between motorways and urban roads of 9-12 dB. A likely conclusion could be that noise from a motorway is more annoying than noise from an urban road equivalent to a difference in exposure of about 10 dB. However, a similar comparison between the Alpine studies show that the difference is only about 3 dB.

Gjestland *et al.* have studied the connection between aircraft noise annoyance and number of aircraft movements [61]. They have shown that a doubling of movements is equivalent to about 2 dB in noise exposure. In the Danish studies the traffic volume on the motorways is about 5 times higher than for the urban roads. If the results from the aircraft noise studies can be applied to road traffic as well, one may hypothesize that about half of the difference in annoyance between the Danish motorways and urban roads is caused by differences in traffic volume. In other words, the difference in the annoyance response is caused by two major non-acoustic factors: traffic volume and road type (driving behaviour, speed, etc.).

For the Alpine studies, the difference in traffic volume between motorways and main roads is smaller, and thus the "volume factor" plays a smaller role.

Conclusions

Analyses according to the CTL method give results that are well suited for comparison of inter-survey differences. The CTL value gives a direct quantification of the effect of non-acoustic factors influencing the annoyance response.

The challenge with respect to the FAMOS project is to find surveys on road traffic noise annoyance that are reported in a sufficiently detailed manner so that different non-acoustic factors can be identified.

11.2. Appendix A2: The relations between annoyance score and percentage annoyed

In Figure 149 the relations between the average annoyance response on the 0-10 scale and the percentage of Highly Annoyed (%HA), Annoyed (%A) and Little Annoyed (%LA) can be seen.

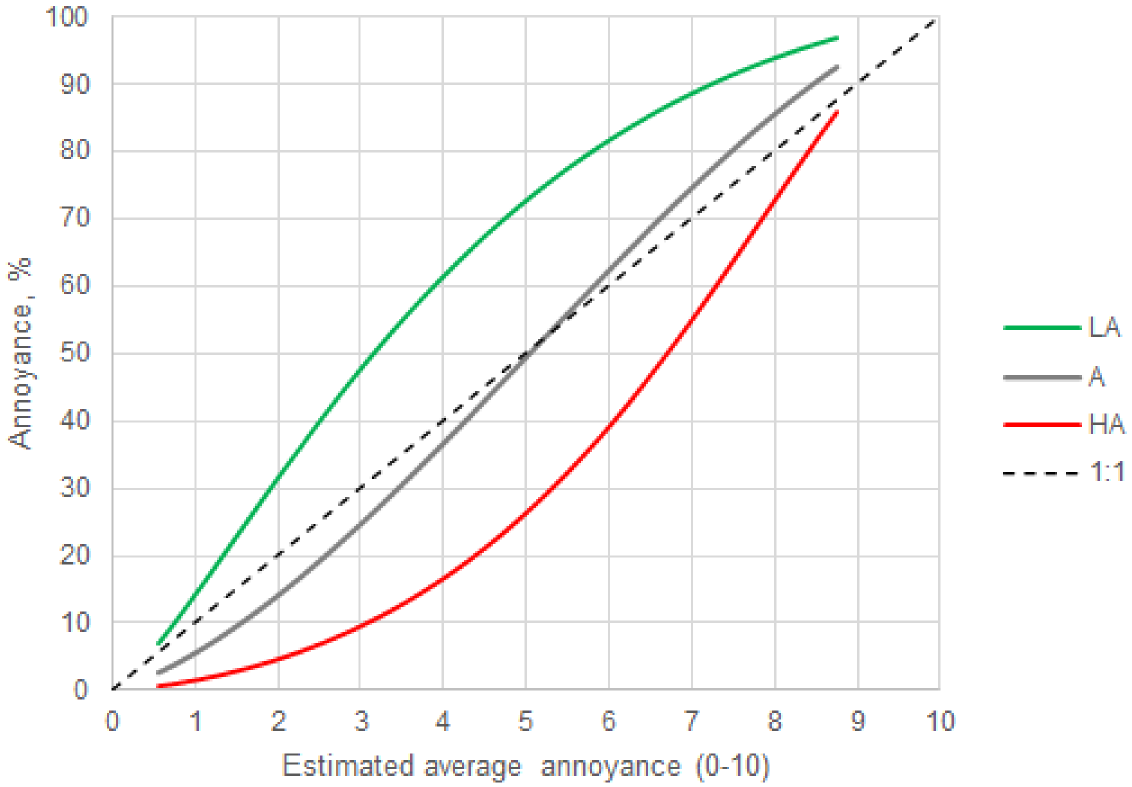

Figure 149 The relation between average annoyance response on the 0-10 scale and the percentage of Highly Annoyed (%HA), Annoyed (%A) and Little Annoyed (%LA).

The graph is based on finding in [48].

It can be seen that e.g., an average response of 3 corresponds to 10% Highly annoyed

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Conference of European Directors of Roads
Avenue d'Auderghem 22-28
1040 Brussels, Belgium

e-mail : information@cedr.eu
Tel. : + 32 (0) 2 771 2478