PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Urban road traffic noise interventions: a method to quantify their effects on annoyance and sleep disturbance at a small scale

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ABSTRACT

Road traffic is the main source contributing to noise exposure in urbanized areas. With the rapid urbanization and increasing attention on the way sound can affect health and wellbeing, the question is how to shield ourselves from harmful effects. In the most common noise intervention studies only large-scale interventions, like noise barriers along a highway, are assessed. The effects on health and wellbeing are based on rough estimations of sound reduction. In this study, the effects of a small scale intervention on annoyance and sleep disturbance will be investigated, considering relative changes in dose-response relationships to account for local effects. It will give more insight into the subtle changes due to interventions on a local scale, providing more detail additional to existing conventional studies.

To develop this methodology an intervention study in Rotterdam was taken as a test case. The location and its intervention were modelled using a 3D geometrical acoustics software (Olive Tree Lab). The predicted noise reduction due to the interventions, as well as the predicted health effects, were compared with measured data and local surveys. The results shed a light on the suitability of this approach to predict health effects due to interventions at a local scale.

Keywords: Intervention, Mitigating Measures, Exposure Response Functions, Health effects, Annoyance, Sleep disturbance

1. INTRODUCTION

In 2014, 54% of the world population lived in urban areas. It is predicted that by 2050 this will increase to 66% (1). This increasing urbanization comes with an increase of infrastructure and industrial areas in and around cities, creating major sound sources that can affect a large number of people. Possible effects of noise on people can be: hearing damage, sleep disturbance, annoyance, increased risk to get cardiovascular diseases, increased blood pressure and cognitive impairment. The world health organization (WHO) estimated in 2011 that 1.0-1.6 million healthy life years are lost due to noise exposure (2).

Road traffic is the main source contributing to noise exposure in urbanized areas. To shield ourselves from the harmful effects, interventions are needed. The available studies on the effect of interventions on levels from road traffic noise and health effects are limited due to the difficulty of doing measurements before and after the interventions. When available, studies mainly focus on large-scale interventions, like barriers along a highway. These areas are more likely to be less densely populated than inner city areas, where the rapid urbanization will play a major role. Also, the effect on health and wellbeing is often based on rough estimations of sound reduction (3).

In this study, the focus is shifted to small scale urban areas, investigating the effect of noise interventions on annoyance and sleep disturbance. By combining detailed acoustic calculations with local survey data, the aim is to provide a method to study interventions on a local scale and get more information of their effect on sound, health and wellbeing, and to provide a methodological base for further research.

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The study is unique in its approach to develop an assessment method combining 3D acoustic modeling and available exposure response functions (ERFs) from literature. For this study a test case is needed, a location where an intervention has been performed and health and wellbeing data are recorded. With these health data and acoustic data (measured and calculated) insight can be given into the applicability of generalized ERFs.

2. TEST CASE

The following criteria were used for the selection of a Dutch inner-city test case: an intervention was performed at the location; survey data on health and wellbeing was available before and after the intervention and road traffic is the main source of noise. The chosen location was the Strevelsweg (see Figure 1), an intervention study in Rotterdam performed by the Municipal Health Service of Rotterdam (GGD) (4). This case pertains a street where the asphalt was covered with a noise reducing top layer (Dutch: Dunne Geluidsreducerende Deklaag (DGD)), the goal being to lower the noise level on the facades and thereby reducing negative health effects. Before and after the intervention, health and wellbeing surveys have been carried out by the GGD. The location is characterized by a wide main road with closed building blocks and smaller, secondary roads located parallel to it.

Figure 1 – Test case, Strevelsweg (indicated in red) Rotterdam, The Netherlands © OpenStreetMap contributors.

3. THE MODEL

3.1 Acoustic model

The location was modelled in the 3D acoustic software application Olive Tree Lab (OTL) from Mediterranean acoustics. The advantage of the program is its accuracy, which lies in-between commonly used noise mapping software and detailed wave-based calculation programs. The order of reflection and diffraction, atmospheric absorption and turbulence, and Fresnel zone corrections are taken into account.

The scenario was abstracted to its acoustically essential form. Buildings were modelled only with flat roofs, the ground surface was modeled as acoustically hard and other elements like trees, street lanterns and parked cars were not taken into account. Road traffic sound sources were represented in the form of an incoherent line source placed at 0,05m height. The acoustic model was verified with measurements, see Section 3.2.

3.2 Prediction model verification

Acoustic measurements were performed on the location to verify the OTL model. Five measuring points were chosen on both sides of the street (see Figure 2). The choice of locations was based on noise maps provided by the municipality of Rotterdam (5). At position 1, 4 and 5, low levels of around 40 dB(A) are indicated. However, position 1 and 4 still have a view on the Strevelsweg and this suggests that there is a possibility for direct sound to reach the position and result in higher sound levels. Next to measuring point 3, a camera was positioned to record the traffic, which was counted afterwards to determine the traffic flow. The measurements were performed with a Tascam DR-40 recorder with an external ISEMcon ¼” EMM-7101-CSTB microphone mounted on a 1,5 m tall tripod. During the recordings, sound events (e.g. people walking past, car door slamming) were noted and later removed from the sound file using the Audacity software. The cleaned recording was then processed further in Matlab resulting in a sound pressure level in dB per 1/3 frequency band per measurement location.

Figure 2 – Noise map with measurement positions (5).

3.3 The model

The measurement positions were placed in the model together with two line sources representing the two traffic lanes. The counted traffic flow is used as input for the traffic sound power spectrum calculation using the CNOSSOS method (6). The resulting spectrum was used in OTL as a line source.

The results from the measurements were compared to the modeled results of OTL. Settings (e.g. number of reflections, diffractions etc.) in OTL were adjusted, such that the model are in satisfactory agreement with the measured results.

From the verification process it was determined that the situation as it was at the time of the measurement (d.d. 2018) mostly resembled the situation before the intervention, a road surface with regular asphalt. This can be attributed to the fact that the measurements were performed 5 years after implementation of the noise reducing top layer. It is commonly known that noise reducing top layers have a short lifespan and therefore it might have been at the end of its performance at the time of the measurements.

While the calculated noise exposure in L_{den} ranged from 58 to 77 dB(A), two thirds of the receiver positions had an L_{den} of over 70 dB(A). It was observed that receiver positions located further from the line sources experienced a larger deviations in calculation results (up to 5 dB(A)) when calculations were repeated.

3.4 Acoustic data for the Exposure Response Function (ERF)

To develop a local ERF, a connection needs to be made between survey data on annoyance and sleep disturbance and the exposure. Exposure is measured in the form of L_{den} 2 m from the façade at a height of 4 m. Therefore, the model was expanded with more receivers, placed at the addresses where survey data were known, see Figure 3. With this model, both the before and after intervention exposure can be calculated. The available survey data were spread over a large area and not all receiver positions with available survey data were included in the model. Only the positions that experienced a change in sound exposure according to the research by the GGD were included in the model.

Figure 3 – Positions where survey data was available © OpenStreetMap contributors.

4. SURVEY DATA

The survey for the GGD research had a total of 69 respondents spread over multiple zip code areas. Only 28 respondents could be detected that lived in an area exposed to the noise of the Strevelsweg. The remaining group was used as a control group.

Within the survey, people were asked to rank their noise sensitivity, rate their satisfaction with their living environment on a number of domains including a general rating, noisiness, safety and visual quality. 29% Percent of the people in both the exposed and the control group indicated that they were noise sensitive. Remarkable was that within the exposed group, less people evaluated their neighborhood as noisy compared to the control group (56% vs. 78%) whilst the sound levels in the exposed group are significantly higher than in the control group. Another noteworthy result was that the general satisfaction with the environment (rating above 8/10) decreased from 11.5 to 7.7 % after the intervention. This can be due to the dissatisfaction with the results of the intervention, because only 10% of the people expected a change in noise due to the intervention. Finally, the number of people experiencing annoyance or sleep disturbance was higher in the control group than in the exposed group. The number of people (highly) annoyed and (highly) sleep disturbed before and after the intervention can be seen in Figure 4 and 5. To be classified as highly annoyed or sleep disturbed the rating on the "annoyance/sleep disturbance by road traffic noise" needed to be equal to 8 or higher on a 11-point scale from 0-10, for annoyed/sleep disturbed the rating needed to be equal to 5 or higher.

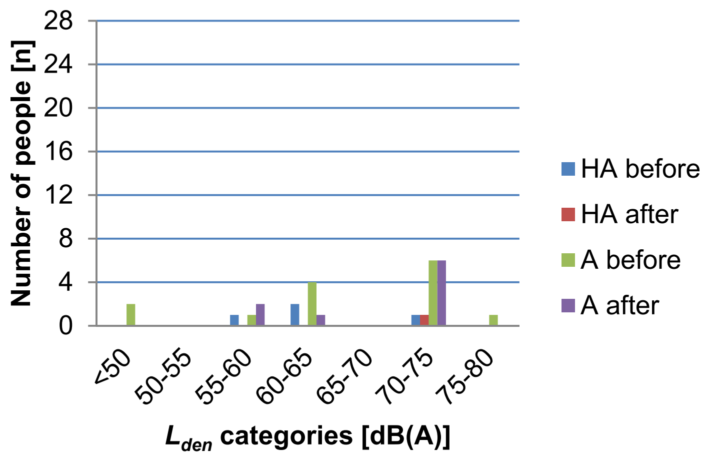

Figure 4 – Number of people (highly) annoyed (A) in the exposed group (n=28), before and after the intervention

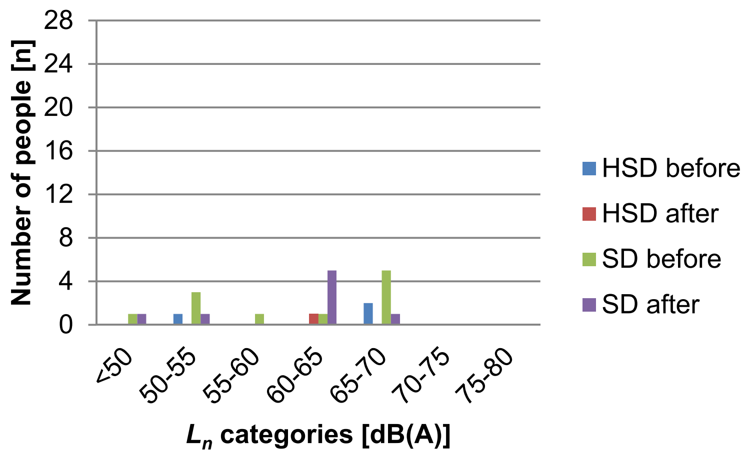

Figure 5 – Number of people (highly) sleep disturbed (SD) in the exposed group (n=28), before and after the intervention

4.1 Analysis and interpretation of exposure response functions

Exposure effect relationships used in decision making processes, like those in literature reviews preceding the WHO guidelines (the Miedema curves (7, 8)), are aggregated from many (steady state) studies of large groups all over the world. The applicability of these relations to lower scale areas can be questioned. At low scale, contextual factors like opinions on neighborhood quality, noise sensitivity, start to play a role in the perception of sound. These contextual factors are ignored in generalized data. The goal in this study is to see if the generalized curves can be used to obtain accurate results regarding the prediction of the percentage (highly) annoyed or sleep disturbed. This was done by using survey data of the Strevelsweg before and after the intervention. These data were compared to the predicted levels of percentages highly annoyed (HA) and sleep disturbed (SD) of generalized curves at the corresponding level. An important note is that information on predicted levels of percentages of lower level annoyance and sleep disturbance is unavailable in the new WHO review on ERFs (9) or recent Dutch studies.

The survey dataset from the Strevelsweg consisted of 69 respondents, however only 28 where located directly along the Strevelsweg. Due to the small dataset, the number of people who experienced high annoyance or high sleep disturbance was limited, see also Figure 4 and 5. In addition, the majority of the exposed group had a calculated L_{den} above 70 dB(A) before the intervention as well as after, the other noise classes were therefore not represented well. The choice was made to not analyze the percentage HA and HSD but to analyze the percentage A and SD. The sound exposure was further processed in categories of 5 dB(A) instead. The ERFs will be displayed as a function of 5 dB L_{den} and L_n categories ranging from 50-80 dB(A).

The downside of this method is twofold, firsly a change in A or SD cannot be read from the curve if the exposure change is within a L_{den} or L_n category. Second, the most recent ERFs (d.d. 2018) from the WHO (9) cannot be compared to the local curves, since these only predict the percentage HA and HSD. The Miedema curves (d.d. 2001 for annoyance and d.d. 2007 for sleep disturbance) predict percentage of low annoyance, annoyance and high annoyance as well as for sleep disturbance. These curves may be older, but are not outdated; they are still used for governmental and research purposes at a European level and international level.

4.2 Local exposure response functions

In Figure 6 and 7 the ERF, composed of the calculated noise levels and the survey data, before and after the DGD intervention can be seen for annoyance (A) and sleep disturbance (SD) together with the Miedema curves (7,8) respectively. In both cases the local curves lie underneath the Miedema curve. The annoyance curve follows the same trend as the Miedema curve up until the 55-60 dB(A) category, after the local curve continues at a more constant level and the Miedema curve increases rapidly. The local SD curve follows the trend of the Miedema curve quite closely, however the after curve is higher than the before curve indicating that the sleep disturbance increases after the intervention. However, the shift in the curve is small (2%) and the explanation may lie in the limited data used for fitting the curve. In the before situation, the number of people SD are 1 and 5 in category 60-65 and 65-70 dB(A) respectively. In the after situation there are 5 people SD in category 60-65 dB(A) and only one in category 65-70 dB(A). Therefore, in the after situation the maximum is shifted more towards the middle of the noise exposure scale, moving the curve upwards. In theory these could be the same five people from the before situation, being equally annoyed in spite of the level change.

There are a few remarks which have to be made regarding these graphs. First point concerns the study group on which the Miedema curve is based. The exposure levels within this group are mainly below 60 dB(A), the annoyance response above this level is extrapolated from the response in the lower exposure levels, so this is a mere prediction. The fact that the local annoyance curve follows the trend of the Miedema curve until 60 dB(A) is promising.

Second point concerns the confidence interval, in the graphs the 95% confidence interval is displayed, however a tolerance level can also be used. The tolerance level is higher/wider than the confidence interval, which makes it more likely that the local curves will fall within the tolerance limits than in the confidence interval. Unfortunately, applying the tolerance limits for the Miedema curves in the graphs below was not feasible within this study, due to the small sample size.

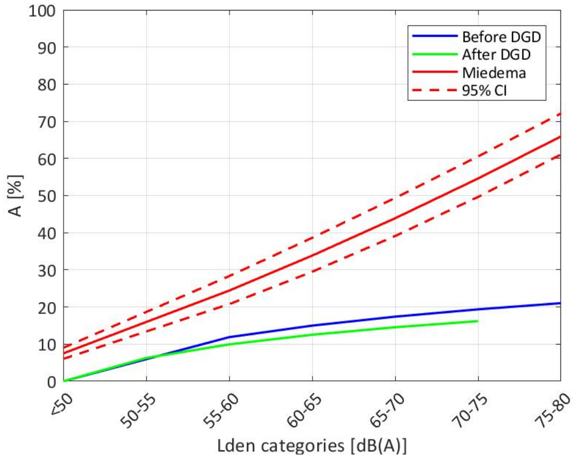

Figure 6 – Calculated local ERF for annoyance before the placement of the noise reducing top layer (DGD) and after, compared to the Miedema curve with 96% CI.

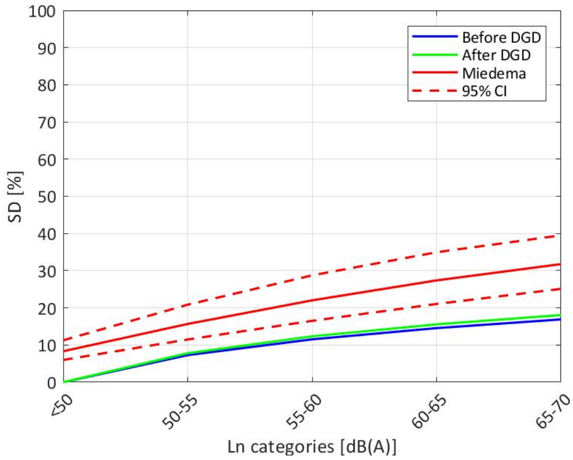

Figure 7 – Calculated local ERF for sleep disturbance before the placement of the noise reducing top layer (DGD) and after, compared to the Miedema curve with 96% CI.

4.3 Predictions by Exposure Response Functions

The local curves, in theory, can be used to predict the effect of other interventions on health and wellbeing. The method to do this is by looking at the population within one exposure group, e.g. 65-70 dB(A), and see what the curve predicts. In the case of the SD after curve this is 18.1% SD for the A after curve this is 14.5% A. The same method could be used to verify the results from this study, however the population is too small to do this. When looking at a specific exposure group, especially with lower levels, the groups are small. This can lead to misleading results, e.g. in a group of four people where one person as an annoyance score above 5 (experiences annoyance) the whole group is 25% annoyed, whilst the curve might suggest a 10% annoyance.

It should be kept in mind that annoyance and sleep disturbance differ per person and the percentage, which is presented by the curves, should not to be taken as an absolute figure. When analyzing the effect of an intervention it is better to look at the change in percentage rather than the actual percentage itself. As an example, a group of 25 people is taken who were in exposure category 65-70dB(A) before the intervention and in 60-65 dB(A) after the intervention. It is better to say they had a change of 1.2% in SD and 4.9% in A rather than 16.8% of the group was SD before and 15.6% or 17.4% was A before and 12.5% after.

When looking at this relative change, it can be seen that the Miedema curve can predict the local response of SD well, due to the similar slopes. For A this is also true up until 60 dB(A).

5. DISCUSSION

The goal of this study was to develop a method to analyze the effect of noise exposure on health and wellbeing on a smaller scale and to see how local ERFs compare to generalized ones. It was found that generalized ERFs as used in current policy documents do not predict the percentage annoyed or sleep disturbed well in the terms of absolute values, as the local curves, modelled in this study, lie below the generalized curve. However, for sleep disturbance, the trend of the Miedema curve and the local curve was the same, meaning that the relative change in sleep disturbance can be predicted by the generalized Miedema curve. Regarding annoyance, a similar relative change was also found until the noise exposure category 55-60 dB(A). The position of the local curves below the Miedema curves is in contradiction with the findings of the literature study. In intervention studies most local curves were located above the Miedema curve and that Miedema under estimated the health effects (10-17).

5.1 Strengths and limitations

The strengths of this study lie with the unique approach of using modelled sound data and survey data on such a small scale. The method used shows promising results, however there are limitations to the acoustic model that was used. The acoustic model was made using just one ground type. The Strevelsweg shows a variation of ground types since in-between the two traffic lanes a strip of grass is present, as well as areas of grass are present in the side streets. It was however not possible to take into account more than one ground type in the modeling program without it producing errors. In addition, performing calculations with higher order diffractions was not possible without errors, therefore the measurement positions located in parallel streets to the Strevelsweg have no modeled data. Finally, there were large difference between identical calculations, although some difference is expected since it is a random model, deviations of up to 5 dB(A) were found. This makes the modeled data unfit to base definitive conclusions on. Therefore the exposure levels were clustered into categories of 5 dB(A).

The survey data used had its limitations as well. As stated many times already, the database was very small due to the low response rate to the survey, however when initially thought to be working with a population of 69 people, this decreased to 28 when just the people are taken into account for which the interventions affected the noise levels. But even when the exposed group would have been larger, the OTL process would also have restricted the size of the modeled location and thus the exposed group.

Within the survey, it was found that some questions were not asked in the traditional, standardized way. For example, the annoyance and sleep disturbance due to road traffic was split into road traffic (meaning cars) and scooters. The questions making up the Groningen sleep scale were also not complete, some questions from the original protocol had have been left out. There were also adjectives added to the question relating to the perception of the sound environment. There is little consensus in the population regarding the meaning of these extra adjectives, therefore they have little added value to the study.

Finally, the distribution of the participants over the different exposure categories was not even. The population in the highly exposed group was dominant which makes predicting effects in low exposure categories nearly impossible because conclusions are based on the information from one or two people.

6. CONCLUSIONS

In this study it was assessed if it is possible to develop a method to quantify the effects of road traffic noise interventions on health and wellbeing on a small urban scale. For this purpose, a 3D acoustic model is used (Olive Tree Lab), combined with survey data from a study performed by the municipal health service of Rotterdam (GGD).

The location under investigation was the Strevelsweg in Rotterdam, where a noise reducing top layer has been applied to the road surface in 2013. Before and after the implementation of the intervention, questionnaire surveys have been performed by the GGD. Using a 3D model of the location, the noise levels on the facades of the participants were modeled before and after the intervention. The model was verified with measurements. The results from the survey regarding annoyance and sleep disturbance related to road traffic noise were combined with the modeled noise exposure to create local ERFs.

The combination of modelled sound data and survey data on such a small scale is unique and the method applied in this study shows promising results, however it has shown that a much larger survey population is needed to verify the results and to find results with meaning. In addition, extensive measurements data or a higher consistency and applicability of the prediction method are needed to obtain more accurate results.

ACKNOWLEDGEMENTS

This study is carried out under commission of the Ministry for Infrastructure and the Environment in the Netherlands, department Climate, Air and Noise (KLG) - Now Infrastructure and watermanagement. M/240039/18/SI. This study was made possible with the help of Mediterranean acoustics, Tom Koeman (the Municipal Health Service of Rotterdam-Rijnmond (GGD)), Lex Burdorf (Erasmus MC) and Lex Brown (Griffith University). Maps were made available by © OpenStreetMap contributors under the Open Database License which can be found at www.openstreetmap.org/copyright

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