The application of a notice-event model to improve classical exposure-annoyance estimation

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Abstract: Sound perception of humans is determined by a variety of factors such as intensity, frequency, temporal structure, masking and localization. Furthermore, a wide range of non-acoustical factors determine whether certain sounds are perceived as annoying.

However, classical exposure-response determination for the assessment of annoyance and health effects is based on *average sound levels* - sometimes with applied penalties for evening and night noise (Lden).

A research collaboration between Ghent University and the Medical University Innsbruck focuses on the improvement of exposure-annoyance modeling by including characteristics of the temporal structure of both sound exposure and the attention of the involved human subjects. The basis for this work is the"notice-event-model". Intensive traffic modeling serves as input for extended individual noise mapping per dwelling. The model allows testing the additional impact of derived acoustical indicators for the temporal pattern of the main sources (Highway, main road, railway) and for the human activity pattern to accommodate for masking and habituation.

In the single source analyses the inclusion of specific fluctuation parameters provide interesting insight into the effect on the percentage of highly annoyed in main road or motorway exposed.

In the multi-source case the LAeq threshold for high annoyance is significantly lowered in the notice event case model (home and wake) when compared with the classical Lden analysis

The comparison with previous analyses shows a strong agreement with the thresholds for 25% highly annoyed in the multi-source situations, although further development is needed to replicate the results in single source situations.

Keywords: Sound perception, annoyance, fluctuation, emergence, activity pattern, exposure – response, multi-source environment

1. Introduction

Sound perception of humans is determined by a variety of factors such as intensity, frequency, temporal structure, masking and localization. Furthermore, a wide range of non-acoustical factors determine whether certain sound sources are perceived as more annoying than others [Fields, 1993; Lercher, 1996; Miedema and Vos, 1999].

However, the classical assessment of annoyance (and health effects) is largely based only on intensity information by using average sound levels – in the European Union typically with applied penalties for evening and night noise (Lden). It is well known that the classical assessment can lead to distorted environmental health impact assessments when acoustical, environmental, social and health conditions do

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not coincide with those in the classical archival exposure response information. Substantial deviations from classical exposure response information have been reported. Fields et al. (2000) calculated that communities may differ on average the equivalent of about 7 decibel. The reasons for these substantial deviations are still subject to controversy.

Moreover, the assessments are made separately for each sound source in the absence of valid and established methods to summarize sound exposure information from several sound sources [Lercher, 2011]. However, the combination of rail and road (highway, main roads) noise exposure is highly prevalent in European countries and the understanding of the interactive effects of noise from combined sources is critical to effective regulation [Job and Hadfield, 2001].

A combined research effort between Ghent University and the Medical University Innsbruck focuses to improve the overall environmental sound assessments by additionally implementing the temporal sound structure and the human time-activity pattern into the acoustic assessment. The basic ideas are outlined in a recent paper [De Coensel et al., 2009] and an application of this concept using a large survey in Tyrol, Austria, was reported [Bockstael et al., 2011].

In this paper we report the application to a second survey in a different valley in Tyrol, Austria, which was conducted within the ALPNAP-study [Heimann et al., 2007].

The extended approach reported here included also socio-demographic and basic health variables in the exposure response analyses. Furthermore, results from both single source and multi-source analyses are compared. Eventually, a short comparison of the results from both surveys is presented.

2. Material and methods

2.1 Survey information

The area of investigation, the Unterinntal, is the most important access route for heavy goods traffic over the Brenner. The goods traffic over the Brenner has tripled within the last 25 years and the fraction of goods moved on the road has substantially increased (up to 2/3). The area consists of small towns and villages with a mix of industrial, small business and agricultural activities. The primary noise sources are motorway and rail traffic. Other sources are main roads, which link villages and the motorway.

People aged between 25 and 75 years were contacted by phone selected by a stratified, random sampling strategy. The address base was stratified by use of the GIS (Geographic information system), based on fixed distances to the major traffic sources (rail, highway, main road), leaving a common „background area“ outside major traffic activities and an area with exposure to more than one traffic source, i.e. “mixed traffic”. From these five areas households were randomly selected and replaced in case of non-participation. An exclusion criterion was duration of living less than one year at this address. 45% did not want to participate. The rest of the addresses were not valid (commercial etc), did not have telephone or could not be reached by 3 attempts at different times of the day. Finally, 1643 persons (35 % of the original sample on an individual basis) participated. On household level the participation was much higher. Women were more willing to participate (61%).

Age is used as a continuous variable. Education was measured with 5 grades (basic, skilled, labor, vocational school, A-level, University degree). The last two grades were combined in the category "higher education". Health status and noise sensitivity were subjectively judged on a standard 5-grade scale (1 to 5). Noise annoyance was measured with a 5-point verbal scale according to ICBEN and ISO standards (Fields et al., 2001). In the present analyses, highly annoyed was defined by responses to the two upper points (4+5) on the 5-point verbal scale.

2.2 Sound exposure

A two-stage procedure is followed to estimate the time-varying sound level at the dwelling façade of each survey participant. First, time series of levels caused by each source are simulated, taking into account the closest highway, major road and railway only, and using free field propagation conditions. Secondly, the simulated time series are calibrated such that the Lden corresponds to that obtained from a noise map, taking into account the particular alpine propagation conditions of the study area (Heimann et al., 2007). Percentile levels were then calculated for the total sound exposure and for the exposure caused by all combinations of sources. From the percentiles, measures for 'fluctuation' and 'emergence' can be calculated per source. Fluctuation is defined as the difference between the source event (L1 for highway, L5 for main roads, L10 for railway) and the source background level (L90 for highway, L99 for main roads, L90 for railway). Emergence is defined as the difference between the source event (L10 for highway, L5 for main roads, L10 for railway) and the overall background level originating from all natural and traffic sources except the source under study (L90 for highway, L99 for main roads, L90 for railway). For the three sources, particular percentile levels are selected to establish minimal correlation between fluctuation, emergence and other noise measures.

2.3 Implementation of the notice event model

The simulated sound level time series serve as input to the notice-event model (De Coensel et al., 2009), which is used to estimate, for each dwelling in the survey, the time periods that a person living at that dwelling would pay attention to the sound of each of the considered sources. Activity patterns, collected from activity diaries of people living in the ALPNAP study area, and from the Austrian Time Use Survey of 2008-2009, are used to simulate the time use of modeled individuals, and to account for activity-based sound, which may mask intruding transportation noise. A first outcome of the notice-event model is the (indoor) exposure LAeq for each source, calculated over the 'home-and-awake' periods, i.e. those time periods that the modeled individuals are actually at home and not asleep. A second outcome is an estimate of the total duration of attention paid to each sound source, the notice time. Inspired by the hypothesis that only consciously noticed sounds contribute to annoyance, a third outcome is the sound exposure level (notice SEL) of each source during those periods that it is paid attention to (notice time). Additionally, assuming that the contribution of an event to annoyance is proportional to its audibility above the background, a fourth outcome is the noticed sound exposure level above the notice-threshold, noted as notice SELthr.

2.4 Statistical analysis

Exposure-effect curves were calculated with extended logistic regression methods using restricted cubic spine functions to accommodate for non-linear components in the fit if appropriate [Harrell, 2001]. Approximate 95 % confidence intervals were estimated using smoothing spline routines with three knots and exposure-effect plots generated with the RMS-library [Harrell, 2011]. Predicted probabilities of highly annoyed are derived from the estimated odds with a specific function in the RMS-library (plogis).The predicted probabilities of highly annoyed in the exposure-effect plots are adjusted to the median (continuous variables) or the reference category (non-continuous variables) of the other variables in the model. The analysis was carried out with R version 2.12.2 [R, 2012] using the contributed packages “Rms” and “Hmisc” from F Harrell (2011).
Candidate variables are introduced in the different models through a manual stepwise procedure. Socio-demographic and health variables were kept in the model – independent on statistical significance. Likewise, distance to source. The acoustical and notice event parameters were then added and its value judged on classic statistical but also Public health criteria (significance and importance).

3. Results

3.1 Single source models

Distance to source (p=<.0001) age, gender and education (p=0.0031) remained significant only in the motorway model (p=<.0001). Noise sensitivity and health status stayed significant in all source models. Through the inclusion of the socio-demographic and health variables the threshold for 25% highly annoyed was reduced by 3 to 4 dBA,Lden. The 25% thresholds were lowest for main road (46 Lden,dBA), followed by motorway (52 Lden,dBA) and railway (67 Lden,dBA). The R^2 was lowest for the railway model (14%) and similar for main road and motorway (18 vs 19%).

By adding fluctuation to the main road model its contribution gets larger than the one from the Lden due to confounding. Thus, due to the extremely high correlation (0.98) of the parameters, a valid assessment of its additional contribution was not guaranteed. Therefore, we skipped the Lden from the model and evaluated the fluctuation parameter alone: the exposure annoyance curve shows a non-linear increase between 10 to 16 dBA (25% highly annoyed) and continues to increase linearly (Figure 1).

Although not statistically significant (p=0.09) an increase in emergence from 0 to 10 dBA lowers the 25% threshold for main road highly annoyed by 4 dBA. All notice time indicators did not improve the model compared with the use of fluctuation or emergence.

The motorway model improved by including fluctuation (p=0.0135). The model was biased due to the high correlation between fluctuation and Lden (r=0.88). Leaving Lden off the model fluctuation is highly significant (p= 0.0001) and shows a steep linear increase of % HA between 5 and 12 dBA (25% HA around 9 dBA) and then levels off (Figure 2). Neither emergence nor one of the notice parameters did improve the model beyond the full health model.

In the railway models none of the psychoacoustic parameters did improve the model.

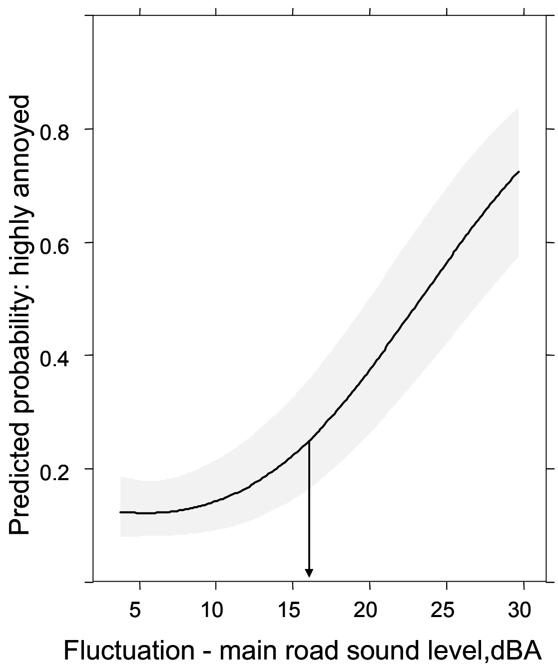

Figure 1 – Fluctuation (LA01-LA90) - % highly annoyed by main road sound

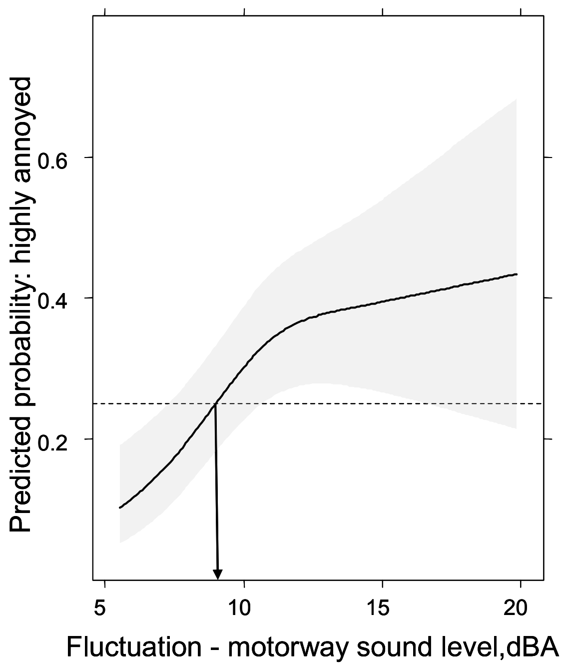

Figure 1 – Fluctuation (LA01-LA90) - % highly annoyed by motorway sound

3.2 Multi-source models

The models including the sound from all three sources were related to annoyance from all traffic sources. Both, the classical Lden model and the alternative notice event model (LAeq during home and awake periods) did show about the same variance explanation (R^2=16.2 vs 16.5%). However, a comparison of the exposure response curves reveals quite a difference in the threshold for the highly annoyed (Figure 3+4). When fluctuation (p=0.09) is included in the LAeq-home-awake-model the 25% threshold level for high annoyance lowers further down to 44 dBA. Fluctuation does also contribute (p=0.06) to the overall Lden model – but does not further lower the threshold (59 dBA).
All other parameters (Notice time, Notice SEL, Notice Threshold) did not further contribute to either the Lden model or the LAeq during home and awake model, which is different from the ICBEN report.

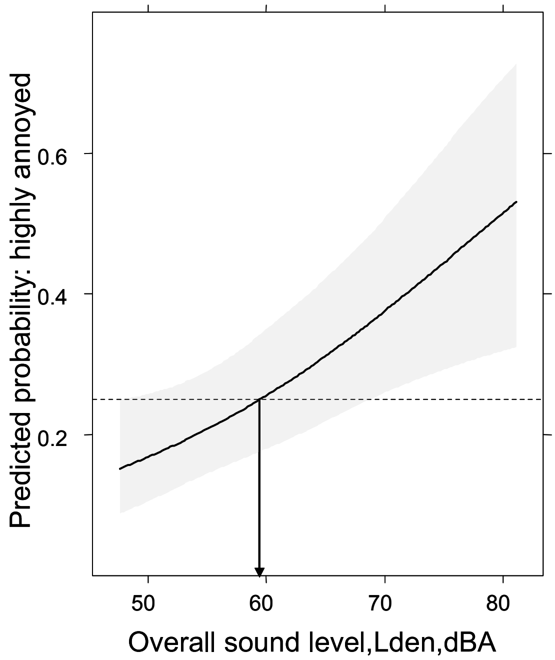

Figure 3 – Overall sound level, Lden - % highly annoyed by all sources (main, rail, motorway)

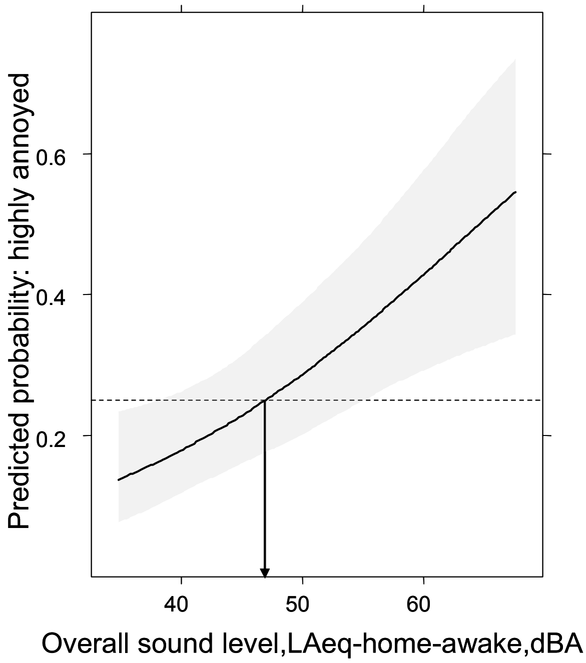

Figure 4 – Overall LAeq-home-awake - % highly annoyed by all sources (main, rail, motorway)

3.2 Survey comparison

A comparison with the results reported at ICBEN (Figure 5+6) show a remarkable agreement concerning the thresholds for the percentage highly annoyed for both surveys. The models differ slightly: the current analysis included health related variables. The ICBEN analyses contained additional notice parameters, which led to a significant model improvement in this analysis, which is not replicated in this study..

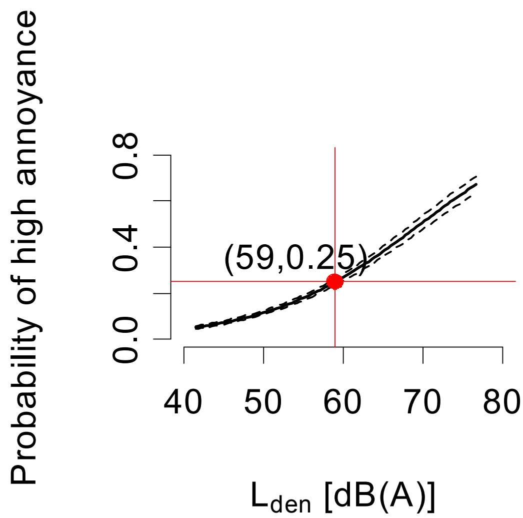

Figure 5 – Overall sound level, Lden - % highly annoyed by all sources (main, rail, motorway) BBT-study

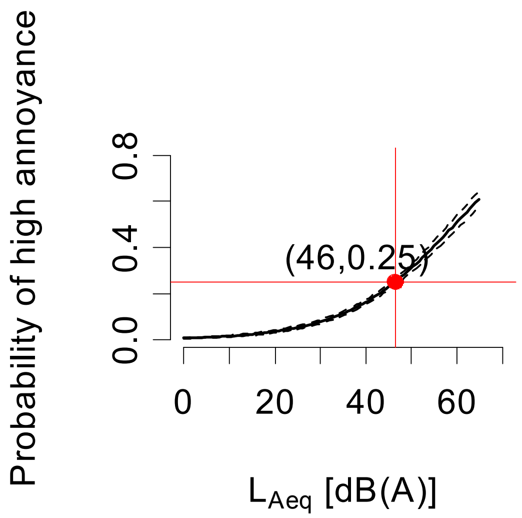

Figure 6 – Overall LAeq-home-awake - % highly annoyed by all sources (main, rail, motorway) BBT-study

4. Discussion

The consistency of the results in two surveys from 2 different valleys concerning the prediction of multi-source noise annoyance is reassuring. The link of activity pattern with notice events seems a highly promising approach to tackle the currently unsolved multi-source issue in environmental health impact assessment and in noise-health research.

The inclusion of socio-demographic and basic health variables is encouraged to make assessments between different areas more comparable. Other health outcomes beside annoyance should be tested.

Furthermore, the inclusion of simple fluctuation or emergence indicators is promising – since the computational burden is much smaller. It has, however, to be clarified whether in the analysis with the railway as single source neither notice event parameters nor fluctuation/emergence are sensitive.

The results need to be repeated in other surveys with different background conditions.

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