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THE EFFECTS OF NOISE CALCULATION METHODS ON ANNOYANCE AND HEALTH ASSOCIATION ESTIMATION

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1 INTRODUCTION

Noise pollution is increasingly regarded as a growing public health problem[1,2,3]. This is addressed by the European Noise Directive (END) by requiring member states to determine public exposure, and to adopt action plans for prevention and reduction of environmental noise where necessary[4,5]. The available noise – health association's still show large variations, depending on where and how the exposure-effect relations are generated[6,7,8]. In order to accurately evaluate or predict the effects of noise action plans or large scale transportation projects, major efforts are needed to improve on both estimation of noise and annoyance or health outcome measures.

The annoyance assessment was standardized by an ICBEN-initiative and eventually an ISO-standard was established. For the measurement of effects on sleep and cardiovascular health by survey methods, researchers are dependent on the quality of health information that is available from registries, clinical units or community doctors or on the memory of the study participants.
Accurate exposure estimation is undoubtedly another indispensable prerequisite for a valid estimation and prediction of noise associated health effects. It is a widely held belief that noise maps are a suitable tool for this purpose. Such noise maps are nevertheless approximations of reality based on simplified and standardized engineering type propagation models, which are often the result of a compromise of calculation efficiency and accuracy.

Typically, engineering methods and the resulting noise maps are validated against long term noise measurements in "simple" open area propagation conditions and not in complex residential settings where most people actually live. The European Harmonoise/Imagine initiative is a large effort to establish a contemporary calculation model for outdoor sound propagation that is highly configurable and can perform better on complex cross sections[9,10]. Although this is an excellent way to test the accuracy of the sound propagation and source model in terms of physical intensity, there are further aspects of the sound climate to consider which determine the reaction of humans to the actually perceived and psycho-psychologically processed sound input. Without evaluation of the various acoustic models in the framework of the actual noise – health relations something important is missing.

In this paper we report about the first integrated efforts between acousticians, meteorologists and health epidemiologists to assess the quality of the noise mapping process by means of health survey results. This work was carried out in the framework of the INTERREG IIIB project ALPNAP. It was funded to describe the Alpine-specific processes that determine the propagation of air and noise in Alpine valleys and their impact on health[6]. This collaboration across disciplines aimed at assessing the effects on the estimation of annoyance and other noise associated health impacts in an alpine valley for rail and main road traffic due to the use of different modeling techniques (ISO9613 (Bass3 by INTEC), NMPB-96 (Mithra-Sig by CSTB). Additionally, for motorways a simplified version of the Harmonoise/Imagine method (implemented by INTEC and CSTB) was evaluated.

2 METHODS

2.1 Area, sampling and population

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 highway and rail traffic. In addition a main road is of importance. This road links the villages and access roads to the highway.
People were contacted by phone based on 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 "mixed traffic". From these five areas households were randomly selected and replaced in case of non-participation. Selection criteria for people were age between 25 and 75 years, sufficient hearing and language proficiency. 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. Eventually, 1643 persons (35 % of the original sample on an individual basis) participated in this study. On household level the participation was much higher. Women were more willing to participate (61%).

2.2 Noise exposure estimation and assignment

Three groups of traffic noise sources are covered: Motorway traffic, traffic on main roads, and railway traffic. For motorway traffic the yearly average load (light and heavy vehicles) is combined with an average diurnal traffic pattern. Traffic intensity data on main roads were supplemented with additional counting data. Road traffic noise emission is calculated on the basis of the Harmonoise/Imagine source model[11]. Railway noise emission is extracted from a typical day of noise immission measurements at close distance to the source.
Bass3 is an extended version of ISO9613. The model includes up to four reflections and two sideway diffractions[12, 13].
Mithra-Sig is the NMPB-96 implementation by CSTB, the current standard engineering method recommended by the END for road traffic modeling.
The Harmonoise/Imagine point-to-point propagation model is a candidate European standard engineering model that builds upon the Nord2000 project[10, 14]. It promises better performance in complex terrain – but is computationally quite intensive and some simplifications had to be made to be applicable in such a large area. Only one reflection and two vertical diffraction edges were accounted for in this implementation.
An extensive noise monitoring campaign was conducted to check the validity of these simulations. At 38 locations sound levels were recorded for over one week during winter (October to January) and during summer (June to August). In addition, the predicted sound pressure levels resulting from PE-modelling have been evaluated against these long-term measurements[15]. In a next step, the validated PE model has been used to check in detail the Harmonoise/Imagine point-to-point sound propagation model in this mountainous region, in combination with the assumptions made to relax the computational effort in a noise mapping software[13].
Indicators of day, evening, night exposure and Lden were calculated for each source and total exposure at several points on the facade of the building of the survey participants. In the present analyses the maximum Lden of the four home facades of the respective source was utilized.

2.3 Health information

The questionnaire covered socio-demographic data, housing, satisfaction with the environment, general noise annoyance, attitudes toward transportation, interference of activities, coping with noise, occupational exposures, lifestyle, reported sensitivities, health status, selected illnesses and medications. The phone interview took about 15-20 minutes to complete. Noise annoyance was measured with a 5-point verbal scale according to ICBEN and ISO standards[16, 17]. In the present analyses, highly annoyed was defined by responses to the two upper points (4+5) on the 5-point verbal scale. The noise impacts on sleep were assessed by an independently asked question on sleep medication – unrelated to noise – as recommended.

2.4 Statistical methods

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[18]. The non-parametric regression estimate and its 95% confidence intervals are based on smoothing the binary responses and taking the logit transformation of the smoothed estimates. The analysis was carried out with R version 2.9.1 and 2.10.1 (R Development Core Team 2006)[19] using the contributed packages "Design" and "Hmisc" from F Harrell[20, 21].

3 RESULTS

3.1 Annoyance

Figures 1, 2 & 3 show a side-by-side comparison of the noise-annoyance relationships for motorway, main road and railway sound levels for BASS3-ISO, MITHRA-SIG and HARMONOISE/IMAGINE (only motorway) noise modeling. For comparison, the standard exposure-annoyance curve (from END) is inserted (black line) in addition.

For motorway noise, the sound modeling with MITHRA-SIG shows reasonable agreement with the standard curve, except for an underestimation at higher sound levels. Both, the BASS3-ISO and the HARMONOISE/IMAGINE modeling depart substantially and indicate higher annoyance at any noise level.

The strongest deviation from the standard curve is observed in the main road graph while both modeling techniques agree quite well. Railway annoyance (Figure 3) is increasingly underestimated at higher levels by MITHRA-SIG modeling - but much less when compared with motorway sound modeling.

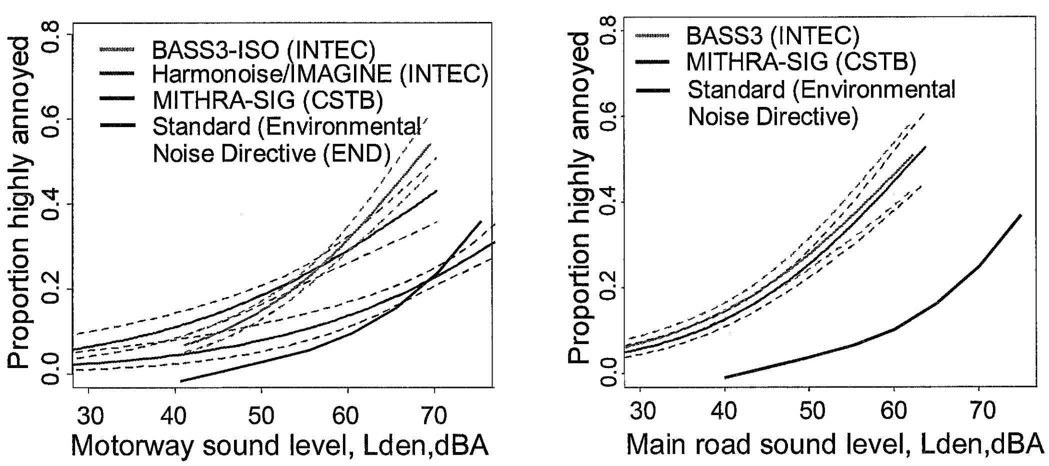

Figure 1 and 2. Exposure effect relationships: highly annoyed by motorway (left) and main road sound exposure (right) by different noise modeling procedures compared with the standard curve (Environmental Noise Directive). Dashed lines indicate 95% confidence intervals.

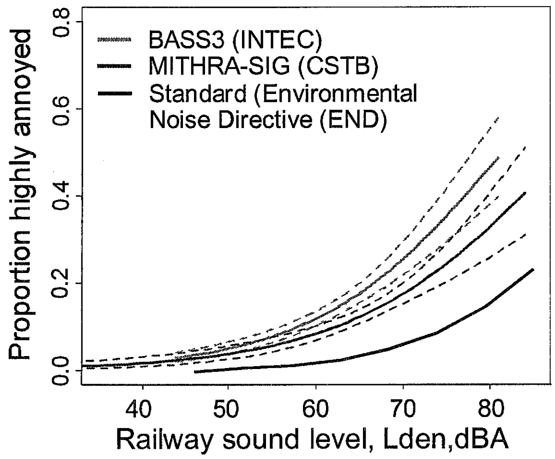

Figure 3. Highly annoyed by railway sound by two modeling strategies and compared with the Standard annoyance relationship

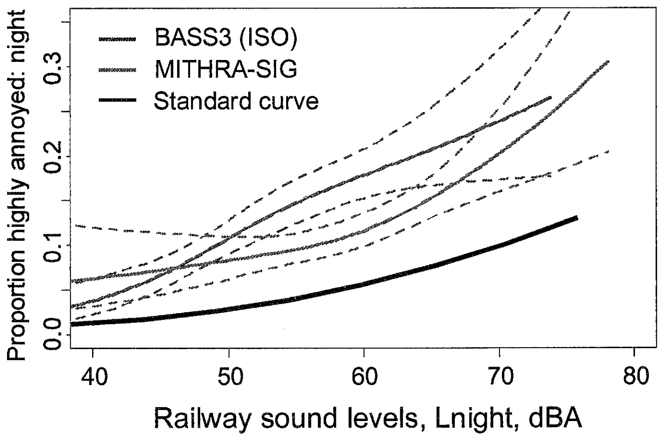

Figure 4. Highly annoyed by railway sound by **during night** by two modeling strategies the and compared to the Standard annoyance curve

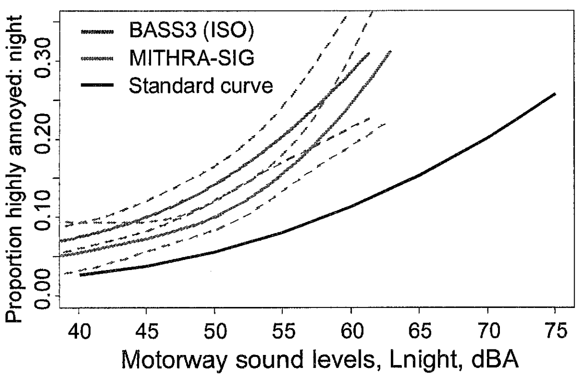

Figure 5. Highly annoyed by motorway sound **during night** by two modeling strategies and compared with the Standard curve

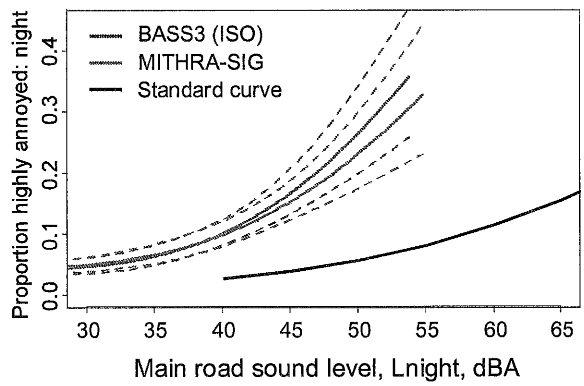

Figure 6. Highly annoyed by main road sound **during night** by two modeling strategies and compared with the Standard curve

Viewing the modeling differences between Mithra and Bass3 for the Lnight-indicator (Figures 4, 5, 6) it is evident that they are not completely mimicking the differences seen with the Lden-indicator. Especially, the motorway curve shows a smaller systematic difference and the difference for the railway is shaped in another way. However, the distance of the annoyance curves to the standard curves remains about the same.

3.2 Sleep medication

Taking sleep medication is an obvious sign of the severity of an underlying sleep problem. At first (Figure 7) the importance of adjusting relevant covariates is shown to tease the single effects of noise on sleep apart. In the second graph (Figure 8) we see a surprisingly good agreement of both sound-medication-effect curves (MITHRA and ISO-variant Bass3).

However, in the case when the true Public health impact is at stake then the question about the application of adjustments may be asked again. Since the average population has a certain distribution of all these risk factors to which the additional sound exposure contributes what is reflected by the increase in the slope with increasing sound level. While the increase in the slope in the unadjusted model may not be statistically significant – since most people are exposed between 50 and 65 Lden, dBA it may nevertheless be relevant in terms of Public health.

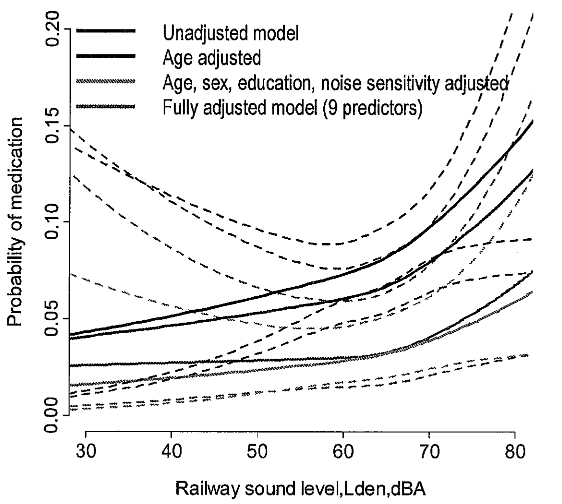

Figure 7. Exposure effect relationship (MITHRA) rail sound exposure and sleep medication: the effect of adjustments on effect estimation

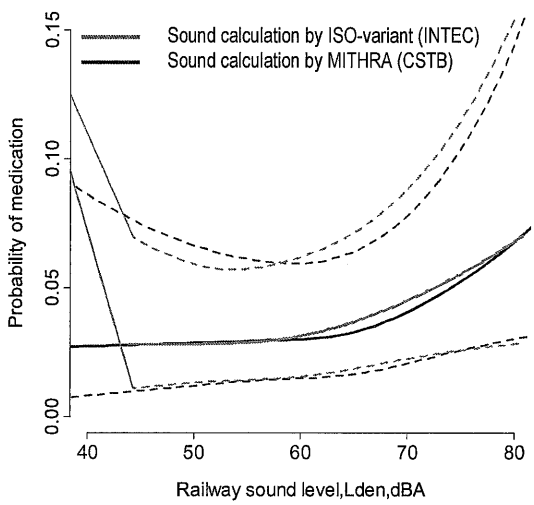

Figure 8. Exposure effect relationship: rail sound exposure and sleep medication intake: comparison of two modeling techniques

Under this understanding and considering the minimal difference in effect estimation the choice of the sound exposure modeling technique seems to be of secondary importance. Taking a look at Table 1 you see that the small visible difference in the slope resulting by the two modeling techniques could suggest a different Public health regulation based on statistical significance.

Table 1. Increase in the probability (prevalence odds ratio) of taking sleep medication at different railway sound level intervals comparing two methods of exposure modeling

	Increase in Odds ratio (95% CI) at different sound levels			
Sound calculation method	50-60 Lden,dBA	55-65 Lden,dBA	60-70 Lden,dBA	65-75 Lden,dBA
MITHRA-method **	1.05 (0.67-1.66)	1.13 (0.77-1.64)	1.37 (1.05-1.78)	1.63 (1.10-2.42)
ISO-method: Bass3 ***	1.11 (0.74-1.68)	1.29 (1.02-1.64)	1.46 (1.04-2.06)	1.53 (1.00-2.33)

** Fully adjusted model (9 predictors)
*** Fully adjusted model (9 predictors)

3.3 Hypertension

Hypertension is an important Public health outcome due to its high prevalence in the adult population. For this reason and also due to the very good biological foundation of a noise contribution via the stress axis it is a paradigmatic case for risk assessment.

In the ALPNAP-study we had the opportunity to evaluate three different exposure modeling procedures for motorway sound. Figure 9 shows a comparison between the ISO-method implemented by INTEC (Bass3) and MITHRA, implemented by CSTB.
Overall we observe a very good agreement of the slope with both methods above 55 dBA. In the lower part of the curve the result diverges to some degree suggesting a threshold effect through the ISO-modeling and a more linear increase starting at very low levels. Obviously the confidence intervals are rather wide below 50 dBA in both techniques. Thus the trust in this result is not great at these lower levels although a bunch of variables (age, gender, education, duration of living, house type, BMI, family history of hypertension, health status) were adjusted for in the statistical model.

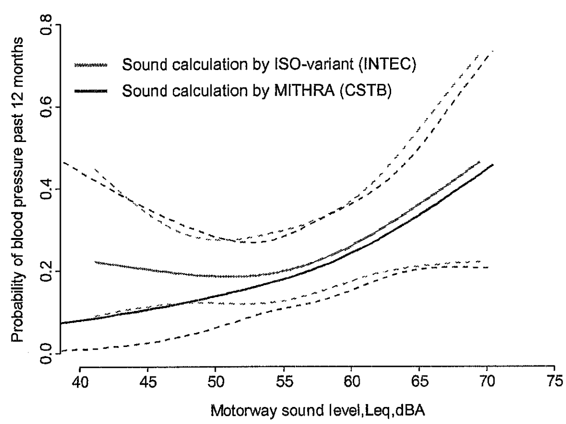

Figure 9. Probability of hypertension by motorway sound exposure: a direct comparison of two modeling strategies

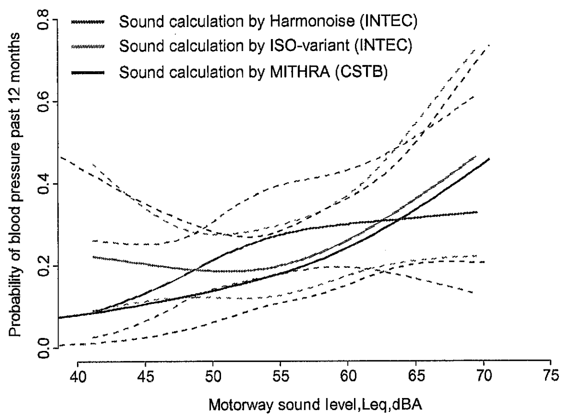

Figure 10. Probability of hypertension by motorway sound exposure: a direct comparison of three modeling strategies

Nevertheless, while the slopes agree well from 55 dBA on we feel confident to make a good judgment about the relevant contribution motorway sound may make to the hypertension load.
It gets, however, more complicated, when the exposure is modeled by means of a HARMONOISE variant implemented by the acoustics group of INTEC. The overlaid plot is shown in Figure 10. The slope of the HARMONOISE implementation shows a linear increase from 40 to 50 dBA, and then transforms into a saturation curve between 55 and 60 dBA. On visual inspection the confidence interval seems narrower at the lower – but wider at the higher levels. To clarify the statistical soundness of the three calculation methods to predict the noise contribution to hypertension the odds ratio increase from lower to higher levels is displayed in Table 2.

Table 2. Increase in the probability (prevalence odds ratio) of hypertension during the past 12 months at different motorway sound level intervals comparing three methods of exposure modeling

Sound	Increase in Odds ratio (95% CI) at different sound levels				
calculation method	40-50 Lden,dBA	50-60 Lden,dBA	55-65 Lden,dBA	60-70 Lden,dBA	65-75 Lden,dBA
MITHRA method*	1.83 (0.43-7.76)	1.99 (0.78-5.07)	2.30 (1.16-4.58)	2.51 (0.81-7.80)	2.54 (0.76-8.51)
ISO method**	0.78 (0.27-2.26)	1.54 (0.99-2.38)	2.27 (1.01-5.06)	2.58 (0.97-6.84)	2.60 (0.97-7.00)
HARMONOISE***	3.18 (0.75-13.50)	1.59 (0.96-2.64)	1.22 (0.53-2.79)	1.14 (0.45-2.92)	1.14 (0.45-2.92)

* Imlemented by CSTB, ** Implemented by INTEC, *** Implemented by INTEC

The inspection of Table 2 makes clear that the piecewise estimation of risk is associated with wide confidence intervals. Although the point estimate increases with increasing sound level statistically significant increases are only observed between 55-65 dBA with the MITHRA method. The ISO-method provides better statistical evidence showing three borderline and one significant result while the model using the HARMONOISE-exposure assignments fails to indicate a significant increase also at the lower half of the exposure-axis.

4 DISCUSSION

Through independent comparison of standard techniques in noise modeling we observed significant differences in the estimation of the highly annoyed by sound from different sources.
The best agreement among the modeling procedures was found for main road noise followed by railway noise exposure. The largest discrepancy observed was with motorway noise. The HARMONOISE/IMAGINE mapping implementation was closer to the ISO-variant Bass3 than to MITHRA.

What would be the effects on risk assessment for Public health purposes (e.g. in an EHIA)? Under the assumption that all calculation procedures worked as intended Mithra noise mapping would underestimate the percentage highly annoyed at 70 dBA against HARMONOISE/IMAGINE mapping by 20% and even 30% against the Bass3-ISO mapping implementation in the case of motorway noise. This is quite a relevant finding for planning, risk assessment and noise control. However, because no gold standard is available for absolute comparisons it cannot be decided on the ground of this study what the truth is.

The case is much better with the prediction of annoyance due to railway noise and nearly no differences were observed when the main road estimates were compared.
Notably, the estimation of nighttime annoyance due to motorway sound did reveal smaller differences in the prediction of highly annoyed than in the case of overall annoyance.

With the "harder" health endpoint sleep medication intake the differences between the sound calculation methods in estimating the noise associated risk increase are much smaller. The ISO-method would indicate a significant increase in sleep medication already when noise exposure increases from 55 to 65 Lden, dBA, while MITHRA indicates this at 5 dBA higher levels.

In the case of hypertension diagnosis the MITHRA- and the ISO-method showed good agreement at middle and higher sound levels – the statistical uncertainty involved was slightly greater with the MITHRA assignments. The simplified Harmonoise/Imagine point-to-point propagation, a candidate European standard engineering model, performed less well than the other two models showing the largest statistical uncertainty for the effect estimation and displayed a different exposure-effect curve.

5 CONCLUSIONS

The observed effects different noise mapping procedures may exert on annoyance estimation can introduce significant bias in environmental health impact assessment for different sound sources. Notably, the differences in the estimation of more serious health outcomes such as sleep medication intake or diagnosis of hypertension in relation to the sound exposure levels are less pronounced.
In addition to the classical evaluation strategies of noise mapping software further evaluation and testing is needed in conjunction with important health outcomes in survey research to minimize bias in noise risk assessment. Thus a move from mere exposure modeling to exposure- effect modeling is required to minimize bias in Public health risk assessment of the effects of sound on humans.

6 ACKNOWLEDGEMENT

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