Alternative traffic noise indicators and its association with hypertension

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Summary

The current evidence supporting an association between traffic noise exposure and hypertension is mixed. Hypertension is the most prevalent and preventable ill health condition in adults of OECD countries and an established risk factor for more severe cardiovascular endpoints such as myocardial infarction and stroke. Several methodological flaws hinder a proper assessment. Among those are study design issues, hypertension assessment, lack of handling of other risk and contextual factors in the regression models and eventually misclassification of exposure. Studies in acoustics have demonstrated that standard indicators of sound intensity (Leq 16hrs, Lden) may not always suffice to explain effects of noise on humans. Studies on annoyance responses revealed that indicators of noise characteristics and dynamics are likewise important. Moreover, standard noise mapping methods do often not include all roads and are known to underestimate the real exposure on the quiet sides and the exposure from the neighborhood.

In a secondary analysis of a cross-sectional survey (N=2002, 80% participation) we were able to derive several dynamic noise indicators from original sound recordings for 1500 participants. In addition, we included necessary medical and contextual factors in the multiple logistic regression models to evaluate the relative potency of the noise indicator contribution. Eventually, we evaluated both, diagnosis and medication use of hypertension as separate health outcome indicators.

Overall, an association between several noise indicators and hypertension diagnosis and medication could be confirmed after adjustment for a basic set of potential confounders (age, sex, bmi, health status, sensitivity, education, area). The applied noise indicators performed slightly different regarding the traffic sources. With Lnight even a significant relation with highway noise was observed. The dynamic indicators fit slightly better with traffic sources where higher fluctuation (main road, railway) and contexts with lower background noise levels exist.

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1. Introduction

The current evidence supporting an association between traffic noise exposure and hypertension is mixed. The largest systematic effort (WHO evidence reviews) showed recently [1] a significant relative risk increase per 10 decibel for road traffic noise and prevalence of hypertension (RR of 1.05 (95% CI: 1.02–1.08) based on results from 26 studies (comprising 154,398 individuals and 18,957 cases of hypertension). The result for aircraft and railway noise were not statistically significant [RR of 1.05 (95% CI 0.95–1.17), resp. of 1.05 (95% CI: 0.88–1.26)]. However, the evidence base was smaller (9, resp. 5 studies). No significant evidence from incidence studies was found (only 1 study/traffic source). One weakness of this evidence assessment was that the quality of the exposure data used in those studies was not quality graded at all: all measurement or mapping routines were equally accepted. In contrast, strict study quality criteria (risk of bias) were applied to many other study aspects according to GRADE. Lden was used as noise indicator of choice and if other measures were used (e.g. Leq,16) a standard conversion to Lden was applied. Thus no new evidence was achieved regarding the validity of other noise indicators.

Therefore, still more innovative work is needed to improve exposure assignment for epidemiologic studies to guarantee a valid exposure assessment for critical time segments (e.g. evening, night), and critical spatial situations (e.g. topography, street canyons, backyards). We know that sleep disturbance correlates better with event number, maximum noise levels and arousal potential [2]–[4]. In addition, psychoacoustic approaches [5]–[7] and other advanced studies in acoustics have shown that standard indicators of sound intensity are not sufficient to explain effects of all noise and soundscape types on humans [8]–[14]. At least studies on annoyance responses revealed that indicators of noise characteristics (spectrum, pitch and temporal dynamics) are likewise important. Moreover, standard noise mapping methods do often not include all roads and are known to underestimate the real exposure on the quiet sides and the exposure from the near neighborhood [15]–[17]. Eventually, the type of source combination, a subject is exposed to, can affect the human response [18]–[22].

Our group has investigated the effect of temporal fluctuation and emergence in sound exposure on annoyance, based on an event related methodology [23]–[26]. Others have provided information on various specific [10][27][28][11] or reviewed general sound indicators [29]–[32]. However, the relationship of these alternative noise indicators with more severe health outcomes beyond annoyance (e.g. hypertension) needs still to be established [33].

Our primary aim in this secondary analysis of a cross-sectional study around the Brenner pass (Austria-Italy border) is to apply and compare the performance of traditional (Lden vs. Lnight) and selected alternative sound indicators in determining the exposure relationship of main road, highway and railway noise with physician reported hypertension diagnosis and reported use of antihypertensive medication.

2. Methods

2.1 Study areas and samples

The area of investigation - the Wipptal and its side valleys - is part of the most important north-south access route for heavy goods traffic over the Brenner Pass. The area consist of small towns and villages with a mix of small business and agricultural activities.

The selected study population (age 20-75 yrs) was approached by phone with a two-step sampling procedure. First, the area was divided into 5 sampling groups based on road type and distance to the sound sources.

From these areas persons of the appropriate age range and gender were randomly sampled with replacement.

People with short duration of living (<1 yr) were excluded. The sampling included also the side valleys without exposure to highway and railway but to a main linking road. Therefore, the available sample varied for the traffic sources and was smaller for the highway and railway exposure (~800). For main roads the full sample (~1500) was available. The overall participation was high (80%). Female participation was higher (65%) compared with data from the micro-census (53%).

2.2 Sound exposure and assignment

The major sound sources are the motorway, the railway and a main road in the main valley. In the side-valleys mainly exposure to a main road is relevant. However, villages at the entry of the side valleys experience also some exposure by highway or railway. Road emissions were calculated with an early version of the Harmonoise source model [34] supplemented with additional traffic counting and micro-simulations of the traffic flow with Paramics. Railway noise emission was extracted from a typical day out of several long-term sound immission measurements near the source (25 m). Sound propagation modeling was carried out with Bass3 [35], [36], an extended version of ISO9613.

The model includes up to four reflections and two sideway diffractions. The validity of these simulations was calibrated against measurement results from extensive sound monitoring campaigns during summer and winter.

Indicators of day, evening, night exposure and Lden were calculated for each sound source and total exposure for all facades of the participant's home.

To estimate the time-varying sound level at the dwelling façade of each survey participant 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. In a second step, 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 [37]. Moreover, percentile levels were calculated for each source, combinations of all sources and total sound exposure. From the percentiles, measures for 'fluctuation' and 'emergence' were calculated per source. Lden, Lnight, emergence and fluctuation indicators at the most exposed façade were used in the present analyses and assigned by GIS-linking. Detailed information about the definition of the used acoustic indicators is provided in earlier publications.

2.3 Questionnaire information

Persons were contacted by phone three times from a CATI-laboratory and then replaced. The standardized interview took about 15-20 minutes. The questionnaire covered socio-demographic data, housing, and satisfaction with the environment, noise annoyance, and interference of activities, coping with noise, occupational exposures, life styles, dispositions (noise, weather sensitivity), health status, selected illnesses and medications. Hypertension ever and current use of anti-hypertensive medication was inquired as "doctor-related information".

2.4. Statistical methods

Exposure-effect curves were calculated with extended logistic regression methods using restricted cubic spline functions to accommodate for potential non-linear components in the fit [38]. Approximate 95 % confidence intervals were estimated using smoothing spline routines with three knots and exposure-effect plots generated with the RMS-library from R [39]. Predicted probabilities of hypertension ever or anti-hypertensive medication are derived from the estimated odds with a specific function in the RMS-library (plogis). Due to collinearity problems the combined use of the Lden with either the fluctuation or emergence indicator was generally avoided. Only with combined road traffic used after several tests. The predicted probabilities in the exposure-effect plots are adjusted to the median (continuous variables) or the reference category (non-continuous variables) of the variables adjusted for in the full model. The analysis was carried out with R version 3.3.2 [40].

3. Results

3.1 Reported hypertension: Lden - Lnigth

Figure 1 compares the response relation for main roads with Lden or Lnight exposure assignments.

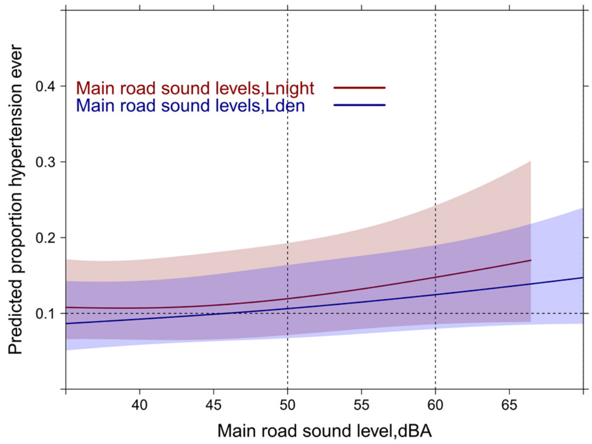

Figure 1. Relationship between main road exposure and reported hypertension ever comparing Lden with Lnight

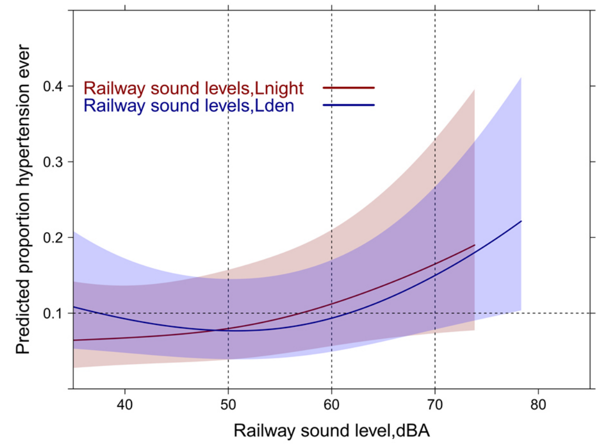

Figure 2. Relationship between railway exposure and reported hypertension ever, comparing Lden with Lnight

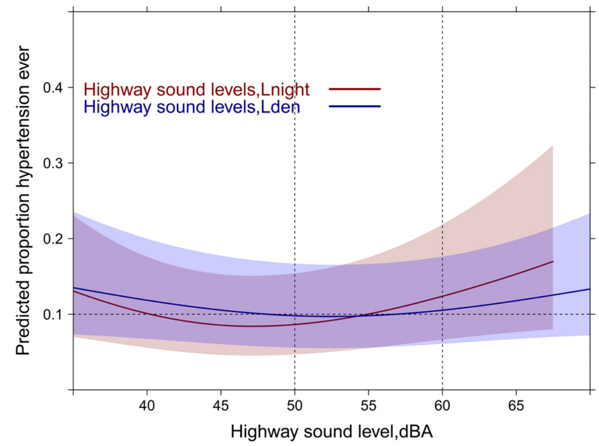

Figure 3. Relationship between highway exposure and reported hypertension ever comparing Lden with Lnight

In Figure 2 the exposure response relations with the same sound indices from railway noise are shown.

In Figure 3 the relation between Lden and Lnight is examined with highway noise and hypertension. While the associations with main road and railway noise are significant, no obvious relationship is observed with highway noise Lden while Lnight is showing a linear relation between 50 and 65 dBA.

3.2 Reported hypertension by emergence

In Figure 4 a comparison between the emergence levels of three sources and their relationship with reported hypertension is shown. As with Lden no significant relation is seen with highway noise. Main road exhibits a significant increase between 5 and 25 dBA but not beyond. The relation with Railway noise is of borderline significance between 10 and 25 dBA emergence (OR=1.68, 0.99- 2.84).

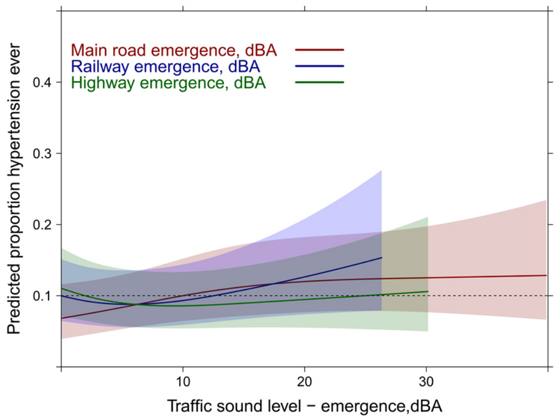

Figure 4. Relationship between emergence from three traffic sources and reported hypertension.

3.4 Reported hypertension by fluctuation

Nearly identical results were obtained with the fluctuation indicator.

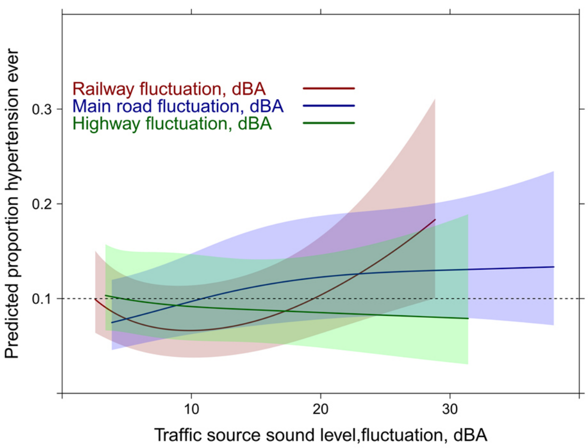

Figure 5. Relation between traffic sound fluctuation of three sources and reported hypertension.

In spite of large confidence intervals, the main road fluctuation is significantly related between 5 and 25 dBA (OR= 1.71, 1.21-2.42). Railway noise is significantly associated between 10 and 30 dBA (OR= 3.45, 1.53-7.76) with a nonlinear component.

3.5 Reported antihypertensive medication by Lden versus Lnigth

Figure 6, 7 show the relations with antihypertensive medication, comparing the Lden with the Lnight traffic sound indicator. Again no significant relation with highway noise (not shown). Lnight of main road is starting to be significantly already between 45 and 55 dBA (OR= 1.43, 1.08-1.90), Lden between 50 and 60 dBA (OR 1.34, 1.09- 1.65). Similar results are observed with railway noise.

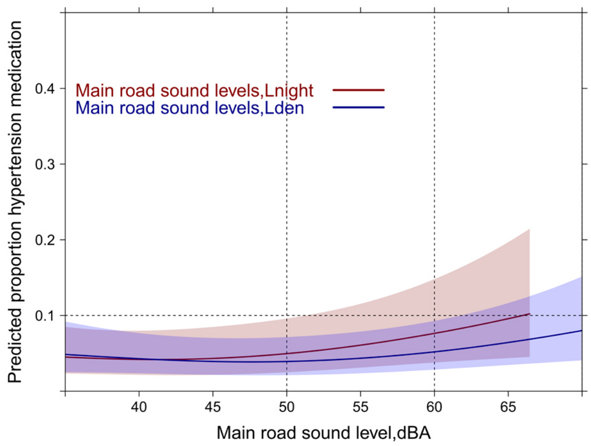

Figure 6. Relation between main road exposure and antihypertensive medication by Lden and Lnight.

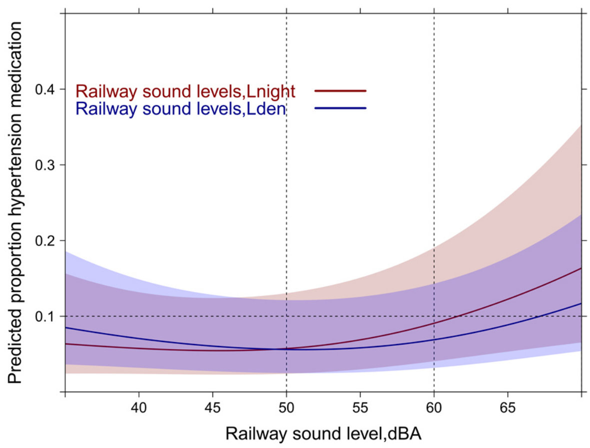

Figure 7. Relation between railway noise and antihypertensive medication by Lden and Lnight.

3.6 Reported medication by emergence

As with hypertension ever, highway did not exhibit a significant relation (Figure 8). Railway showed a significant increase between 10 and 30 dBA (OR=1.56, 1.04- 2.35). Main road emergence was of borderline significance between 10 and 25 dBA (OR=1.68, 0.995- 2.84).

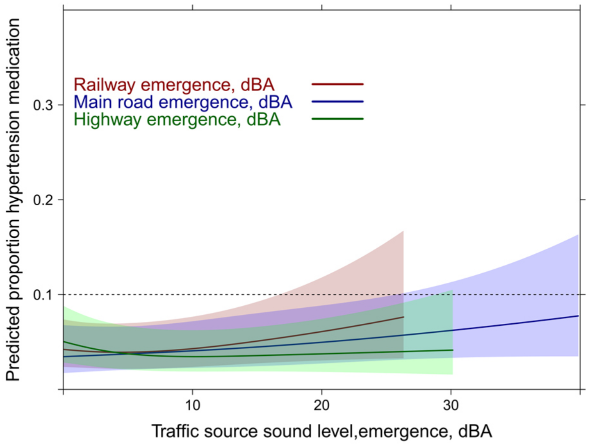

Figure 8. Relationship between emergence from three traffic sources and use of antihypertensives.

3.7 Reported medication by fluctuation

Highway fluctuation is not related to current antihypertensive use (Figure 9). Main road shows a linear increase with fluctuation (OR= 1.76, 1.14- 2.72). Rail noise fluctuation is strongly related to medication (OR=3.91, 1.52-10.06) with a significant nonlinear component.

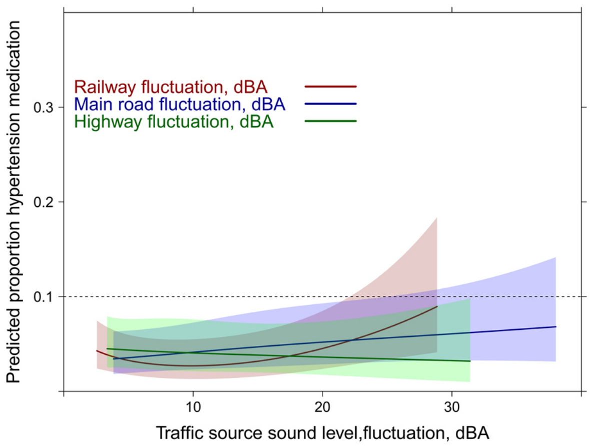

Figure 9. Relation between traffic sound fluctuation of three sources and current antihypertensive use.

3.8 Combined road traffic exposure with reported hypertension and medication

This analysis sampled persons only exposed to both main road and highway exposure. Here, with Lden, fluctuation and emergence indices of both sources were included in the model. Although the pseudo R^2 was already high in the other models (between 0.30 and 0.32) it increased slightly to 0.34 in the fluctuation model. In Figure 10 and 11 the adjusted standard models including fluctuation, respective emergence, are displayed for both the relation with reported hypertension and medication. Both Lden-fluctuation models are strongly significant from 55 dBA,Lden on. Both with a borderline nonlinear component and a significant fluctuation term.

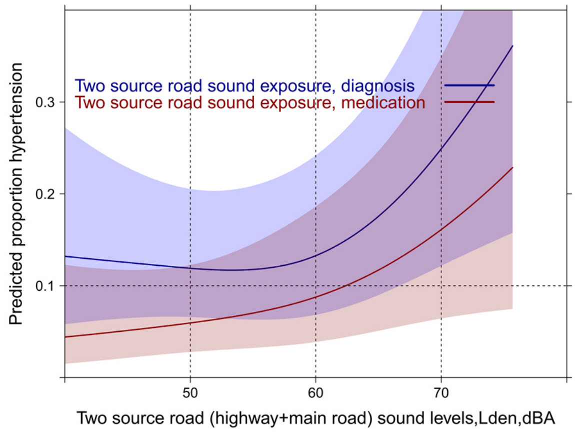

Figure 10. Combined exposure to two traffic sources, in addition adjusted to the fluctuation index of both sources, and the relation to either reported hypertension or current antihypertensive use.

The Lden-emergence models show similar statistical indices – although the medication model starts between 50-60 dBA to touch significance. The emergence term for main road is significant only in the hypertension diagnosis model.

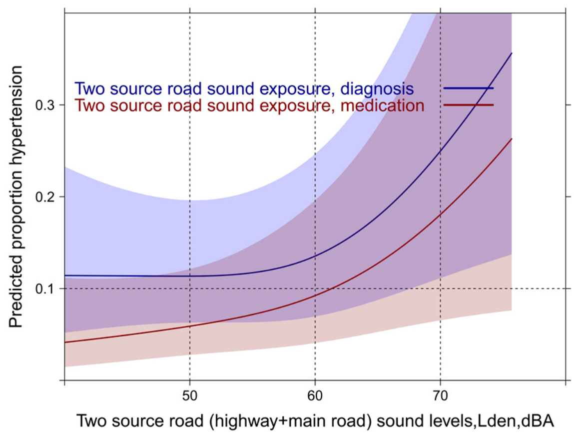

Figure 11. Combined exposure (two traffic sources), in addition adjusted to the emergence index of both sources, and the relation to either reported hypertension or current antihypertensive use.

4. Discussion

The results using and including additional acoustic indicators need a differentiated interpretation regarding sources as well as applied indicators. We observed the general trend for all sources that Lnight is a useful indicator beyond the Lden. This means when not using Lnight, this can lead to overlooking a significant relationship – as it would have been in the case of highway exposure (Figure 3). Furthermore, there is some indication from the analyses of finding a lower starting point of significance with the use of Lnight. Also the slope of the various exposure response curves is slightly steeper for most results. This may depend, however, on the day-evening-night difference in the survey samples you analyze. Notably, the recent WHO evidence review did not have data about Lnight results. Taking these observations together there is real need to require data about Lnight from all reported studies and downgrade the quality, if no information is given, in systematic reviews. Concerning alternative indicators, both fluctuation and emergence show similar relations with the analyzed endpoints of hypertension. Interestingly, both indicators did not observe a relevant relationship with highway noise, while the Lnight indicator exhibited such a positive relationship with hypertension – but not the Lden. Note: the calculation of both indicators was based on statistical levels simulated for the day and validated on measurements during the day. It may be therefore, that this calculation basis is not sensitive enough to detect health relationships which are stronger determined by the nightly sound exposure. A very clear relationship was observed in this smaller sample (N= 936) with combined exposure to main road and highway traffic. Notably, the significant fluctuation term for the main road indicates that the higher fluctuations of this type of road are contributing to the hypertension outcome beyond the Lden indicator. Concerning the two health indicators used: Unfortunately, there is no gold standard for measuring hypertension. Not all persons know about their hypertension (19% in this study), only a fraction takes medications (12% in this study) and another (unknown) fraction of this patient segment is not appropriately controlled or treated by their doctors. In our analyses we did not see relevant differences in the exposure response relation regarding the two measures of hypertension. We observed a consistent relation with all traffic types, except for highway noise. Here, we found a significant association only with the use of the Lnight indicator. Since the fluctuation and emergence indicators did not indicate a significant association you can hypothesize whether highway traffic with its more continuous flow is less disturbing than railway or main road traffic. This finding is supported by the analysis of the sample with combined road traffic exposure, where the main road fluctuation or emergence was a significant term in the full model. On the other hand the highway fluctuation or emergence did not contribute significantly or even in the wrong direction, which could also be a statistical artifact resulting from residual collinearity.

Nevertheless, the present study and its analyses have several strength as well as limitations. Among the strength of this study are the high participation (80%), the standardized interview protocol (CAT-Lab) and the detailed sound recordings as basis for the exposure assignments. Specifically, to mention are the additional traffic counting on smaller roads and the micro-simulations of the traffic flow with Paramics. In addition four sound indicators were utilized in the analyses.

The statistical treatment has considered the necessary adjustments and two outcome surrogates have been used for hypertension and provided a consistent picture.

An obvious limitation is the cross-sectional design. A drawback with the fluctuation and the emergence indicators in more sophisticated models (with more than 6 variables) is the very high correlation with Lden or Lnight, which often inhibits the use of both indicators together in a Lden or Lnight model.

In a next step further indicators mentioned in the literature or through personal contact within the "noise indicator" project will be tested with other health outcomes and in other surveys.

5. Conclusions

The results indicate the application of additional acoustic indicators is useful in health effect studies. Further methodological ideas are required to avoid the high correlations with the standard indicators. This means using indicators known to show less correlation with Lden [31] or through personal contact within the "noise indicator" project will be tested with other health outcomes and in other surveys. Eventually, the effect of combined source exposures is still not enough investigated.

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