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Noise and hypertension: Testing alternative acoustic indicators

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ABSTRACT

Standard acoustic indicators are reasonable means for health impact assessment of average transportation noise exposure situations. However, in its Annex I.3, the environmental noise directive admits problem areas (low frequency, tonal or impulsive components, quiet areas), where the application of "supplementary" indices may be necessary. Various indices accounting better for the traffic dynamics were proposed recently, with intermittency ratio (IR) being one of these. Hitherto, IR was mainly evaluated in the SIRENE study and the additional contribution was small. Our aim is to test, whether IR and another indicator (Leq-L50) works similar in an alpine study, which covered main and side valleys with a different transportation mix.

In a secondary analysis (cross-sectional survey, N=2002, 80% participation) we were able to estimate IR and Leq-L50 for 1500 participants from the original data set. These indicators were tested against diagnosis of hypertension in multiple logistic regression analyses, adjusted for main confounders (age, sex, BMI, health status, sensitivity, education, air pollution, smoking). The relationship with hypertension varied. Models explained 30 to 35% of the variance.

The contribution of both indicators differed between sources and source combinations. The strongest contributions were observed in mixed noise source scenarios.

Keywords: Sound indicator, Intermittency ratio, traffic dynamics, hypertension

1. INTRODUCTION

The use of standard acoustic indicators is a reasonable first step, when a health impact assessment of a typical transportation noise exposure is required. However, in its Annex I.3, the environmental noise directive admits problem areas (low frequency, tonal or impulsive components, quiet areas), where the application of "supplementary" indices may be *necessary*.

Specifically, the recent WHO evidence review on annoyance indicated rather large differences in standardized highly annoyance judgements not only at high but also at lower road traffic sound levels (1). Notably, the exposure effect curves of the included five alpine studies in the evidence review show a consistently higher annoyance response. At first glance, you may judge this as a systematic response bias related to psychological factors involved in annoyance judgements (e.g. media attention or the like). However, the cardio-vascular evidence reviews also show consistently increased risk for more severe illness (ischemic heart disease, hypertension) in the same alpine studies (2).

In previous analyses we found other perceived factors associated with road traffic exposure (exhaust fumes, vibration) explain some of the observed higher risk of annoyance (3). In addition, high coping efforts, (closing windows etc.) associated with anger, and sleep disturbance contributed. Another finding, related to main roads and railways, was the contribution of higher emergence of the sound exposure (signal to noise ratio) in the context of multiple sound sources.

In a follow-up analysis on the annoyance findings, we tested whether indices of emergence or fluctuation or Lnight would contribute to adjusted models with hypertension, an objective indicator of disease, beyond the classical Lden (4). We could repeat the importance of emergence and Lnight also in participants with reported diagnoses of hypertension or on antihypertensive medication. In addition, indicators of fluctuation played a role, while the perceived factors (exhaust fumes, vibration) or

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needed coping efforts did not play the role they had when annoyance was the outcome.

A major problem of the analyses was, however, to keep both Lden and the indicators of emergence or fluctuation in the same regression model due to its mutual high correlation.

In our current analyses, our aim was to test other sound indicators, which account for the sound level dynamics as in the previous analyses – but at the same time are not so highly correlated with the classic Lden.

The noise indicator Intermittency Ratio (IR) (5)has been recently applied within the SIRENE study with annoyance as outcome (6). IR showed lower correlation with Lden as compared to other noise metrics. The observed additional contribution was significant but small compared with the Lden. Furthermore, no moderation was observed between these two indicators. Also, IR was tested in the nationwide Swiss National Cohort (SNC) with cardiovascular mortality (CVM) and diurnal variability of noise exposure in focus (7). While the effects on CVM of noise exposure were confirmed with Lden as indicator, except for stroke, the IR did not show a clear picture, and revealed even an opposite trend with mortality due to hypertensive disease. This raises the question, whether the IR, better reflecting the temporal features of noise, may be a helpful indicator for annoyance assessment, but not for possible far distal effects of noise, such as mortality, where the immediate perception of noise is not important anymore

As hypertension is a precursor (intermediate) for more serious cardiovascular illness (IHD, stroke), and such persons are known to be vulnerable to stress reactions by noise exposure – the perception of temporal pattern may be more important for the induction of biologic reactions.

Our common aim in this analysis is therefore to test how the IR and another indicator (Leq-L50) performs in an alpine data set with proven, strong traffic dynamics and with hypertension as health outcome in addition to the Lden.

2. METHODS

2.1 Study Areas and Samples

The study took part in the Wipptal and its side valleys. The main valley is part of the most important north-south access route for heavy goods traffic over the Brenner Pass. The area consist of villages with a mix of small business, service and agricultural activities. In the side valleys touristic activities dominate.

The selected study population (age 20-75 yrs) was approached by phone with a two-step sampling procedure based on traffic source and distance. The available sample varied for the traffic sources and was smaller for the highway and railway exposure (~800). For main road exposure the full sample (~1500) was available. The overall participation was high (80%).

2.2 Sound Exposure Assessment and Sound Indices

Road emissions were calculated with an early version of the Harmonoise source model (8) 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 (9)(10), an extended version of ISO9613.

The propagation 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 were simulated (11). Therefrom, percentile levels were calculated for each source, combinations of all sources and total sound exposure.

From these percentile levels of the overall sound exposure, the IR was estimated with the following procedure: The percentile sound levels L1, L5, L10, L50, L90, L95 and L99 were used to fit a cumulative distribution function (CDF) of the level with a resolution of 0.1 dB based on a shape-preserving piecewise cubic inter- and extrapolation. The probability density function (PDF) of the level was calculated as the derivative of the CDF by finite differences. Finally, the Leq and subsequently the IR was derived by energy integration considering the PDF. The indicator Leq-L50 was calculated from the same acoustic data basis.

2.3 Questionnaire Information

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. Reported hypertension ever and current use of anti-hypertensive medication was inquired as "doctor-related information". A CATI-laboratory contacted participants by phone three times before replacement. The standardized interview took about 15-20 minutes.

2.4 Statistical Analysis

The analysis was carried out with R version 3.3.2 . Exposure-effect curves are calculated with extended logistic regression methods. When appropriate, restricted cubic spline functions were applied to accommodate for non-linear components in the fit .

Approximate 95 % confidence intervals were estimated using smoothing spline routines with three knots and exposure-effect plots generated with the RMS-library from R (12). Predicted probabilities of hypertension ever or anti-hypertensive medication are derived from the estimated odds with a specific function in the RMS-library (plogis). 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.

3. RESULTS

3.1 General Descriptive Statistics

Table 1 shows the univariate descriptive statistics for the categorical variables used in the hypertension models. Age, education, family history of hypertension, and health status are highly significant predictors. Gender and area are nearly significant associated, while noise sensitivity is not.

Table 1. Statistical description of categorical model variables by hypertension diagnosis

Categorical variables	Reported hypertension No n(%)	Reported hypertension Yes n(%)	Total Sample	Test statistic d.f. – χ^2	P value
Total	1269	299	1572		
Age, years				χ^2 (3 df) = 193.97	< 0.001
<30	206 (16.2)	14 (4.7)	220 (14)		
30-44	521 (41.1)	52 (17.4)	573 (36.5)		
45-59	369 (29.1)	93 (31.1)	462 (29.5)		
>=60	173 (13.6)	140 (46.8)	313 (20)		
Gender				χ^2 (1 df) = 3.18	0.075
Male	836 (65.9)	180 (60.2)	1016 (64.8)		
Female	433 (34.1)	119 (39.8)	552 (35.2)		
Education				χ^2 (3 df) = 50.52	< 0.001
Basic	324 (25.7)	137 (46.1)	461 (29.6)		
Skilled	341 (27)	51 (17.2)	392 (25.2)		
Vocational	267 (21.2)	56 (18.9)	323 (20.7)		
Higher	329 (26.1)	53 (17.8)	382 (24.5)		
Area				χ^2 (1 df) = 3.42	0.064
Northern Wipptal	859 (67.7)	185 (61.9)	1044 (66.6)		
Southern Wipptal	410 (32.3)	114 (38.1)	524 (33.4)		
Family history				χ^2 (1 df) = 38.94	< 0.001

No	891 (70.8)	154 (51.7)	1045 (67.1)		
Yes	368 (29.2)	144 (48.3)	512 (32.9)		
Health status				χ^2 (2 df) = 104.73	< 0.001
Excellent	392 (31.3)	36 (12.1)	428 (27.6)		
Good	525 (41.9)	93 (31.2)	618 (39.8)		
Poor	337 (26.9)	169 (56.7)	506 (32.6)		
Noise sensitive				χ^2 (3 df) = 1.53	0.675
I fully agree	213 (16.9)	42 (14)	255 (16.3)		
I somewhat agree	321 (25.4)	76 (25.4)	397 (25.4)		
rather not correct	271 (21.5)	68 (22.7)	339 (21.7)		
Not correct at all	457 (36.2)	113 (37.8)	570 (36.5)		

In Table 2 the univariate descriptive statistics with all noise indicators and body mass index (BMI) is broken down by hypertension diagnosis ever. Among the tested exposure variables, significant associations are seen with main road Lden, main road and railway Lnight and the Intermittency Ratio (IR). BMI is a highly significant health variable.

Table 2. Statistical description of exposure variables used in the models by hypertension

Continous variables	Reported hypertension No (median, IQR)	Yes (median, IQR)	Total sample median, IQR	Ranksum test P value
Main road, Lden				0.034
median(IQR)	48 (41.2,56.9)	49.5 (42.2,59.8)	48.1 (41.4,57.4)	
Railway, Lden				0.074
median(IQR)	53.7 (42.8,61.8)	56.4 (45.2,64.8)	54.1 (43.3,62.8)	
Highway, Lden				0.939
median(IQR)	52.1 (46.2,59.1)	52.4 (44.1,59.8)	52.3 (45.6,59.2)	
Main road, Lnight				0.037
median(IQR)	41.4 (36.1,49.5)	44.8 (36.2,53)	41.8 (36.1,49.9)	
Railway, Lnight				0.013
median(IQR)	49.9 (42.2,57.1)	52.4 (44.7,59.8)	50.4 (42.8,57.7)	
Highway, Lnight				0.923
median(IQR)	45.4 (40,52.2)	45.7 (38.9,53.1)	45.4 (39.6,52.5)	
Main road (Leq-L50)				0.091
median(IQR)	13.5 (6.2,26.2)	15.3 (8.3,28.7)	13.7 (6.4,26.6)	
Railway (Leq-L50)				0.363
median(IQR)	42.6 (33.9,53)	44.1 (34.3,54.8)	43 (33.9,53.5)	
Highway (Leq-L50)				0.227
median(IQR)	0.5 (0.3,1.1)	0.6 (0.4,1.2)	0.6 (0.3,1.1)	
Intermittency Ratio				0.003
median(IQR)	34 (7,61)	42 (16,64)	37 (8,62)	
Body mass index				<0.001

median(IQR)	23.1 (21.1,25.4)	25.7 (23.5,28.4)	23.5 (21.3,25.9)

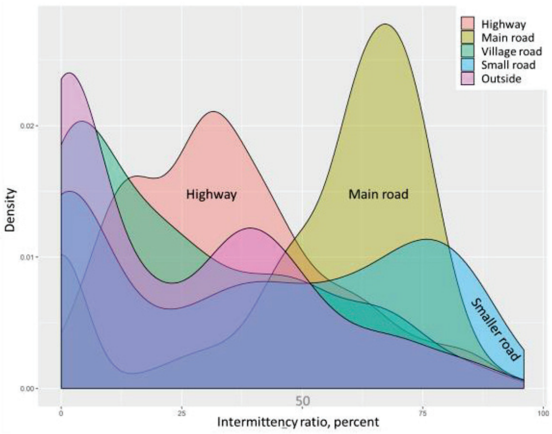
3.2 Detailed descriptive Statistics of the alternative Sound Indices

Table 3 describes the correlation between the classical sound exposure indices and the new ones (Leq-L50 and IR). The IR shows a gradual relationship in the expected direction with the highest correlation with main road (r=0.6) and railway Lden (r=0.5). The IR and highway even shows a negative correlation. The correlations of the Leq-L50 indicators with its Lden equivalents are generally lower, when compared with the IR.

Table 3. Correlation statistics of the sound exposure variables

	Highway, Lden	Main road, Lden	Railway, Lden	Highway (Leq-L50)	Main road (Leq-L50)	Railway (Leq-L50)	Intermittency ratio
Highway, Lden	1.00	-0.03	0.06	0.08	0.00	-0.01	-0.31
Main road, Lden	-0.03	1.00	0.40	0.18	0.50	0.15	0.60
Railway, Lden	0.06	0.40	1.00	0.17	0.22	0.36	0.50
Highway (Leq-L50)	0.08	0.18	0.17	1.00	0.36	0.01	0.16
Main road (Leq-L50)	0.00	0.50	0.22	0.36	1.00	-0.10	0.32
Railway (Leq-L50)	-0.01	0.15	0.36	0.01	-0.10	1.00	0.26
Intermittency ratio	-0.31	0.60	0.50	0.16	0.32	0.26	1.00

Figure 1a describes the distribution of the IR across several road type. Main roads show higher intermittency characteristics than the highway. Notably, smaller roads exhibit also significant proportions of high intermittency characteristics. Also across the investigated areas, differences in the distribution of the IR can be noted (Figure 1b). The Northern main valley shows higher prevalence of relevant intermittency episodes, but also in side valleys (South) this feature is relevant.



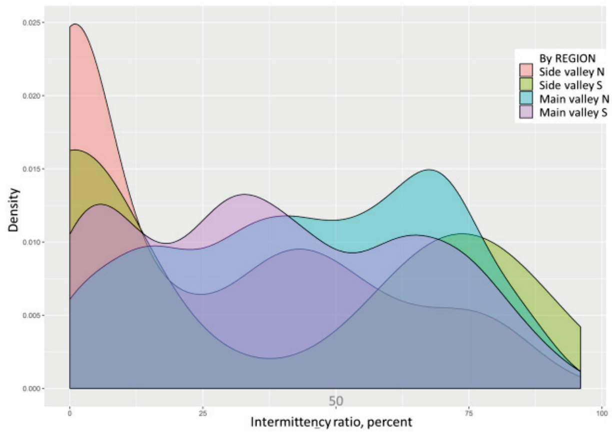


Figure 1a (left) – Distribution of the Intermittency Ratio across the varying types of roads in the sample

Figure 1b (right) – Distribution of the Intermittency Ratio across the geographic features

3.3 Preliminary Results of the Hypertension Model

The multivariable regression models presented here refer to reported diagnosis of hypertension only. The models are adjusted for age, gender, education, BMI, family history of hypertension, smoking and air pollution (PM10). Due to the non-linearity of both noise indices, restricted cubic splines are used in all models. Combined traffic sound exposure in **Figure 2** means that only those, who are exposed to all three sources (main road, railway, highway) are in this analysis. Therefore, the sample is smaller. The odds ratio for Lden becomes significant between 60 and 70 dB (OR = 1.58(1.10-2.3)). The IR is not significant (OR between 10 and 40 percent = 1.65(0.88-3.07). The pseudo R^2 of the model is 0.33.

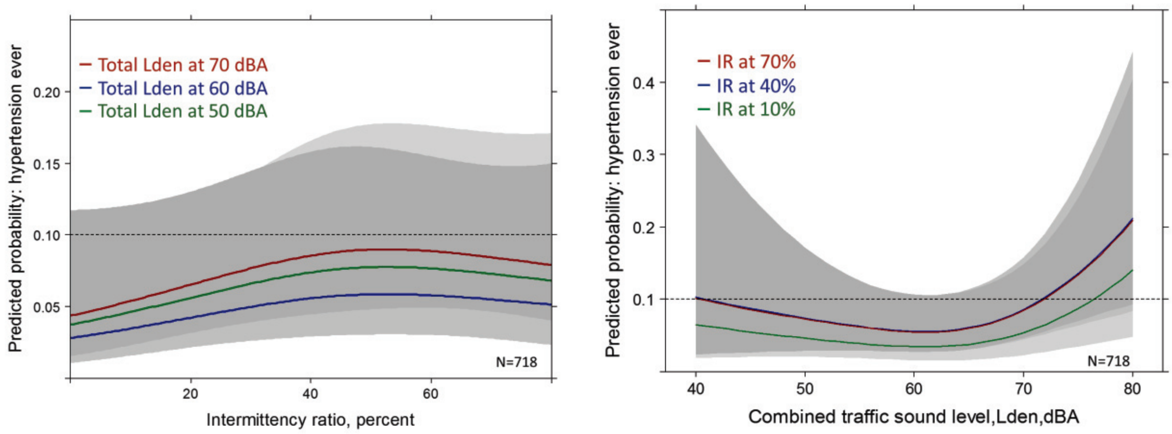


Figure 2a (left) – Intermittency ratio by increments of the combined sound level exposure as Lden

Figure 2b (right) – Combined sound level as Lden by increments of the Intermittency ratio

Total traffic sound exposure in **Figures 3** means that participants are exposed to either one, two or three sources. Therefore, the sample is larger. The odds ratio for Lden becomes significant between around 57 dB (OR = 1.31(1.01-1.7)). The IR is not overall significant (p=0.13) but the OR between 10 and 50 percent = 1.46(1.01-2.10) is significant due to the smaller confidence intervals. The χ^2 contribution is larger than for gender, education, air pollution, smoking or noise sensitivity. The pseudo R^2 of the model is also 0.33.

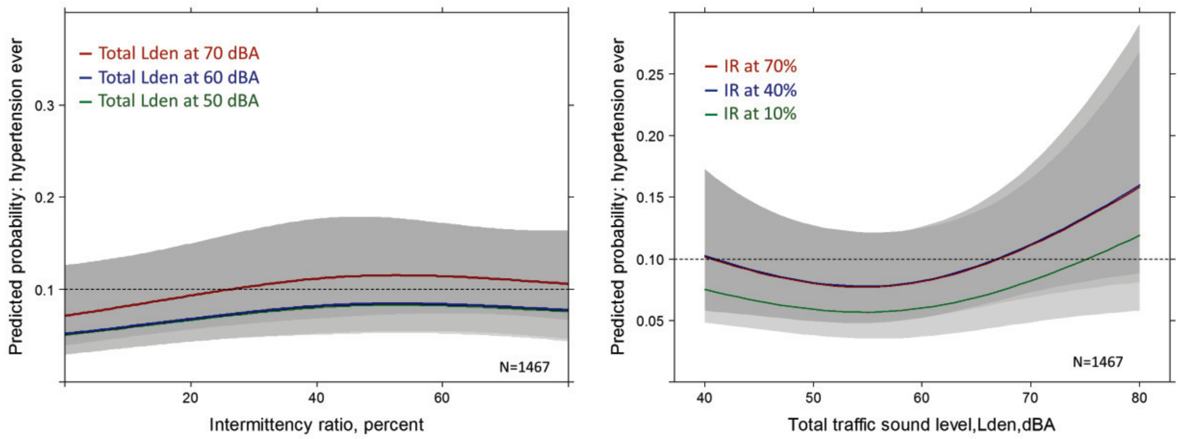


Figure 3a (left) – Intermittency ratio by increments of the total sound level exposure as Lden

Figure 3b (right) – Total sound level as Lden by increments of the Intermittency ratio

4. DISCUSSION

In this analysis, we can confirm the earlier findings (6,7), that the IR shows lower correlations with the main classical sound indicator Lden as compared to other indicators. Therefore, we did not experience relevant collinearity problems in the multiple regression models. The highly variable and not fully normal distribution of the IR indicator across the sample can pose a statistical problem and categorization may be necessary in some situations. Notably, we tested for interaction between Lden and IR, but no relevant effect could be observed – which replicates earlier findings (6,7).

The IR was created with the idea in mind to provide an integrated description of a mixed source exposure situation, which could add to the Lden, where temporal features of the sources are averaged out. Therefore, this preliminary analysis was restricted to indices capturing the overall sound exposure in this area.

For this purpose, we used two different sound exposure scenarios. In the "Combined exposure" scenario, we included only those, who are exposed to all three sources (main road, railway, highway), which resulted in a much smaller sample (N=718) and consequently lower power.

In the “Total exposure” scenario, we included all participants exposed to one, two or three sources. While we observed a significant association with Lden in both scenarios, the association with got stronger in the larger sample with the IR and the OR for the IR between 10 and 50 percent was significant (OR=1.46(1.01-2.10)). Obviously, the most important contributors in the hypertension model were age, family history of hypertension, BMI, and health status. Notably, the IR, did make a modest contribution – compared with other factors in the model like gender, education, air pollution, smoking or noise sensitivity and was close after Lden in terms of importance.

The Leq-L50 indicators exhibit even lower correlations with the Lden (Table 3). Furthermore, they were not so critical with respect to its distributions – although the observed distributions differed strongly by source. It may make sense, therefore, to use the Leq-L50 in situations when the effect of single sources need to be compared. Due to the limited space, we omit to present the larger variations in the specific association of the three traffic sources with hypertension.

In the paper at Euronoise 2018 (4), where we tested the additional contribution of indicators of emergence or fluctuation, we found that the most pronounced effects were observed in two-source models, namely the combination of main road and highway. In these analyses, even both indicators contributed similar to the model in terms of importance.

In our current analysis, using the IR indicator, we could replicate the importance of this predictor for two mixed source exposure situations. In both models, the “Total exposure” scenario and the “Combined exposure” scenario, the IR made a contribution of relative importance.

Although this study has several strengths on the exposure assessment side (micro-simulations of the traffic flow, traffic counting on smaller roads, extended version of ISO 9613 for modeling, calibration against hundreds of spring and autumn measurements across the area), other issues, discussed in the literature, may still limit conclusions.

The sound exposure was assigned to the most exposed façade. The modeling did not consider larger buffers (13,14) and the A-weighting could underestimate the disturbing effect of low frequencies (15,16) from trucks against the low background sound on the valley slopes. This may be responsible for the higher response between 40 and 50 dB Lden.

Eventually, the cross-sectional design limits causal inference – although adjustments were made for the most important, including also high quality air pollution assignments.

Nevertheless, given the current not well-established state of the noise-hypertension relationship, the results of this preliminary analysis add to the knowledge and show the feasibility to use further supplementary noise indicators beyond Lden (17).

5. CONCLUSIONS

There is still place for further research implementation of acoustic indices in health related surveys. At least, it may help to establish a more firm relationship between traffic noise with hypertension, especially in two-source situations, where the traffic dynamics differ substantially. This requires more researcher applying alternative sound indicators in different data sets to verify or refute the single findings from the Swiss and BBT-studies.

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