Noise and hypotension - potential association and moderation

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Summary
Health effects studies of noise have exclusively focused on hypertension or blood pressure increases as outcomes. This strong focus was very plausible as the stimulation of the sympathetic system by loud sounds as a typical response towards an external stressor was well supported. Secondly, hypertension is the major risk factor for cerebro-vascular disease and mortality.
Nevertheless, early experimental studies did not show only increases in blood pressure but also recorded no response or decreases of blood pressure. Due to the narrowed focus on increases in blood pressure the results were analyzed and reported only with respect to blood pressure increases and the distribution of the observed effects in the whole sample were not shown.
Only some German studies reported also the percentage of respondents with decreases in blood pressure. One larger institutional report even presented the overall response matrix of the participants in an Annex.
We took up on this evidence and included questions on self-reported hypotension into 2 of our surveys and recently published two articles showing a potential and moderated relation of hypotension with traffic sound exposure.
We present a summary of the results obtained in the two studies, discuss potential patho-physiological pathways and conclude what consequences this association may have in general for the investigation of sound – blood pressure relationships in epidemiological studies.

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1. Introduction

While the effects of occupational and environmental noise on high blood pressure are well studied and exposure response curves are available for road and air traffic noise the potential relation with low blood pressure has not been addressed in epidemiologic studies. There are two good reasons: firstly, the obvious fact that hypertension is of larger public health importance and secondly, the mechanism of action (stress response) is well understood. However, earlier experimental studies on the effects of noise on blood pressure revealed often inconsistent results and used high intensities (>75 dBA). While some studies found increases, others reported no change or even decreases. The observed discrepancies were not subject of serious discussions in the literature. All analyses of those studies focused exclusively on increases in blood pressure and did not report the overall response information. This information would have been required to see the proportion of participants who responded with decreases or showed no effect. Since most studies were small and designed to investigate mean effects of noise exposure on blood pressure, information about subgroups was rarely available. The subgroups studied were typically persons with mild hypertension or a family history of hypertension: groups where a higher sensitivity toward stressors was expected. These groups more consistently responded with increases in blood pressure. Although, one study of normo-tensive male industrial workers found a differential effect of noise with age: while the younger group showed an increase in systolic BP the older group (aged 45 to 65) exhibited a decrease after adjustment for potential confounding factors. No investigation dealt with participants labelled with essential or orthostatic hypotension.

Thus, it is rather difficult to draw firm conclusions regarding everyday sound exposure at environmental levels: The noise exposure in the majority of studies was high (75 to 100 dBA) and exposure duration short (10 to 30 min). Moreover, the study participants were young and healthy, or prone to develop hypertension. Eventually, the typical sound exposure applied in these experiments (often white or meaningless noise) was mostly ecologically invalid.

An exception was a series of carefully conducted field experiments under naturalistic working conditions at the Environmental Agency in Berlin [1,2,]. Smaller experiments with higher (occupational) noise exposure showed already some decreases (4 to 13%) in subgroups. Another German investigation used short-term traffic noise of 72 dBA and found a larger proportion of blood pressure decreases (33 % systolic and 23% diastolic). Of central interest for the rationale of our investigation was, however, the larger (N=46) experiment in Berlin with ecologic valid traffic noise exposure (60 dBA vs 50 dBA) of longer duration, where the full distribution of noise effects on blood pressure was reported. They found in subgroups maximum decreases in blood pressure readings of up to 12 mm systolic and 9 mmHg diastolic after 6:30 hours exposure to traffic noise (60 dBA) compared with a control day exposure of less than 50 dBA. Moreover, this investigation could show that, by accepting both increases and decreases of blood pressure as noise effects, the explained variance increased in noise sensitive persons from 29 to 53%. Furthermore, in a follow-up of persons (1 to 3 weeks) the observed response pattern (increases or decreases) remained stable with a few exceptions. These pieces of evidence were our rationale to include reported hypotension (defined either as self-reported, doctor diagnosis or by recorded blood pressure) in two of our surveys. The aim of this paper is to report the results from these two studies and discuss potential pathways for the observed effect.

2. Samples and methods

Survey 1: This cross-sectional noise and health survey was conducted in fall 1989 among adults (age 25-65, N = 1989, overall participation = 62%) with permanent residence (>1 year). Persons were sampled systematically or based on clusters from five selected communities in the Tyrol area along two major through-traffic routes in the Austrian part of the Alps. Although, the participation varied between the communities (50-75%) and across the noise exposure classes a recruitment analysis did not reveal an exposure related sampling bias in the overall study sample. A specific exposure feature was the high proportion of heavy traffic during night (nearly 50%) at all traffic routes due to through-traffic. Two of the highway communities experienced also railway traffic exposure. Therefore, overall noise exposure was used in the analyses.

An extensive standardized questionnaire (45-60 min interview) covered socio-demographic data, housing, satisfaction with the environment, general noise annoyance, attitudes toward transportation, interference of activities, coping with noise, occupational exposures, life-styles, dispositions such as noise and weather sensitivity, health status and sleep. In addition a check list of doctor diagnosed diseases and prescribed medications (referring to the past 12 months) were presented. Hypotension was queried: "During the past 12 months did you experience or do you suffer currently from one of the following illnesses? Hypotension (yes, no)".

Blood pressure was measured twice by resident doctors in the home of the subject in a sitting position on the right arm.

In this study, the propagation results were calculated by national guidelines (VDI guideline 2714-noise propagation outdoors, VDI 2720-Noise control by barriers outdoors). As the topography in Alpine valleys is very complex we adjusted the calculated noise exposure from highway, main road, and railway with a large number of short- and long-term day/night recordings simultaneously taken in the respective communities. Written consent was obtained from the participants after the interview.

Survey 2: This cross-sectional study was conducted in fall 1998. The study area covered a stretch of about 40 km in the lower Inn valley (east of Innsbruck, Austria). 807 participating persons (50.5 % = full sample)with permanent residence of more than one year (aged 20-75 yrs) were sampled randomly from circular areas around 31 noise measurement sites (radius = 500 m) by GIS-stratification of noise exposure (35-44, 45-54, 55-64, >64 Leq,dBA). Only 572 persons were participating in all blood pressure measurements (= reduced sample).No significant selection bias was observed. Prior written consent was taken from the participants before the interview and the anthropometric measurements were made. The primary noise sources were road (highway, main road) and rail traffic. During the past decade a slight increase in night time freight trains could be observed. At the same time, a night ban on non-noise-abated trucks led to a slight decrease (~3 dBA) in night time noise levels of highway traffic. The final individual assignment of the source specific noise exposure (dBA,day and night, Ldn) was made after calibration of the modelling results against the measurements from the 31 sites in the center of the circular areas. The measurements were carried out in the year preceding our survey and covered day, evening and night. The measurements were accompanied by recordings of traffic counts for all sources and types of traffic. These traffic and measurement data were then used as calibration input against the original noise map which was based on yearly average daily traffic of the respective sources. All procedures were carried out according to Austrian guidelines (ÖAL Nr 28+30, ÖNORM S 5011) with a resolution of 25 m × 25 m.

The extensive standardized questionnaire covered socio-demographic data, housing, satisfaction with the environment, general noise annoyance, interference of activities, coping with noise, occupational exposures, life-style, general dispositions such as noise and weather sensitivity and health status. Illnesses were obtained by an exhaustive list (e.g. ”low blood pressure”, “high blood pressure”) which was preceded by the general question: “Has a doctor diagnosed one of the following health problems” and linked to three answer boxes: “during the past 12 months”; “ever”, “never”.

Information on medication was questioned in the same way “During the PAST 12 MONTHS, have you taken medication because of the following health problems” with an exhaustive list including the two options ”against low blood pressure” and “against high blood pressure”.

In addition, physical and mental health was assessed by two subscales (14 items, Cronbach’s alpha = 0.89) of the 28 item version of the General Health Questionnaire (GHQ), namely the somatic and anxiety scales. Sleep quality was measured with a summary scale (Cronbach’s alpha = 0.86) derived from five sleep frequency items.

In the exposure response analyses we employed total sound level, railway and highway sound and included distance to the main road and annoyance due to other close-by local roads in all models.

Statistical treatment was done similarly for both surveys. Exposure-effect relationships were modelled with multiple logistic regression techniques using Harrell's RMS-library. To account for non-linearity in selected predictors splines were applied. Approximate 95% confidence intervals were estimated using smoothing spline routines with three knots and the exposure-effect plots were generated with the RMS-library. Predicted probabilities are derived from the estimated odds with a specific function in the RMS-library (plogis). The predicted probabilities in the exposure-effect plots of self-reported hypotension or hypertension medication are adjusted to the median (continuous variables) or the reference category (non-continuous variables) of the other variables in the model. Based on a priori knowledge interactions (IA) were tested one by one and kept in the model when either indicators of fit improved or the adjusted R^2 increased – balancing variance inflation. The statistical criterion for the inclusion of IA in the model was relaxed (to p=0.2). In the analysis of the second survey distance to the main road and annoyance by local roads were entered as additional interactions in all models.

3. Results

Survey 1:

Women and persons reporting exhaustion, fatigue, depression or rating high on noise or weather sensitivity did exhibit the highest prevalence of reported hypotension. Furthermore, sleep problems were significantly associated with self-reported hypotension. A more than four-fold excess of self-reported prevalence of hypotension is evident in younger women. This large difference in the reported sex prevalence almost disappears in the older age group. The total noise exposure (Leq24, dBA) does exhibit a near significant non-linear component in the presence of some IAs and it is not advisable to interpret this result in isolation. Thus the presentation focuses on the most important interactions.

Figure 1 shows the adjusted exposure-effect relationship between sound level and self-reported hypotension with the most important determinants sex and age. Outstanding is the change of the relationship for sex with increasing age (IA P < 0.001). At age 60 men and women exhibit a similar relationship while up to age 42 the relation with noise is evident only in women where the prevalence is also much higher.

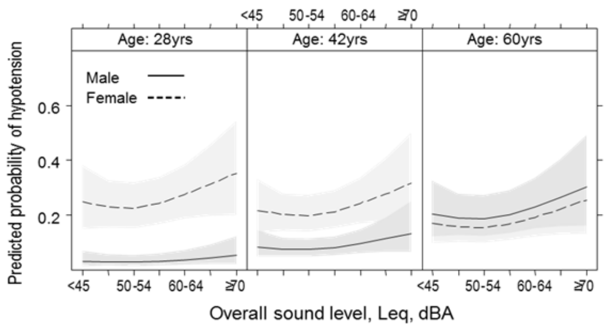

Figure 1. Adjusted predicted probability of reported hypotension past year with total sound level exposure by sex and three age groups

An overall non-linear relation is evident, but the slope starts to ascend linearly around 55 dBA.

Weather sensitivity was not only a strong main predictor. It exhibited also an effect modification with age and noise sensitivity. A very noticeable aspect of Figure 2 is the difference in hypotension prevalence among weather sensitive persons with age (IA P = 0.065).

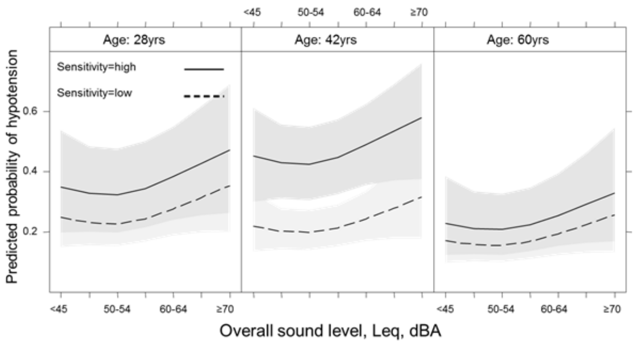

Figure 2. Adjusted predicted probability of reported hypotension past year with total sound level exposure by weather sensitivity and three age groups

Eventually, we could not establish a sufficiently stable model for the relation between noise and the casual blood pressure readings due to the small number of subjects.

Survey 2 - full sample: Concordantly with both outcomes (reported hypotension and hypotension prescription) significant relations were observed with sex, health status or GHQ-score, anti-hypertensive treatment, noise or weather sensitivity and sleep score. Age was significantly higher (p=0.05) in the medication group while the group with reported hypotension was younger (p=0.11). Both total and rail noise are significant contributors in the full sample.

Both exposures show a significant non-linear component and a relevant moderation with weather sensitivity in Public health terms. A statistically significant interaction is also observed between health and weather sensitivity. The most important moderation in all models is with age and sex. Reported hypotension prevalence is highest among younger women and increases with age in men. Highway noise is unrelated to hypotension – but an interaction with main road distance shows up.

Figure 3 shows the overall exposure response information by sex adjusted for age, education, anti-hypertensive treatment, family history of hypertension, weather sensitivity, health status, sleep score, distance to main road, annoyance by local roads, region and the IA-terms age*sex, weather sensitivity*health, weather sensitivity*sound exposure, distance*sound exposure, annoyance*sound exposure.

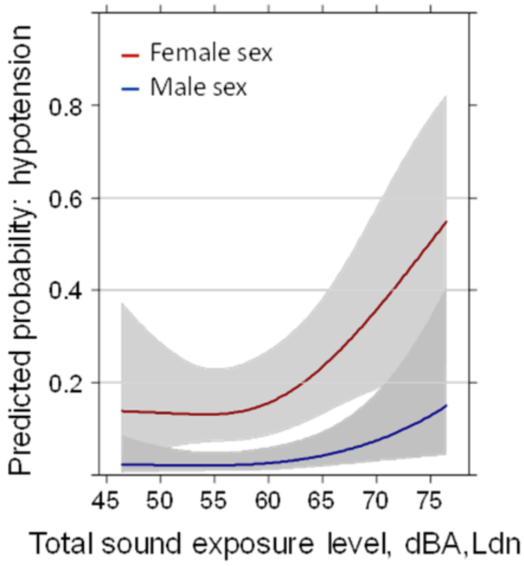

Figure 3. Adjusted predicted probability of reported hypotension past year with total sound level exposure by sex

Figure 4 shows the relationship with railway noise.

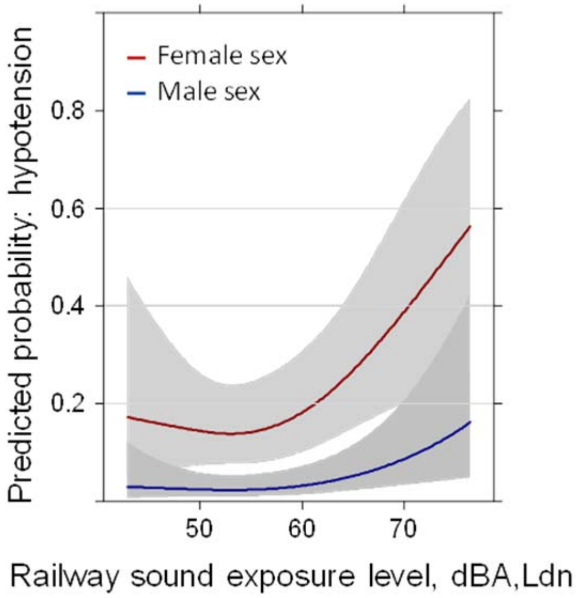

Figure 4. Adjusted predicted probability of reported hypotension past year with railway sound level exposure by sex

Sample 2 – reduced sample: In the smaller sample (N=572) the relations with both exposure indices were exactly repeated. Sex and weather sensitivity remained the dominant predictors. With the inclusion of body mass index as additional variable (bmi, P=0.02) in the model the health status variable lost both - its relative importance and its interaction with weather sensitivity.

The moderation by distance to the main road and the annoyance experienced by local roads remain statistically significant. The adjusted pseudo R^2 increased slightly to 0.42 (from 0.39 in the full sample). Very impressive is the significant moderation of both significant sound indicators with weather sensitivity. In Figure 5 only the relationship with railway noise is presented.

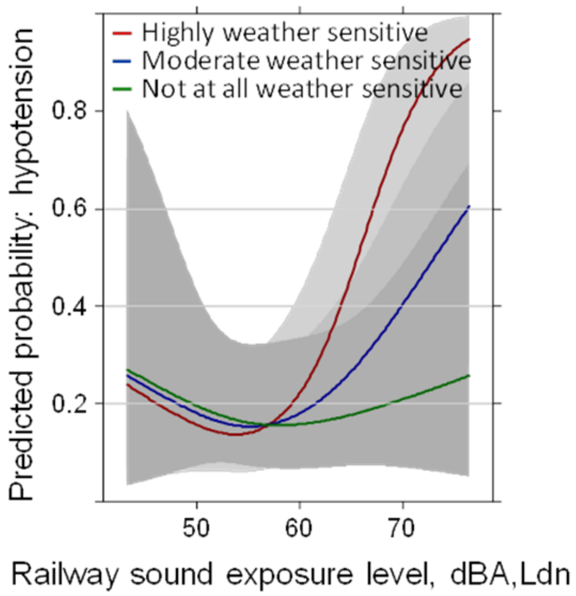

Figure 5. Adjusted predicted probability of reported hypotension past year with railway sound level exposure by weather sensitivity

An identical model with "hypotension ever" as health outcome revealed similar qualitative results without reaching statistical significance. This is an expected result due to the larger exposure misclassification for the earlier residential exposure estimation.

Sample 2 – reduced sample with hypotension medication as health outcome:

The medication model differs in some important aspects from the model with reported hypotension as outcome: Apart from the lower reported prevalence of medications (~70%) compared with reported hypotension, age became a more important cofactor than sex and the age*sex interaction lost almost completely its importance. The higher importance of age originates from the fact that general practitioners were more likely to give medications to patients complaining about symptoms related to low blood pressure with increasing age. All other interactions could not be replicated in these models although the cofactors weather sensitivity, health status, antihypertensive treatment and bmi remained highly important main predictors of medication use.

Distance to the main road and annoyance by local roads was completely unrelated to medication prescription. Nonetheless, the total sound level and the railway sound continued to be significant predictors. The highway exposure nearly approached a significant inverse relation. Due to space limitation we integrate all results of the hypotension medication model in the summary Table 1 where the odds ratio increases for all models of survey 2 are shown. Notable are the significant increases in the odds ratios for both the total and railway sound exposure levels starting at 55 dBA,Ldn for reported hypotension. For hypotension medication significant increases start around 60 dBA (except railway sound in the reduced sample). Note also the large confidence intervals due to the relatively small samples.

Table 1. A summary of the increase in the odds ratio (95% CI) at different sound levels in all adjusted models

Sound source: and health outcome	**Increase in Odds ratio (95% CI) at different sound levels**		
Full sample	55-65 Ldn,dBA	60-70 Ldn,dBA	65-75 Ldn,dBA
Total sound: reported hypotension	2.01 (1.23-3.30)	3.00 (1.42-6.32)	3.31 (1.40-7.84)
Railway sound: reported hypotension	2.22 (1.36-3.62)	2.84 (1.43-5.67)	2.98 (1.43-6.24)
Highway sound: reported hypotension	0.63 (0.15-2.60)	0.61 (0.14-2.73)	0.61 (0.14-2.73)
Total sound: hypotension medication	1.08 (0.73-1.59)	2.00 (1.09-3.70)	2.35 (1.16-4.74)
Railway sound: hypotension medication	1.43 (0.95-2.15)	1.95 (1.09-3.51)	2.08 (1.11-3.88)
Highway sound: hypotension medication	1.63 (0.49-5.44)	1.72 (0.48-6.10)	1.72 (0.48-6.10)
Reduced sample (incl. BMI)			
Total sound: reported hypotension	2.05 (1.26-3.34)	4.28 (2.04-9.01)	5.57 (2.22-13.94)
Railway sound: reported hypotension	2.44 (1.53-3.89)	3.99 (1.96-8.13)	4.64 (2.06-10.44)
Highway sound: reported hypotension	1.13 (0.30-4.24)	1.13 (0.28-4.57)	1.13 (0.28-4.57)
Total sound: hypotension medication	1.11 (0.71-1.74)	2.74 (1.36-5.52)	3.79 (1.60-86)
Railway sound: hypotension medication	1.59 (1.01-2.49)	2.58 (1.30-5.11)	2.99 (1.38-6.50)
Highway sound: hypotension medication	2.57 (0.66-10.00)	2.80 (0.66-11.80)	2.80 (0.66-11.80)

4. Discussion

We could replicate in two surveys [3,4] the central result of a statistically significant non-linear relationship of overall and railway noise exposure with self-reported hypotension in the presence of some effect modifications. Caution is needed in the interpretation. The observed effect cannot be attributed to the sound levels alone but can be interpreted only in the context of the other interactions involved. In the hypotension medication models of survey 2 also a direct non-linear relationship with noise was observed without an interaction involved. Highway sound exposure did not show any relation – but there was a significant moderation by the distance of the home from the main road. Thus, why is railway noise contributing so much to the total effect? Rail passages are intermittent events with high peak levels which dominate strongly during night. The peak levels of the trains during night are 13 dBA higher than those from the highway and we have observed a higher sleep medication intake associated with rail noise in a larger study in the same area [5]. Likewise, the exposure characteristic of a main road is also intermittent and perceived as more annoying due to its acceleration and deceleration sounds, especially in scattered residential living in rural and suburban areas.

Why are sex, weather sensitivity and bmi very important moderators and predictors? Women and weather sensitive persons are known to exhibit reduced autonomic nervous system regulation capacity. Weather sensitivity has been used as general indicator of vegetative instability in European practical medicine and subjects reporting sensitivity to weather showed the strongest relation (OR = 7.12 (4.81-10.53) with “circulatory problems” out of a list of 17 reported co-morbidities. A lean body habitus (low bmi, especially in young females) is a well- known predictor of hypotension in clinical practice and has been identified as the most important predictor of hypotensive events in a study using ambulatory blood pressure monitoring and as predictor of low blood pressure in field studies. Body fat has been shown to influence autonomic regulation and to change sympatho-vagal balance. Lab-studies have shown that weight loss reduces sympathetic activity and is significantly related to an increase in cardiac parasympathetic activity and to lower blood pressure in experimental studies. Growing recent evidence supports the idea of a general cardiovascular down-regulation in essential hypotension. Recent studies observed a reduced cortical activity associated with a decrease in cerebral blood flow in subjects with mild hypotension [6].

However, no significant association was found with measured blood pressure in any of the models. A main reason may be that a large fraction of people reporting hypotension episodes take medication (~70%). Furthermore, the number of repeated measurements was probably too small to single out persons suffering from hypotension by blood pressure recordings only.

Obviously, the cross-sectional design of both studies prevents a causal interpretation.

5. Conclusions

We could replicate the central result of a statistically significant non-linear relationship of overall noise exposure with self-reported hypotension in the presence of some effect modifications in two cross-sectional surveys and in the subsample of the second survey in spite of smaller sample sizes. However, the involved cofactors (sex, age, bmi, health) and moderators (weather sensitivity, adjacent main roads and associated annoyance) need to be considered as indispensable part of the observed relationship. The more detailed sound exposure information in the second survey uncovered that the main sound component contributing was the dominant intermittent exposure from the nightly freight trains. In the face of a prevalence of reported hypotension (14%) and reported medication use (10%) the public health relevance of even a small contributing effect of noise is undisputable. Larger studies covering the same depth of inquiry and the replication in different regions and populations are needed to verify the associations.

Eventually, the observed poor relation between noise and recorded blood pressure (in contrast to hypertension) in epidemiological studies may be the result of the hitherto neglected counteracting effects of noise to lower blood pressure.

Acknowledgement

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Please consult the large reference lists in the two original articles [3,4]