The effects of railway noise on sleep medication intake: results from the ALPNAP-study

P. Lercher[1], M. Brink[2], J. Rüdisser[1], T. Van Renterghem[3], D. Botteldooren[3], M. Baulac[4], J. Defrance[4]

[1] Department of Hygiene, Microbiology and Social Medicine, Medical University Innsbruck

[2] D-MTEC Public and Organizational Health, ETH Zürich, Zürich, Switzerland

[3] Acoustics group, Department of Information Technology, Gent University, Gent, Belgium

[4] CSTB, Saint-Martin-d'Hères, France

Abstract

In the nineteen eighties/nineties a number of socio-acoustic surveys and laboratory studies about railway noise effects have observed less reported disturbance/interference with sleep at the same exposure level compared with other modes of transportation. This lower grade of disturbance has received the label "railway bonus", was implemented in noise legislation in a number of European countries, and was applied in planning and environmental impact assessments. However, the majority of studies investigating physiological outcomes did not find the bespoke difference. In a telephone survey (N=1643) we investigated the relationship between railway noise and sleep medication intake, and the impact of railway noise events on motility parameters during night was assessed with contact-free high resolution actimetry devices. Multiple logistic regression analysis with cubic splines was applied to assess the probability of sleep medication use based on railway sound level and nine covariates. The non-linear exposure-response curve showed a statistically significant leveling off around 60 dB(A),Lden. Age, health status and trauma history were the most important covariates. The results were supported also by a similar analysis based on the indicator "night time noise annoyance". No railway bonus could be observed above 55 dB(A), Lden. In the actimetry study, the slope of rise of train noise events proved to be almost as important a predictor for motility reactions as was the maximum sound pressure level – an observation which confirms similar findings from laboratory experiments and field studies on aircraft noise and sleep disturbance. Conclusion: Legislation using a railway bonus will underestimate the noise impact by about 10 dB(A),Lden under the conditions comparable with those in the survey study. The choice of the noise calculation method may influence the threshold for guideline setting.

Keywords: railway noise, railway bonus, freight trains, sleep, sleep medication, motility, sound propagation

Introduction

In most European countries the percentage of people exposed to railway noise is relatively small (3-5%) compared with road traffic (60-80%) – but comparable with aircraft noise (3%). When exposure to higher noise levels at night is in focus, railway noise (22%) comes closer to road (70%) and aircraft noise remains within the same percentage range (HCN 2004). When the percentage of highly sleep disturbed is examined, road is responsible for 14%, aircraft for 5% and railway for 3% at the mean population level (WHO-NNGL, 2009, Fig. 1). It is therefore not surprising, that the effects of railway noise on annoyance and human sleep have been considered to be weak or negligible, both in field and laboratory investigations – compared with other means of transportation. However, this effect estimation was mainly based on social surveys using subject's annoyance or disturbance ratings for day and night or recognized awakenings. Furthermore, the study base is rather small.

In a review of acute effects of transportation noise on sleep up to 1991 by Hofman (1991), only one study was concerned with railway noise. This single study including cardio-vascular endpoints did not suggest a lesser effect of rail when compared with road or air traffic (Di Nisi et al., 1990). These findings were replicated during the last 5 years by German and French research groups (Marks & Griefahn, 2005, Griefahn et al., 2006, Griefahn et al., 2008, Saremi et al., 2008, Griefahn & Basner, 2009, Tassi et al., 2009).

A recent summary report from field studies in the Netherlands (Passchier-Vermeer et al., 2007) did make a more detailed analysis based on event duration. They found at passages of average duration noise-induced motility was slightly lower for railway than for road traffic events. However, in passages of longer duration (2 minutes) the chance of noise-induced motility was 1.5 times higher than at the average duration of a road or railway passages. This finding indicates passage duration as an important exposure criterion.

A recent Scandinavian railway noise study (Aasvang et al. 2008) found noise sensitivity, type of bedroom window, and pass-by frequency to be significant factors for noise-induced sleep disturbances in addition to the noise exposure level. No comparison could be made with road traffic noise. Furthermore, the authors pointed to a potential underestimation of sleep disturbances by measuring/calculating the exposure at the most exposed façade – when most of the people in the study actually slept on the quiet side of their dwelling.

TNO-authors (Miedema & Vos, 2007) conducted a new exposure-response meta-analysis of self reported sleep disturbance (highly sleep disturbed). Unfortunately, this analysis was based on a rather small number of field studies (n=5). Among those, 56 % of the sample were also older studies from 1983 (GER1982+UK1983: n=1793) and 50% were from Germany.

In those earlier studies (see Moehler et al. 1988 for a review) sleep even seemed to be less affected by railway noise than indicators of general annoyance. Even in the most recent German interview study a bonus of up to 14 dB(A) could be observed for sleep disturbances and 8 dB(A) for total annoyance during night - compared with road traffic noise (Griefahn et

al. 2000).
In Japanese interview studies a bonus for annoyance could not be observed (Yano et al. 1998, Morihara et al. 2004, Yano et al 2005, Yokoshima et al 2008). Shinkansen express noise was even more annoying than the (objectively) noisier local trains. No clear evidence is available from these Japanese studies, how sleep is affected in a population showing an annoyance bonus for railway noise
Departing from other surveys a Swedish study (Bluhm et al., 1998) around Sollentuna observed both higher sleep disturbance and annoyance ratings in the railway sample compared with road exposed subjects.
In a sophisticated early field experiment using polysomnographic (EEG, EOG, EMG and ECG) recordings of sleep quality, Vernet (1983) did not find a difference between the road and railway noise exposed samples. Differences in recorded sleep disturbance were, however, observed when emergence (the difference between the ambient background level and the noise event level) became higher or the duration of passings increased. Therefore, the specific exposure situation seems to be more important than just the source type.

While a number of surveys have studied the effects of aircraft and road traffic noise on medication use, hitherto no study has investigated the effects of railway noise on consumption of sleep medications at the individual level. With a semi-ecological study design and a large study base (30'322 inhabitants) health insurance medication data were used and related to distance from several noise sources (local and main roads, highway, railway) in the Wipptal, Tyrol (Rüdisser et al., 2008). For the railway exposure group (residence within 150 m of the tracks, high proportion of freight trains) significantly higher odds ratios were found for psycho-sedatives (tranquilizers & hypnotics), and some other medications (anti-hypertensives, antacids, anti-allergic medications). The age group mostly affected was 70 years and older. Due to the limitations of the ecological design, the lumping of medication groups and the use of the surrogate exposure indicator distance no definitive conclusions could be drawn.

In the ALPNAP-project, an EU-funded Interreg-IIIB-study (Heimann et al., 2007) we had the opportunity to reevaluate the potential effects of railway noise on sleep medication intake in a cross-sectional study in the context of a high proportion of freight trains with longer durations of pass-by’s in a different alpine valley, the Unterinntal. Furthermore, we investigated the effects of train noise on motility reactions in a small subsample by means of a contact free-recording system for high resolution actimetry and heart rate.

Methods: Telephone survey

Area, sample selection and recruitment

The area of investigation, the Unterinntal, is the most important North-South-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 railway 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 (railway, 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 area"). From these five areas households were randomly selected and replaced in case of non-participation. Selection criteria for interviewees were age between 25 and 75 years and sufficient hearing and language proficiency as well as residency of at least one year at the current address. 45% did not want to participate. The rest of the addresses were not valid private households, were not listed in the phone directory or could not be reached by 3 call 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 (N=1010, 61.5%).

Noise exposure assessment

Railway noise emission is extracted from a typical day of noise immission measurements at close distance to the source. Two noise calculation procedures were implemented.
Bass3 uses a three-dimensional object precise beam tracer gradually becoming a stochastic ray tracer at larger distance from the source to determine possible propagation paths. Sound propagation phenomena are included in an ISO9613-2 comparable way. The model includes up to four reflections and two sideway diffractions (de Greve et al., 2005, de Greve et al., 2007).
Mithra-Sig is the NMPB-96 implementation by CSTB on of the current interim engineering methods recommended by the Environmental noise directive. It uses 2.5 dimensional tracing for visibility check.

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 (van Renterghem et al., 2007).

Indicators of day, evening, night exposure and L_{den} 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, L_{den} at the façade most exposed to railway noise was utilized.

Questionnaire 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 intake of medications. The telephone interview took about 15-20 minutes to complete. Sleep medication consumption was part of a list of medication questions (did you take medication against sleep problems during the last 12 months?). Education was measured in 5 grades (basic, skilled labour, vocational school, A-level, University degree). The last two grades were combined in the category "higher education". Noise sensitivity was asked with a 5-point Likert-type question. "High sensitivity" was defined by the two upper points on the scale (4 & 5). Health status was judged on a standard 5-grade scale (1 to 5). The three poorest grades were combined as "less than good" in the analysis. Trauma history was obtained by 3 items from the PCL-C (Weathers et al. 1991), based on a German version (Teegen 1997). Active and emotional coping was assessed by a sum score based on 13 items (Botteldooren & Lercher, 2004). The area characteristic (urban, suburban, rural) was defined by residential pattern and community size. Life satisfaction was measured and scored according to the world life satisfaction survey (Diener et al. 1999).

Statistical analysis

The statistical analysis was carried out with R version 2.10.1 (R Development Core Team, 2009). Exposure-effect curves were calculated with extended logistic regression methods using restricted cubic spline functions to accommodate for non-linear components in the fit if appropriate (Harrell, 2001). 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 - using the contributed packages "Design" and "Hmisc" (Harrell 2009). Basic statistics (Chi-square and Wilcoxon Ranksum-Tests) were calculated with Epicalc (Chongsuvivatwong 2009).

Methods: actimetry study

Introduction

When it comes to physiology, investigations of the effects of noise on sleep usually employ either rather complex (polysomnography) or quite simple (actimetry) measurement methods.

Concerning the latter, changes in body movements can be regarded as a consequence of autonomous activation elicited by noise events and can basically be quantified by calculating the difference of the (average) motility level *before* and *during* the occurrence of a noise event. If a big enough difference between motility values *before* the onset of the event and around the point in time, when the event reaches its maximum level is present, a *motility reaction* can be assigned to the event. While there are no generally accepted standards of interpreting actimetry/motility data in a physiological context, it is usually agreed upon, that such measures can usefully approximate sleep versus wake state during a 24 hour period (Ancoli-Israel et al., 2003) and that motility can be regarded as an indicator of vegetative arousals during sleep (Tryon, 1991). Motility measures have been used in several field studies on noise-induced sleep disturbances (e.g. Horne et al., 1994; Ollerhead et al., 1992; Moehler et al. 2000; Passchier-Vermeer et al. 2002; Passchier-Vermeer et al., 2007).
The principle of *Seismosomnography* (SSG), which was used in the actimetry study, constitutes some kind of intermediate approach to objectively quantify sleep disturbances. The SSG principle is based on the fact that the human body, even if motionless, exerts vibration energy on an underlying surface (such as a mattress), by movements of the body itself, but also by the activity of the heart (causing a small displacement of the body due to its rebound at each contraction, called the cardioballistic effect), and the lifting and lowering of the thorax and abdomen while breathing. SSG delivers movemental activity (motility), heart and respiration rate by sensing the tiny shifts of the center of gravity of bed and sleeper. To derive these signals, the system uses just one kind of mechanical transducer, which is installed under each bed post. After filtering out unwanted frequency components, microactimetry data, which were recorded as an indicator of disturbed sleep in the current study, can be obtained. An in-depth technical description of the method has previously been published (Brink et al., 2006). The SSG system we used here has for the first time been applied in an experimental field study about aircraft noise events and sleep disturbances during night time (Brink et al., 2008).

Field setup

The actimetry study aimed at further testing and improving the SSG equipment for use in the home situation and to gain better insights into the relationship between the maximum sound pressure level ($L_{A,F,max}$) and the slope of rise of train passings and motility reactions of sleepers. A total of 8 volunteers (5 females, 3 males; average age 51 years) agreed to the installation of the SSG system in their bedrooms. The study primarily targeted at railway noise, hence all study locations were selected in the neighbourhood of the main railway track at the bottom of the (Unterinntal) valley. The distances to the nearest railway track were between 27 and 815 meters (mean distance: 265 meters). Other noise sources were the A12 highway (mean distance: 400 meters) and main roads (mean distance: 1067 meters). The sound pressure level during night was continuously recorded each second at the half-open window inside the bedroom with a Brüel+Kjaer 2236 sound level meter. In the post-experimental data analysis, noise events were assigned automatically with a computer program. A shoulder point for the beginning of a noise event was defined as at least 33 dB(A), and if a constant (uninterrupted) rise to a minimum of 40 dB(A) over a duration of at the most 120 seconds was present, a noise event was assigned. Due to the economical nature of the actimetry study, the source of each sound assigned a noise event could not undoubtedly be identified since no original waveform signal was recorded. However, a steadily rising sound pressure level likely indicates a traffic related source such as an approaching train or car. Therefore, the simple algorithm used seems to fulfill the aim of reliably identifying as many railway noise events as possible while avoiding false positive assignments. For each noise event, the *motility reaction level* and the binary variable *motility reaction* – as previously defined for SSG (see Brink et al., 2008) – was recorded.

Results

Survey results: railway noise and sleep medication consumption

Based on a literature review and previous experience we started the analysis of the survey data in addition to the railway noise exposure calculations with a predefined set of 11 potential confounder variables, of which 9 remained in the final model. In addition we evaluated the potential importance of 10 variables which could modify noise exposure due to the various sources (bedroom location to single and multiple sources). Although most of these variables revealed some statistical importance (p-values between 0.08 and 0.02) – in the multivariate logistic regression model their contribution vanished.
Table 1 presents 10 variables in relation to the main outcome: sleep medication intake.

Table 1 about here

All variables show highly significant relationships. Also bedroom window behaviour (mostly closed: 36% vs.18) was tightly related to medication intake – but eventually was omitted from the model due to its collinearity with coping activities(r=0.66).

The exposure-response relationship revealed a strong non-linear component (Figure 1), which was accommodated for by a three knot cubic spline function.

Figure 1 about here

The less adjusted models (unadjusted & age adjusted) show more than twice the probabilities of medication intake at any level of railway sound exposure. However, the critical point of deflection in all models starts between 60 and 70 dB(A),L_{den}. Here, the increase in the odds ratio reaches statistical significance and increases further between 65 and 75 dB(A) (Table 2). The spread of the 95% confidence intervals is also smallest in the area between 55 and 70 dB(A).

Table 2 about here

By comparing these results with a second sound classification method (modified ISO-procedure) the exposure-response curve is quite similar (Figure 2).

Figure 2 about here

The curve shows only a slightly earlier non-linear departure before 60 dB(A),L_{den}, which results in a significant increase already in the 55 to 60 dB(A),L_{den} group exposure (see Table 2 last row).

In terms of single effects, health status, age and trauma history are the strongest determinants, when measured by Wald chi-square (not shown).

No statistically significant interaction could be detected. However, when you inspect the predictor plots considering age (Figure 3), trauma history (Figure 4) or even the weaker, although significant factor “area” (Figure 5) you can recognize a steeper slope in the subgroups with the higher medication intake.

Figure 3, 4 and 5 about here

Actimetry study results: railway noise events and motility reactions

Depending on the willingness of the study volunteers, the actimetry study includes between 7 and 14 consecutive days per person. Both acoustical and physiological recordings started at 22:00 hrs in the evening and ended at 08:00, 09:00, 10:00 or 10:30 hrs in the morning, depending on sleeping habits of the individual subjects. One subject was excluded from the analysis because technical problems prevented the equipment from accurately acquiring data. Since the SSG method automatically detects when a bed is weighed down by a person, the point in time of going to bed and leaving it in the morning was derived from the obtained signal for each subject each night. All subjects were assumed having fallen asleep 20 minutes past going to bed, thus the relevant "sleep period" was defined as the period between the estimated sleep onset and the rise time in the morning. All noise events within this period were considered valid for analysis (Table 3). From the 7 subjects who slept during a total of 59 recorded nights, a total of 2634 noise events could be analyzed.

Table 3 about here

Per definition, the lowest analyzed $L_{A,F,max}$ was 40 dB, the highest $L_{A,F,max}$ detected was 74.8 dB. The *slope of rise* was measured as time a noise event needed to gain 10 dB until reaching its maximum level and is expressed in Decibels per second. According to this measure, the average slope of rise amounted to 2.16 dB/s (90th-percentile 3.33 dB/s).

Motility parameters (motility level and motility reaction) were calculated according to the procedures defined in Brink et al. (2008). Logistic regression analyses with random subject effects (using the SAS NLMIXED procedure) were carried out to elucidate the effect of *maximum sound pressure level* ($L_{A,F,max}$)*, slope of rise*, *duration of the event*, *number of* *previously experienced events*, *time elapsed since sleep onset*, the *number of noise-"free" intervals* before the event, the *background level* just before the event and the *distance from the railway track*. The first model tested contained all the predictors above. As the *time elapsed since sleep onset* covaries with the *number of previously experienced events* (r=.74; p<.001), the latter was dropped from the analysis. A priori included in the model were only the *subject* random effect, the *maximum sound pressure level* and the *slope of rise*. All predictors that did not reach the desired 0.01-alpha level significance were dropped. The logistic regression results of the final model are given in Table 4.

Table 4 about here

The number of motility reactions in a night is always larger than the number of reactions *solely* caused by noise events, because roughly one tenth (from Brink et al. (2008): 0.085) of the motility reactions that are observed during noise events are spontaneous and are not caused by the noise event (the same applies to awakening reactions (cp. Brink et al., 2009)). Thus the value of 0.085 was subtracted from the observed probability of a motility reaction to reflect the so called *probability of additional reactions* ($P_{\text{mot, additional}}$). The resulting logistic curves for $P_{\text{mot, additional}}$ are plotted for different combinations of maximum levels and slopes of rise in Figures 6 and 7.

Figure 6 about here

Figure 7 about here

The curves in the Figures 6 and 7 show the expected trend of the probability of a motility reaction with either increasing maximum sound pressure level or increasing slope of rise. Although in this small experimental study, the noise from different traffic modes (as well as from non-traffic sources) could not be distinguished from each other with certainty, due to the close vicinity of the railway track to most of the subjects homes, a rather large proportion of the high-level noise events are likely to have been train passings. This suspicion is supported by the fact, that in the current sample, the slope of rise is related to both the maximum level as well as the distance from the railway tracks. This could be shown with a multiple regression analysis that yielded the following parameter estimates: Intercept [dB/s] -3.58, p<.001; Maximum level [dB] 0.13, p<.001; distance from railway track [meters] –0.00076, p<.001.

The slope of rise is almost as important a predictor for motility reactions as is the maximum sound pressure level – an observation which confirms the findings with aircraft noise events (Brink et al., 2008). Further, it also confirms an older laboratory experiment (Hofman et al., 1993) as well as the results of a quite extensive laboratory study of awakening reactions due to traffic noise events by Marks and collaborators (Marks et al., 2008). The latter study found particularly large effects of the slope of rise from railway noise events and therefore seriously challenged the bespoke "railway bonus”.

Discussion

Telephone survey

The detailed regression analyses have shown a statistically significant association of railway noise with intake of sleep medication due to sleeping problems. Adjustment for nine reaction related co-variates did not make a relevant change to this association. The exposure-response relationship has a strong non-linear component, which starts around 60 dB(A),L_{den}. The curve leveling-off and the starting point of statistical significance slightly depend on the sound calculation method applied. The improved ISO-method, adapted to the specific situation of alpine topography, suggests a significant turning point already between 55 and 65 dB(A),L_{den}, while MITHRA – a recommended interim method by the Environmental noise directive – indicates this change into significance between 60 and 70 dB(A),L_{den} (Figure 3 and Table 2).

There are no other railway studies available that would allow a direct comparison of the results. The current study is the first to apply two different noise calculation methods and to provide an exposure-response curve for sleep medication consumption as dependent variable. We can, however, compare the results of the current study with results obtained from earlier studies as pertaining to high annoyance at night (Heimann et al. 2007, p 127 Fig. 6.8 left). In these analyses the probability of being "highly annoyed at night" showed also an earlier non-linear departure when noise exposure calculations were based on the ISO-method compared with the MITHRA-method. Two further observations from these earlier reported analyses should be mentioned: Firstly, using the ISO-method, the "railway bonus" vanishes around 55 dB(A),Lden when compared with highway noise exposure (Heimann et al. 2007, p 127 Fig. 6.8 right). Secondly, both the ISO as well as MITHRA-based exposure-response curves show a considerable departure from the "EU curve" (Miedema et al 2003) at the same railway noise exposure levels.

The effects of the adjustments for health related variables point to another important issue. Age, gender, health status, trauma history, as well as low education doubles already sleep medication intake in an adult population (see Table 1). The single adjustment for age (Figure 1) has only a modest effect compared with the adjustment achieved by the nine predictors in the full model. Due to the potentially large cumulative effect of these other predictors on sleep medication intake it can be argued that a substantial number of predictors is needed to be sure whether the adjustments made are sufficient.

In this representative sample the 12 month prevalence of sleep medication intake is 8.5%. It varies between urban, suburban and rural areas – with the highest intake in urban areas. The cardio-vascular disease prevalence (12 months) is in the lower range of European prevalence data (angina pectoris: 2.4 %, myocardial infarction: 0.5%). The prevalence of shift work is 20.6 %.

Altogether, we rate the morbidity and exposure structure and the medication intake as somewhat lower than what one generally would expect in European cities.
On the other hand, the area of investigation exhibits some peculiarities in terms of noise exposure patterns such as:

- a high night load from longer freight trains, which results in nearly 3 dB(A) higher noise levels during night compared with the exposure during day (with predominantly passenger trains).

- due to the low background level at night in most alpine valleys, the signal to noise ratio (emergence) is high and the higher intermittent peak exposure levels from freight trains are easily perceptible.

- the longer duration of pass-by's (freight trains 500 to 750 m long) in this study may also contribute. Note: especially on the slopes of the valley you can hear the train passage far longer. Passchier-Vermeer et al. (2007) observed for passages of longer duration 1.5 times higher motility reactions than for passages of average duration of road and rail traffic.

- the noise propagation in alpine valleys differs significantly from the propagation over flat terrain (Van Renterghem et al. 2007). This often results in higher sound exposure on the slopes, where the signal-to-noise ratio is even higher than at the valley floor.

These facts have to be considered when it comes to a generalization of the results. For instance, in the Passchier-Vermeer et al. (2007) publication, only 2.5% of the railway passages were of longer duration (2 minutes). Thus, on average motility reactions due to rail noise in this study were smaller because 97,5 % of pass-by's were of shorter duration.
Finally, some words about the strength and weaknesses of the survey.
Where the study clearly stands out is the amount of detail available about the sound exposure. Real railway emission measurements built the input for the noise calculations which were made by two expert teams who themselves were the developers of the respective sound calculation software. An abundance of long-term measurement served as quality control base. An in-depth study evaluated with more advanced methods the peculiarities of the sound propagation in alpine valleys (Van Renterghem et al. 2007).
From a methodological point it should be mentioned that the medication intake was asked without making reference to noise, since the prevalence of sleep disturbances asked in relation to noise are biased (Barker & Tarnopolsky, 1978).
Although the participation was modest, the final sample was representative of the population where it was drawn, except for gender. Female participants more often replaced males in interviews, thus bypassing random sampling (ALPNAP-Interim report 2006, unpublished).
The various exposure-response models with increasing adjustments show the full path of the analysis and everybody can draw their own conclusions. In addition, the similar results

obtained with the indicator "highly annoyed by night" in an earlier analysis (Heimann et al. 2007) supports the medication study with respect to the exposure-response curve. Further support for a stronger effect of railway lines with a high proportion of freight trains comes from an annoyance study carried out ten years ago (Lercher et al. 1999). In this study the railway bonus against road traffic noise vanished above 55 dB(A),Ldn.

The finding of an association with psycho-sedative drug intake in the semi-ecological study by Rüdisser et al. (2008), when living in close distance to a railway track with a similar night load from freight trains as in this study, does lend further support to the findings.

In retrospect, we would have liked to have more information available about the frequency of the sleep medication intake during the past 12 months. Furthermore, future studies could use established sleeping and sleepiness scales to better assess the severity of the insomnia which ultimately led to the medication intake. This was not possible here due to the limited time the telephone interviews allowed to gather such data.

Eventually, the inherent limitation of the cross-sectional design prevents a causal interpretation. Though, in this case, a certain element of a retrospective cohort design could be argued, since the railway noise exposure increased over the past 15 years. Parallel to the development of the railway exposure, the nightly noise exposure by the highway decreased slightly due to a night ban for loud trucks, in effect since 1990. This change in the soundscape may partly be responsible for the better physiological and psychological perception of the railway noise during night.

Actimetry study

To elucidate the impact of railway noise on actimetry parameters as measured with the SSG system, we conducted a small actimetry study in addition to the telephone survey. As expected, the probability of motility reactions in the actimetry study was strongly determined by the maximum sound pressure level of a noise event. But also the slope of rise, with other words, the steepness of the increase in level, was a significant predictor and confirms the findings of the literature (Hofman et al., 1995; Marks et al., 2008) where higher rates of autonomous activation during sleep were found with steeper slopes of rise. Marks et al. found that railway noise from trains quite often elicits awakenings due to the fact that approaching trains usually display a very steep slope of rise shortly before the L_{max} is reached. It is well possible that train passings in close proximity to dwellings due to their steep slope of rise might evoke quite similar patterns of motility as can be observed with people living right below aircraft landing approach paths (Brink et al., 2008). The energy L_E per train passing (and therefore the legislation-relevant L_{eq} exposure measure) at such locations potentially underestimates the detrimental effect of a fast rise of level on a sleeper as it’s produced from passing trains on tracks that are close to the bedroom of a sleeper. This problem will generally become more important in the future when trains increase not only by number/hour but also in speed. For particular railway noise immission situations, especially at night-time with a high proportion of freight trains, the long standing "railway bonus" might therefore not longer be justifiable, a presumption, that was already expressed earlier (e.g. in Spreng, 1998). In this light, our actimetry study – although limited by the small number and the design – may contribute to increased awareness of railway-induced sleep disturbances in particular and the importance of the slope of rise of noise events in general.

Conclusions

Railway noise can have a significant impact on sleep medication intake and motility reactions under conditions that resemble those in the Inn-valley. The application of a railway bonus under these exposure conditions seems questionable. Whether this is due to the specific noise propagation situation in alpine valleys alone or only in combination with the high exposure load from freight trains during the night cannot be determined on the basis of the current study design. In Austria, the action-level for railway noise in the framework of the Environmental noise directive is set at 70 dB(A),L_{den}. The results of this study challenge this setting. A level of 60 dB(A),L_{den} would be more appropriate for railway lines with a high proportion of nightly freight trains in a valley slope configuration such as the Inntal. Probably, a L_{night}-level around 50 dB(A) would be needed to protect residents from sleep related health impacts.

Eventually, the type of the applied noise calculation method, its implementation, and its application can influence guideline setting and the interpretation of results. A harmonization should aim at setting a higher standard for specific sound propagation needs in difficult terrain.

Acknowledgements

The ALPNAP project received European Regional Development Funding through the INTERREG III Community Initiative. In the context of this study we received data and supporting information from various governmental, private and public institutions. Special thanks to the GEO-information system TIRIS and the traffic administration of the Tyrolean Government and the Brenner railway company (BEG). The phone survey was conducted by the CAT-Lab of IMAD, an opinion research Institute in Innsbruck.

We thank the study participants and greatly acknowledge the field work for the actimetry study done by A. Eisenmann and J. Rüdisser and support by E. Amann. This work was partly supported by ETH Zürich and Section of Social Medicine, Medical University Innsbruck.

References

Ancoli-Israel S, Cole R, Alessi C, Chambers M, Moorcroft W, Pollak CP. The role of actigraphy in the study of sleep and circadian rhythms. *Sleep* 2003; 26, 342-392.

Barker SM, Tarnopolsky A. Assessing bias in surveys of symptoms attributed to noise. *J Sound Vib* 1978; 59: 349-354.

Bluhm G, Rosenlund M, Berglind N. Traffic noise and health effects. In: Carter N, Job RF, editors. Noise Effects 98. *Proceedings of the 7th International Congress on Noise as a Public Health Problem*, Sydney, Vol. 1. National Capital Printing Act: Sydney; 1998. pp 247-50.

Bonnefond A, Saremi M, Rohmer O, Hoeft A, Eschenlauer A, Eschenlauer R, Muzet A, Tassi P. Effects of nocturnal railway noise on subjective ratings of sleep and subsequent cognitive performance. *Somnologie* 2008; 12:130–138.

Botteldooren D, Lercher P. Soft-computing base analyses of the relationship between annoyance and coping with noise and odor. J Acoust Soc Am 2004; 115(6): 2974-2985.

Brink M, Basner M, Schierz C, Spreng M, Scheuch K, Bauer G, Stahel W. Determining physiological reaction probabilities to noise events during sleep. *Somnologie*, 2009; 13, 236-243.

Brink M, Lercher P, Eisenmann A, Schierz C. Influence of slope of rise and event order of aircraft noise events on high resolution actimetry parameters. *Somnologie* 2008; 12: 118–128.

Brink M, Müller CH, Schierz C. Contact-free measurement of heart rate, respiration rate, and body movements during sleep. *Behavior Research Methods* 2006; 38(3):511–521.

Chongsuvivatwong V. R-Epicalc URL:http://cran.r-project.org/web/packages/epicalc

de Greve B, de Muer T, Botteldooren D. Outdoor beam tracing over undulating terrain, *Proceedings of Forum Acusticum* 2005, Budapest, Hungary; 2005.

de Greve B, van Renterghem T, Botteldooren D. Outdoor sound propagation in mountainous areas: comparison of reference and engineering models. In: *Proceedings of ICA* on CD-ROM. Madrid, Spain; 2007.

Di Nisi J, Muzet A, Ehrhart J, Libert JP Comparison of cardiovascular responses to noise during waking and sleeping in humans. *Sleep 1990*; 13(2):108–120.

Griefahn B, Basner M. Noise-induced sleep disturbances and after-effects on performance, wellbeing and health. In: *Proceedings Internoise* 2009. Ottawa, Canada; 2009.

Griefahn B, Bröde P, Marks A, Basner M. Autonomic arousals related to traffic noise during sleep, *Sleep* 2008; 31(4): 569-577.

Griefahn B, Marks A, Robens S. Noise emitted from road, rail and air traffic and their effects on sleep. *J Sound Vib* 2006; 295(1–2):129–140.

Griefahn B, Schuemer-Kohrs A, Schuemer R, Moehler U, Mehnert P. Physiological, subjective, and behavioural responses during sleep to noise from rail and road traffic. *Noise Health* 2000; 3: 59–71.

Harrell FE Jr. Regression modeling strategies. New York: Springer; 2001.

Harrell FE Jr. R-Hmisc and R-Design library. URL: http://cran.r-project.org/web/packages/Hmisc/ and http://cran.r-project.org/web/packages/Design/

Heimann D, de Franceschi M, Emeis S, Lercher P, Seibert P (eds) Air Pollution, Traffic Noise and Related Health Effects in the Alpine Space - A Guide for Authorities and Consulters. ALPNAP comprehensive report. Università degli Studi di Trento, Trento, Italy, Dipartimento di Ingegneria Civile e Ambientale; 2007. pp 335. Online available at: http://www.alpnap.org/alpnap.org_ge.html

Hofman WF. Vliegtuiglawaai, slaap en gezondheid. Achtergrondstudie in opdracht van de Gezondheidsraad. Den Haag: Gezondheidsraad; 1991. Report A91/1.

Hofman WF, Kumar A, Tulen HM. Cardiac reactivity to traffic noise during sleep in man. J Sound Vib 1995;179(4):577–589.

Hofman W, Kumar A, Eberhardt J. Comparative evaluation of sleep disturbance due to noises from airplanes trains and trucks. In: Vallet M (Ed). *Noise as a public health problem*. Proceedings of the 6th International Congress. Volume 2. Nice, France: Institut National de Recherche sur les Transports et leur Sécurité ; 5-9 Julliet 1993: pp 559-562.

Horne JA, Pankhurst FL, Reyner LA et al. A field study of sleep disturbance: effects of aircraft noise and other factors on 5,742 nights of actimetrically monitored sleep in a large subject sample. *Sleep* 1994; 17(2): 146–159

Lercher P, Brauchle G, Widmann U. The interaction of landscape and soundscape in the Alpine area of the Tyrol: an annoyance perspective. Cuschieri J, Glegg S, Yong Y. *Proceedings of Internoise* 1999. Ft. Lauderdale, INCE; 1999. pp 1347-1350.

Marks A, Griefahn B, Railway Noise – its effects on sleep, mood, subjective sleep quality, and performance. *Somnologie* 2005, 9:68-75.

Marks A, Griefahn B, Basner M. Event-related awakenings caused by nocturnal transportation noise. *Noise Control Engineering Journal* 2008; 56(1):52–62.

Miedema HME,Vos H. Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. *Behavioral Sleep Medicine* 2007; 5(1), 1–20.

Miedema HME, Passchier-Vermeer W, Vos H. Elements for a position paper on night-time transportation noise and sleep disturbance. TNO Inro report 2002-59, Delft; January 2003. ISBN-number 90-6743-981-9.

Moehler U, Liepert M, Schuemer R, Griefahn B. Differences between railway and road traffic noise. *J Sound Vib* 2000; 231: 853-864.

Moehler U. Community response to railway noise: a review of social surveys. *J Sound Vib* 1988; 120: 321-332.

Morihara T, Sato T, Yano T. Comparison of dose-response relationships between railway and road traffic noises: the moderating effect of distance. *J Sound Vib* 2004; 277: 559–565.

Muzet A. Environmental noise, sleep and health. *Sleep Medicine Reviews* 2007; 11(2):135-142.

Ollerhead JB, Jones CJ, Cadoux RE, Woodley A, Atkinson BJ, Horne JA, Pankhurst F, Reyner L, Hume KI, Van FAW, Diamond ID, Egger P, Holmes D, McKean J. Report of a Field Study of Aircraft Noise and Sleep Disturbance. London: Department of Safety, Environment and Engineering; 1992.

Passchier-Vermeer W, Vos H, Janssen SA, Miedema HME. Sleep and traffic noise. Summary report. Delft, The Netherlands: TNO; 2007. Report Nr. 2007 L&G N001 64024.

Passchier-Vermeer W, Vos H, Seenbekkers J, van der Ploeg F, Groothuis-Oudshoorn K. (Sleep disturbance and aircraft noise exposure - exposure effect relationships. Delft, The Netherlands: TNO Inro; 2002, Report 2002.027.

R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria; 2009. ISBN 3-900051-07-0. URL http://www.R-project.org.

Rüdisser J, Lercher P, A Heller. Traffic exposure and medication - a GIS based study on prescription of medicines in the Tyrolean Wipptal. *Italian Journal of Public Health* 2008; 5(4): 261-267.

Saremi M, Greneche J, Bonnefond A, Rohmer O, Eschenlauer A, Tassi P. Effects of nocturnal railway noise on sleep fragmentation in young and middle-aged subjects as a function of type of train and sound level. *Int J Psychophysiol* 2008; 70(3):184–191.

Spreng, M. (1998). Kritische Betrachtung des Schienenbonus anhand hörphysiologischer/medizinischer Fakten. In Tagungsband Fachseminar Schienenlärm. Ist der Schienenbonus noch zeitgemäß? 17.10.1997: Institut für ökologische Strategien.

Tassi P, Saremi M, Schimchowitsch S, Eschenlauer A, Rohmer O, Muzet A. Cardiovascular responses to railway noise during sleep in young and middle-aged adults. *Eur J Appl Physiol*, published online Nov 10, 2009. DOI 10.1007/s00421-009-1270-8.

Teegen F. Deutsche Übersetzung der Posttraumatic Stress Disorder Checklist (PCL-C) des National Center for PTSD. Boston, Hamburg: Universität Psychologisches Institut III; 1997.

Tryon WW. Activity measurement in psychology and medicine. New York etc.: Plenum Press; 1991.

Van Renterghem T, Botteldooren D, Lercher P. Comparison of measurements and predictions of sound propagation in a valley-slope configuration in an inhomogeneous atmosphere. *J Acoust Soc Am* 2007; 121: 2522-2533.

Vernet M. Effect of train noise on sleep for people living in houses bordering the railway line. *J Sound Vib* 1979; 66: 483-492.

Weathers FW, Huska JA, Keane TM. PCL-C for DSM-IV. Boston: National Center for PTSD - Behavioral Science Division; 1991.

WHO. Night noise guidelines for Europe. Copenhagen: WHO Regional Office for Europe; 2009. http://www.euro.who.int/InformationSources/Publications/Catalogue/20090904_12

Yano T, Morihara T, Sato T. Community response to Shinkansen noise and vibration: a survey in areas along the Sanyo Shinkansen Line. In: *Proceedings of Forum Acusticum* Budapest: 2005.

Yano T, Sato T, Kawai K, Kurosawa K. Comparison of community response to road traffic and railway noises. *J Acoust Soc Jpn* 1998; 54: 489-496.

Yokoshima S, Morihara T, Ota A, Tamura A. Reanalysis of dose-response curves of Shinkansen railway noise. 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, Foxwoods, CT.

Table 1. Basic relationships between sleep medication intake and covariates used in the fully adjusted regression model.

	Medication: no	Medication: yes	Total		
Variable	n (%)	n (%)	n (%)	Test stat.	P value
Age (years)				Chisq. (4 df) = 47.99	< 0.001
25-34	248 (16.5)	8 (5.8)	256 (15.6)		
35-44	443 (29.5)	22 (15.8)	465 (28.3)		
45-54	361 (24.0)	30 (21.6)	391 (23.8)		
55-64	251 (16.7)	39 (28.1)	290 (17.7)		
65+	201 (13.4)	40 (28.8)	241 (14.7)		
Gender				Chisq. (1 df) = 10.81	0.001
Male	598 (39.8)	35 (25.2)	633 (38.5)		
Female	906 (60.2)	104 (74.8)	1010 (61.5)		
Education				Chisq. (3 df) = 17.69	< 0.001
Higher education (>12 yrs)	494 (32.8)	32 (23.0)	526 (32.0)		
Vocational school (12 yrs)	397 (26.4)	34 (24.5)	431 (26.2)		
Skilled labour (10 yrs)	388 (25.8)	34 (24.5)	422 (25.7)		
Basic education (8 yrs)	225 (15)	39 (28.1)	264 (16.1)		
Noise sensitivity (5-point scale)				Chisq. (1 df) = 21.66	< 0.001
High (4-5)	221 (14.7)	42 (30.2)	263 (16.0)		
Low (1-3)	1283 (85.3)	97 (69.8)	1380 (84.0)		
Health status (5-point scale)				Chisq. (2 df) = 102.55	< 0.001
Very good (1)	449 (29.9)	11 (7.9)	460 (28.0)		
Good (2)	557 (37.0)	22 (15.8)	579 (35.2)		
Less than good (3,4,5)	498 (33.1)	106 (76.3)	604 (36.8)		
Trauma history				Chisq. (1 df) = 51.63	< 0.001
No	1006 (66.9)	50 (36)	1056 (64.3)		
Yes	498 (33.1)	89 (64)	587 (35.7)		
Life satisfaction scale (Diener)				Chisq. (1 df) = 10.7	0.001
High (75th percentile)	440 (29.3)	22 (15.8)	462 (28.1)		
Low (25th percentile)	1064 (70.7)	117 (84.2)	1181 (71.9)		
Area characteristic				Chisq. (2 df) = 11.51	0.003
Rural	399 (26.5)	31 (22.3)	430 (26.2)		
Suburban	574 (38.2)	39 (28.1)	613 (37.3)		
Urban	531 (35.3)	69 (49.6)	600 (36.5)		
Bedroom window closed				Chisq. (2 df) = 28.98	< 0.001
Never	1007 (67.0)	65 (46.8)	1072 (65.2)		
Sometimes	224 (14.9)	24 (17.3)	248 (15.1)		
Mostly	273 (18.2)	50 (36.0)	323 (19.7)		
Coping activity score				Ranksum test	< 0.001
median (IQR)	25 (18.0,34.0)	29 (21.0,40.5)	25 (18.0,35.0)		

Table 2. Increase in the probability (prevalence odds ratio) of taking sleep medication at different railway sound level intervals using two methods of exposure modelling

	Increase in Odds ratio (95% CI) at different sound levels			
Regression model	50-60 Lden,dBA	55-65 Lden,dBA	60-70 Lden,dBA	65-75 Lden,dBA
Unadjusted	1.21 (0.82-1.78)	1.25 (0.90-1.72)	1.37 (1.08-1.72)	1.49 (1.05-2.12)
Age adjusted	1.15 (0.75-1.76)	1.20 (0.84-1.70)	1.34 (1.06-1.71)	1.49 (1.04-2.13)
Partially adjusted*	1.21 (0.77-1.91)	1.25 (0.86-1.83)	1.38 (1.08-1.77)	1.51 (1.05-2.17)
Fully adjusted**	1.05 (0.67-1.66)	1.13 (0.77-1.64)	1.37 (1.05-1.78)	1.63 (1.10-2.42)
Fully adjusted***	1.11 (0.74-1.68)	1.29 (1.02-1.64)	1.46 (1.04-2.06)	1.53 (1.00-2.33)

* Age, gender, education, noise sensitivity

** In addition health status, trauma history, coping load, area (MITHRA-method)

*** Sound exposure calculation by ISO-method

Table 3. Descriptive statistics of noise events in the actimetry study

Hour (h)	*22-23*	*23-24*	*00-01*	*01-02*	*02-03*	*03-04*	*04-05*	*05-06*	*06-07*	*07-08*	*08-09*	*09-10*
Average number noise events per subject per hour	3	14.86	25.71	29	38.57	41.71	57.71	56.43	72.86	34.86	0.57	1
Average $L_{A,F,max}$ [dB]	43.04	45.55	45.55	45.80	44.74	45.52	44.76	46.38	47.13	49.91	46.83	51.37
Average slope of rise [dB/s]	2.89	2.09	1.80	1.83	1.84	1.75	2.16	1.90	2.64	2.93	1.19	4.07

Table 4. Results of the logistic regression analysis of the probability of a motility reaction ($P_{mot, observed}$) in the actimetry study; ** =p<.01, *** =p<.001

Parameter	*Estimate*	*SE*	*p*	*95% Lower CI*	*95% Upper CI*
Intercept	-4.34	0.54	***	-5.67	-3.02
$L_{A,F,max}$	0.04	0.01	**	0.01	0.07
Slope of rise [dB/s]	0.18	0.03	***	0.12	0.25

Figure 1. Relationship between railway sound exposure level and sleep medication intake during the past 12 months, using various adjustments for potential confounders (MITHRA method of sound exposure modelling)

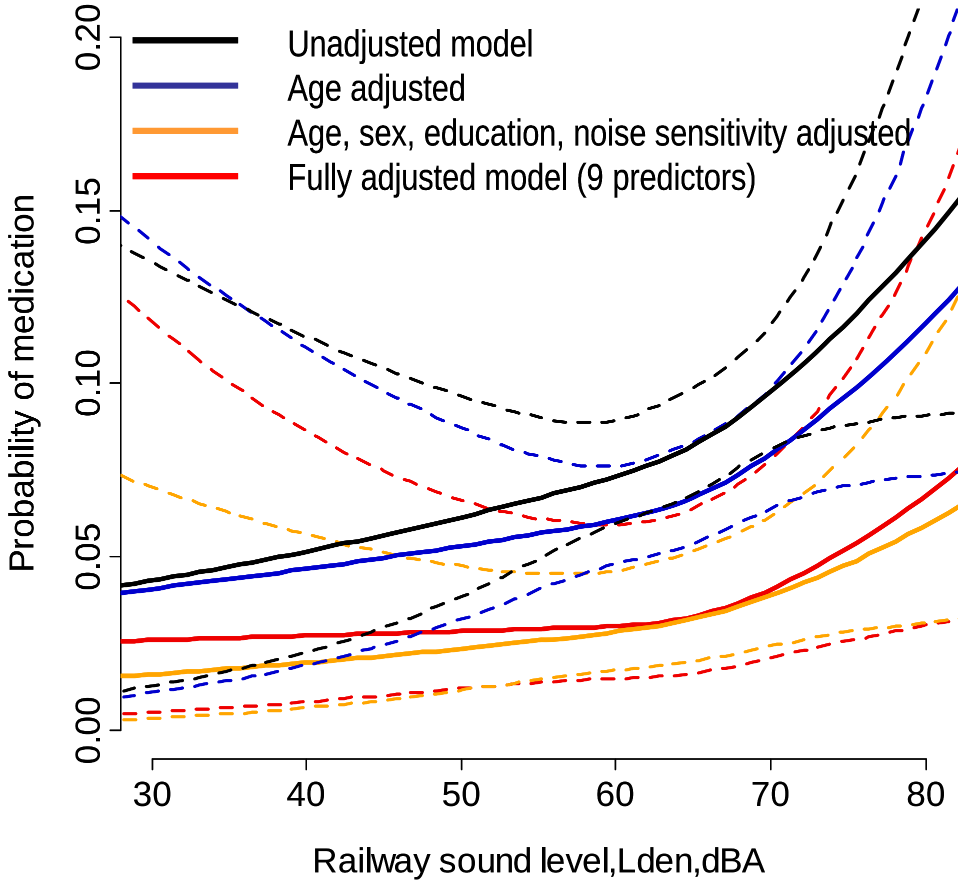

Figure 2. Relationship between railway sound exposure level and sleep medication intake during the past 12 months: comparison of two methods of sound exposure modelling (Fully adjusted model)

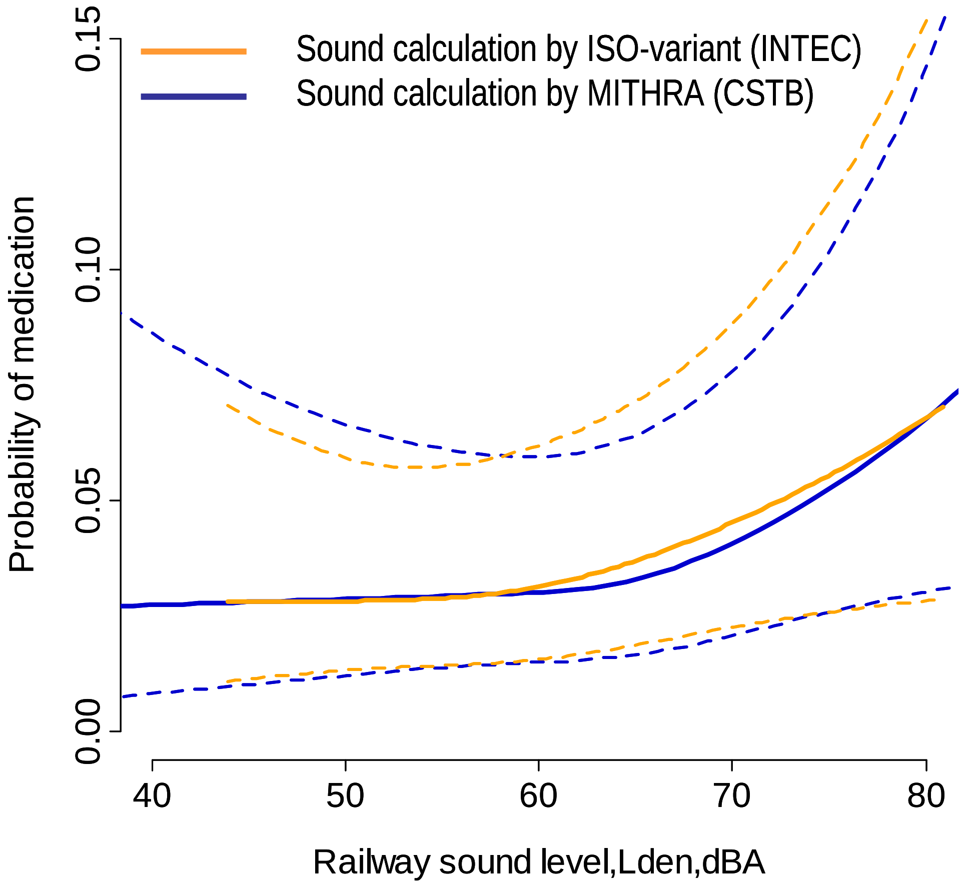

Figure 3. Relationship between railway sound exposure level and sleep medication intake during the past 12 months by three age groups

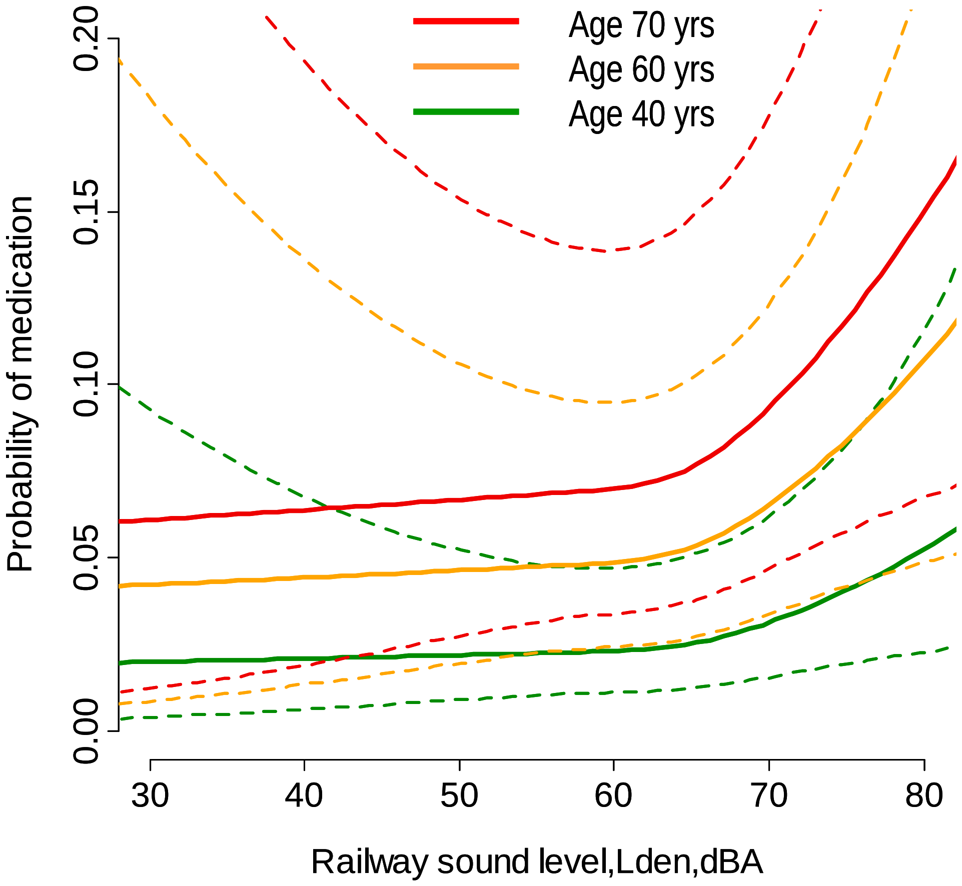

Figure 4. Relationship between railway sound exposure level and sleep medication intake during the past 12 months by trauma history

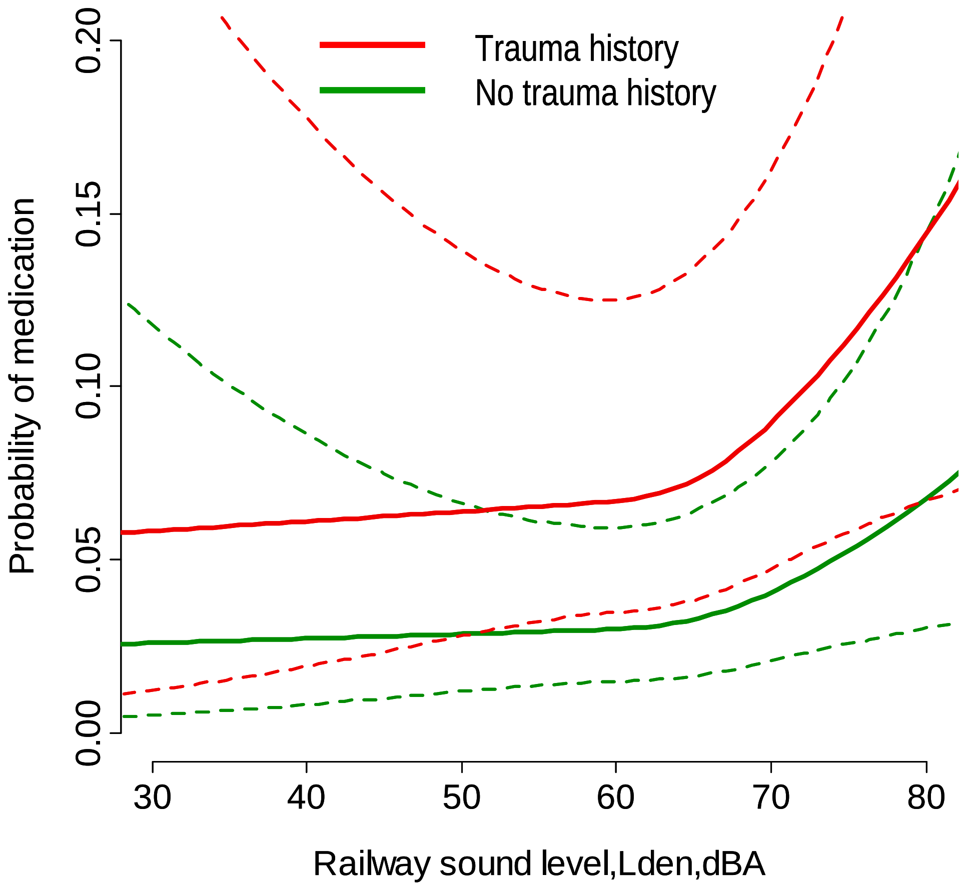

Figure 5. Relationship between railway sound exposure level and sleep medication intake during the past 12 months by area characteristic

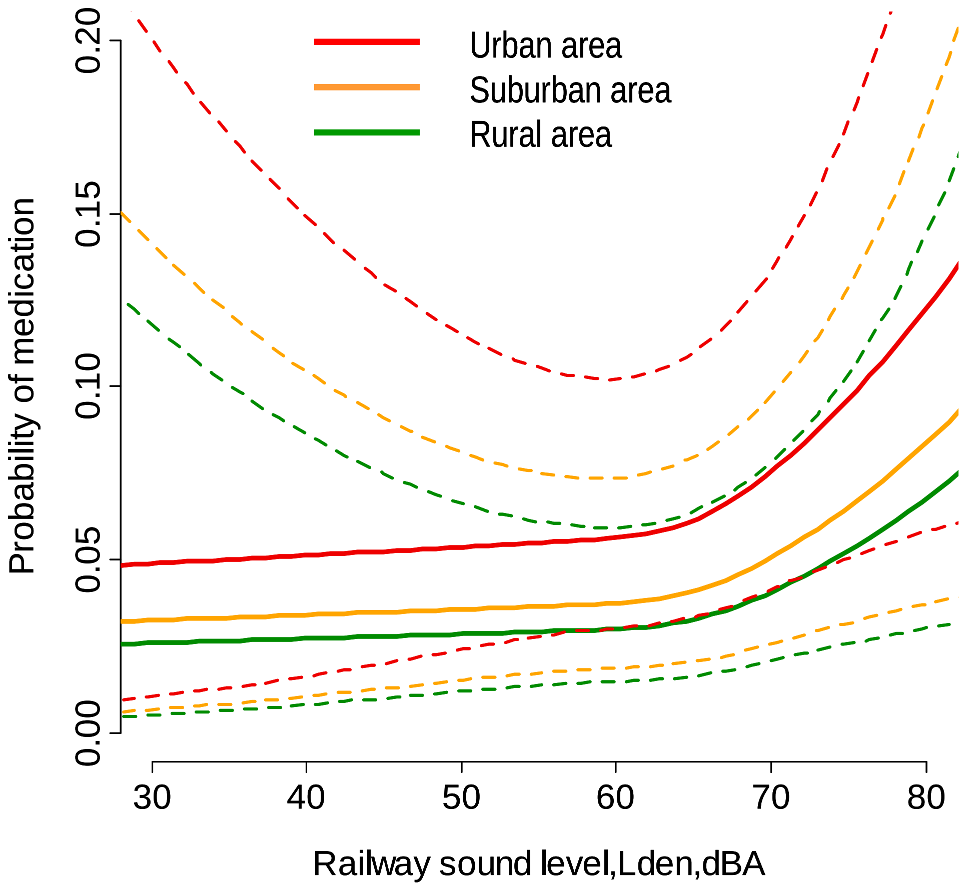

Figure 6. Exposure-effect curves of the probability of a motility reaction depending on maximum sound pressure level, plotted for four different slopes of rise (actimetry study)

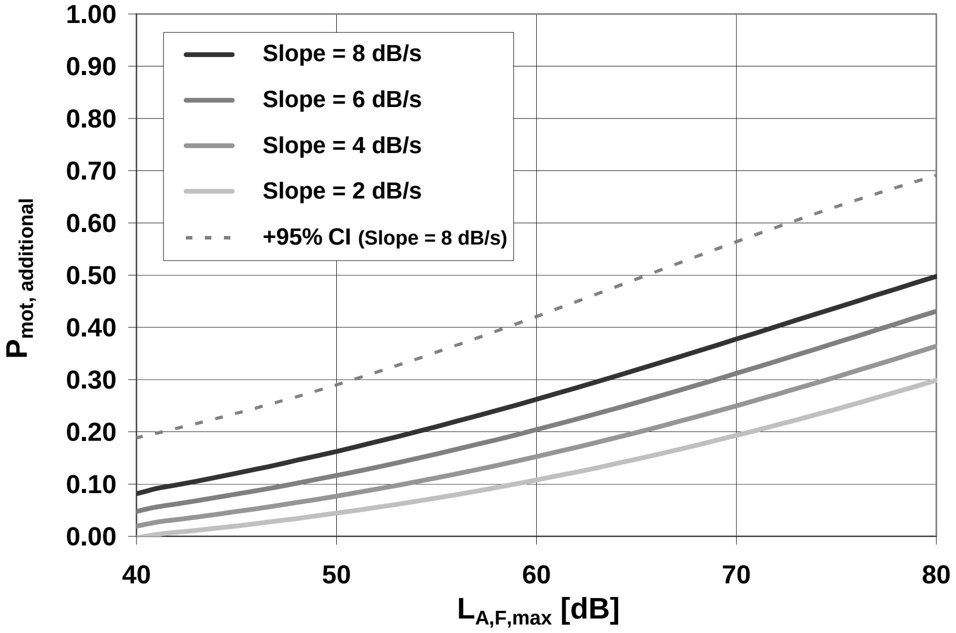

Figure 7. Exposure-effect curves of the probability of a motility reaction depending on slope of rise, plotted for four different maximum sound pressure levels (actimetry study)