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The effect on sleep of nocturnal exposure to noise and vibration from rail traffic

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ABSTRACT

Freight traffic by rail during the night is increasing in Europe. Prognoses for 2020-2030 are uncertain, but public concern about the impact is growing. Scientific evidence on the health effects of rail traffic related exposures is lacking behind. It concerns the impact of noise, vibration and cumulative effects on annoyance, sleep disturbance and quality of life, performance and long-term effects on the cardiovascular system. Evidence of the negative impacts of rail traffic noise has been reasonably well documented, but the (long term) effects of rail traffic related vibration and combined effects of both are rarely studied. This paper presents recent findings on self-reported sleep disturbance in relation with modelled noise and vibration levels at night. This is done in combination with secondary analysis on data from a German study performed in 2008-2009 by DLR among 33 residents along the busy Cologne-Bonn railroad track for nine nights each. This study measured indoor noise and vibration levels and investigated sleep indicators by means of polysomnography including awakening reactions during sleep. This allowed for better interpretation of Dutch findings on self-reported sleep disturbance.

INTRODUCTION

In reaction to questions in the Parliament, the Dutch Ministry of infrastructure and the Environment is preparing a decision regarding further guidelines for vibrations from rail traffic and an enforcement tool for vibrations along the railroad track. In order to define the content for such guidelines, a thorough health impact assessment was seen as necessary. In a recently published literature review [1] it was concluded that the knowledge base is lacking to derive effective norms and guidelines for vibration; research in the field is scarce into the health effects of vibration due to trains. To bridge this gap, a study was aimed at investigating the severity and magnitude of the health effects by means of a survey among residents living in the vicinity of the rail road track. Based on the data that were thus gathered, an estimate was made of the number of people aged 16 years or older in the Netherlands living within 300 meter from a railway track experiencing serious annoyance, sleep disturbance or other health effects. Based on previous studies, it was decided to place the threshold at 300 meter, in which 250-300 can be considered as control area. The survey in this way provided new information on the extent of the exposure, exposure effect relations and potential other determinants as the building blocks for regulation. The findings of this study can be used for economic and health related trade-offs, once an overview of measures and their costs are available. This paper focusses on sleep disturbance as one of the main outcomes of exposure to vibrations from trains in people living within 300 meter from the rail track. In addition, data are used from a study performed in 2008-2009 [8]. In this study 33 participants (mean age 36.2 years±10.3 (SD); 22 females) living alongside railway tracks around Cologne/Bonn (Germany) were polysomnographically investigated. In this study, which was not primarily aimed at studying the sleep effects of vibration, vibration was measured in the bed room of 33 dwellings under the bed. This allowed for better understanding the impact of night time exposure to vibration on sleep and for studying the combined effect of measured noise and vibration on a broad range of sleep indicators in more detail.

Problem

The study thus addresses the following main questions:

1. What is the estimated extent of severe sleep disturbance in people (16+ years of age) within 300 meter from the railroad in the Netherlands?

2. Which exposure effect relations can be derived for severe sleep disturbance for exposure expressed in distance, RMS and $_{Vmax}$. [RMS is a vibration measure over longer periods, while Vmax refers to the highest effective vibration strength]? [3]

3. What is the influence of physical, contextual and personal factors on sleep disturbance?

4. How do our estimated and longitudinal findings relate to findings from secondary analysis on a German data set using measured exposure levels and measured, acute effects on sleep?

STUDY 1: LIVING ALONG THE RAILROAD TRACK IN THE NETHERLANDS

Method

In the Dutch study, information was gathered by means of a questionnaire about sleep disturbance and the determinants of those. Participants were people of 16 year and older residing within 300 meter from the railroad in the Netherlands. They were recruited by sending an invitation to 16.000 addresses selected based on distance, and building year. In addition other situational factors were accounted for such as train intensities. In order to determine to what extent participants differed from non-participants, a nonresponse study was performed among an a-select sample of all non-responders. The information, gathered with a questionnaire containing over 60 questions on a range of topics (residential situation, dwelling, and demographics, perceived vibrations and noise while at home, health and wellbeing, and finally willingness to accept and pay) was completed with modelled vibration estimates and noise levels and information from different registries about situational and contextual factors such as the number and types of trains, soil, speed, building year of the dwellings. Sleep disturbance was measured with a standard question informing “to what extent the sleep was disturbed by vibration from rail traffic in the past 12 months while at home. The question was asked in general and for passenger, freight trains and maintenance separate. Answers could be given on an 11 point scale (0-10) ranging from not at all to very much.

Response

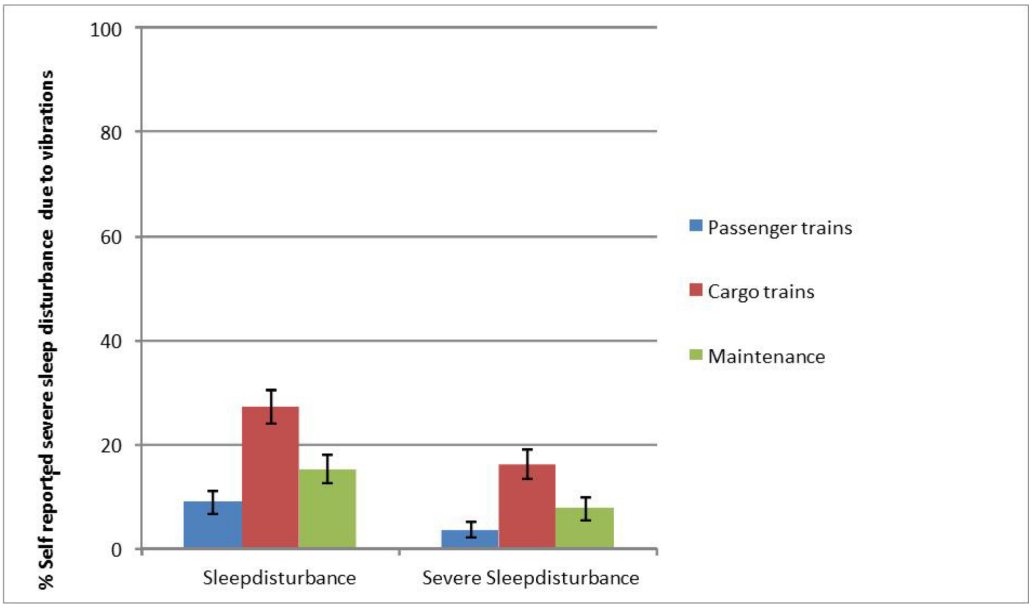
In total 4927 persons (32%) completed the questionnaire. Comparison between responders and non-responders showed some potential selection bias: people who were severely annoyed by vibration of trains participated more often. This leads to somewhat diminished representatively and accompanying distortion of the results. When applying the annoyance findings this potential overestimation has to be taken into account. On the other hand we also observe potential underestimation: the distortion can go two ways. Because of a low response to the nonresponse study (29%) it is not possible to quantify the effect of selective non-response in terms of weighing.

Exposure

For practical reasons in this study the vibration strength was modelled rather than measured, using the so-called Standard Calculation method for vibrations (SRM-T) [2], which was developed several years ago in the Netherlands. In the Netherlands circa 845.000 residential addresses were situated within 300 m from the railroad. At 40% of these addresses, the maximal estimated vibration level lies above the sensibility threshold of 0,1mm/s. Only 1 % lies above the threshold of 3.2 mm/s which is the maximum guideline value in the Netherlands as described in the so called SBR guidelines both in existing as new situations. In view of the reliability of the estimates, it has to be taken into account that we worked with generic model parameters. At the local level the situation can deviate. At the moment this is the best model available, but the risk of exposure misclassification cannot be excluded. For the evaluation of the exposure in the Netherlands this does not necessarily cause a problem because the levels are averaged over a large number of addresses, unless we deal with systematic misclassification.

Results

Based on the survey the percentage severely sleep disturbed is estimated to be 16% in relation to freight trains, and almost 4% by passenger trains.



Exposure effect relationship

Exposure effect relations were derived for sleep disturbance and the exposure to vibrations expressed in Vmax. Distance and RMS. Here we only present the results for Vmax. Vmax used here was conform the SBR guidelines modelled at the middle floor.

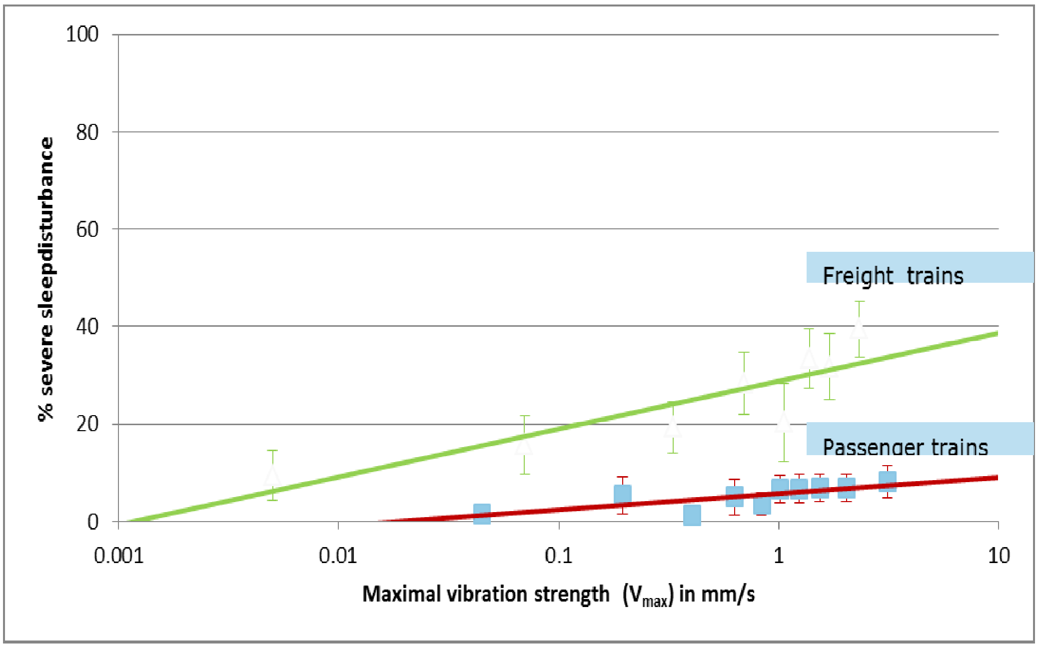


Figure.1: Vmax and percentage severely sleep disturbed (per type of train and 95% confidence intervals).

The role of other factors

After adjustment for a number of potentially disturbing factors, only a significant association was found between maximum vibration levels of freight trains and severe sleep disturbance. When the Vmax levels of vibration due to freight trains increases with 0.1 mm/s the chance of severe sleep disturbance increases with nearly 4%.

A whole range of situational, contextual and personal factors affect the association between vibration levels and sleep disturbance.

The ratio between the number of trains in day and nighttime plays an important role. It is estimated that when the number of trains in the daytime increases with 10%, the odds severe sleep disturbance increases with almost 62 percent. The ratio passenger and freight trains seems not to matter. People who live in an area with a sandy soil experience less sleep disturbance due to passengers trains than people living on clay ground. Also an effect of urbanity was found: people living in strong to very strong urbanized areas experience significantly less sleep disturbance due to trains than people who live in nonurban areas. Night noise exposure does not explain the association between vibration and self-reported sleep disturbance; in other words noise and vibration effect sleep disturbance independently. The location of the sleeping room only seems to play a role in sleep disturbance due to passenger train related vibrations. People with sleeping rooms on the third floor or higher experience more sleep disturbance compared to those living on the second floor or lower. Also it makes a difference whether people sleep with their windows open or closed, with more disturbance when windows are open. Double glazing on the contrary does not show much effect, nor do demographic features as gender, age etc. However, people with a lower level of education score higher on sleep disturbance due to vibration of passenger trains as compared to freight trains.

Social and personal factors also determine sleep disturbance. People who expect an increase in vibration levels due to trains report more sleep disturbance than others. Also worry about damage to the dwelling is significantly associated with sleep disturbance. About the direction of the association no definite conclusions can be drawn since we are dealing with cross sectional data. A negative attitude towards current policy regarding rail traffic and attitudes towards expansion of the night time rail traffic score also higher on sleep disturbance. Non-acceptance of vibration as well as the perception of rattle (windows, dishes, doors) experience more sleep disturbance, but this is only significant for freight trains. And finally type of dwelling was not significantly associated with sleep disturbance.
These findings are in line with those found in the Salford study [4][5] and the EU project Attenuation of ground-borne vibration affecting residents near freight railway lines (CargoVibes) [6].

STUDY 2: SECONDARY ANALYSIS OF THE DLR (GERMAN AEROSPACE CENTER) DATA

The study described above was a cross sectional study addressing self-reported sleep disturbance only in relation to estimated levels of vibration due to passenger trains and freight trains. The findings regarding sleep disturbance due to vibration of freight trains need further interpretation. The survey showed that people were primarily concerned with the (expected) increasing frequency of night time freight train traffic, and the effects on subjective sleep are primarily related to freight train vibration.

Aim

Data available at DLR in the framework of the sub-project RAPS (Railway noise, Annoyance, Performance, Sleep), performed in the period between 2008 and 2009 allowed us to further investigate and validate these findings, using measured noise and vibration data as well as measured sleep indicators over a period of nine nights. Secondary analysis was focussed on night time exposures and relevant sleep indicators as available from the DLR study. The aim was to provide further insight in the association between train related vibrations and sleep while controlling for relevant confounders including noise levels. The measured vibration levels as well as measured sleep indicators allowed us to give further interpretation to previous findings and to inform the Dutch Ministry about the severity of the effects and the mechanisms behind it.

Method

Data used were derived from the DEUFRAKO-RAPS (Railway Annoyance Performance Sleep) project of the German Aerospace Center (DLR). For a detailed description of the approach and method we refer to Pennig et al [7] and Elmenhorst et al, [8]. Vibration measurements were not official part of the study. DLR, however, made vibration measurements at most of the sites on the floor near or under the bed. Vibration accelerations were recorded in x-, y- and z-direction. Physiological measures included electrocardiogram (ECG), electro-encephalogram (EEG), electro-oculogram (EOG), electromyogram (EMG), respiration, finger pulse rate and subjective sleep quality by means of questionnaires. Physical measures included sound pressure levels inside and outside position in bed and actimetry. And finally some performance measures were made including next day single reaction time task and a memory test. In the framework of this paper only awakening reactions are studied in relation to noise and vibration levels expressed in maximum sound pressure levels and Vmax (= the highest level of vibration during a certain period).

Results

A random intercept logistic regression model was run on the data, to account for the repeated measurements per subject. The logistic regression models the probability of awakening for the passing of a train in relation to measured vibration and noise levels. The best model is based on the AIC (Akaike Information Criterion), a measure of the quality of fit of regression model to the data. To model the vibration data the original DEUFRAKO-Model [8] was used. This model was extended to include the vibration parameters Vibr. Max. vert. and Vibr. RMS. vert. In table 1 only results for Vmax are presented. We see a significant effect of Vibr.Max.vert on the awakening probability (p-value < 0.05). With increasing vibration, the number of awakening increases as well. Numerical variables are centered and divided by two standard deviations, categorical variables are kept unchanged.

Modell 3, n=3895, AIC=3150	Estimator	SE	p-Value	Stand. Estimator
Constant	-3.5580	0.4977	< 0.0001	-2.5141
Maximum level	0.0255	0.0082	0.0019	0.4504
Slope (rising ratio)	0.0410	0.0189	0.0306	0.2148
Duration of noise event in seconds	-0.0052	0.0024	0.0311	-0.2787
Elapsed sleep duration in seconds	0.0002	0.0002	0.3890	0.1009
Age (in years)	0.0087	0.0078	0.2685	0.1635
Gender (Male)	0.0723	0.1627	0.6567	0.0723
Elapsed sleep duration in current sleep stage	-0.0375	0.0064	< 0.0001	-0.9470
Elapsed sleep duration in current sleep stage^2	0.0003	0.0001	< 0.0001	0.5808
Current sleep stage 3	-0.7101	0.3595	0.0483	-0.7101
Current sleep stage 4	-0.3322	0.5304	0.5312	-0.3323
Current sleep stage REM	0.2285	0.1245	0.0665	0.2285
Vibr. Max. vert. mm/s	2.1210	1.0360	0.0406	0.2578

Table 1: Results of logistic regression model of the number of awakening on vibration (Vd,max vertical and calculated for matrass of a default IKEA bed)

Figure 2 shows the exposure-effect curve based on the logistic regression model presented in table 1. The maximum sound pressure level is varied and the other parameters in the model are set to fixed values. Those values are based on the values that were used in the original DEUFRAKO-publication as reported by Elmenhorst et al [8].

The exposure response curve was plotted for five different values of the maximum Vmax vertical (this is the weighted Vibration max level in bed (default IKEA bed).

1. Minimum in the data set: 0.006 mm/s
2. 25% percentile in the data set: 0.034 mm/s
3. 50% percentile (Median) in the data set: 0.060 mm/s
4. 75% percentile in the data set: 0.113 mm/s
5. Maximum in the data set: 0.528 mm/s

The maximum level [5] in this data considered as outlier in the sense that it pertains to only a few people, giving a large difference compared to the other curves, which are very close to each other. However, awakening probability can double for a given maximum sound pressure level due to vibration.

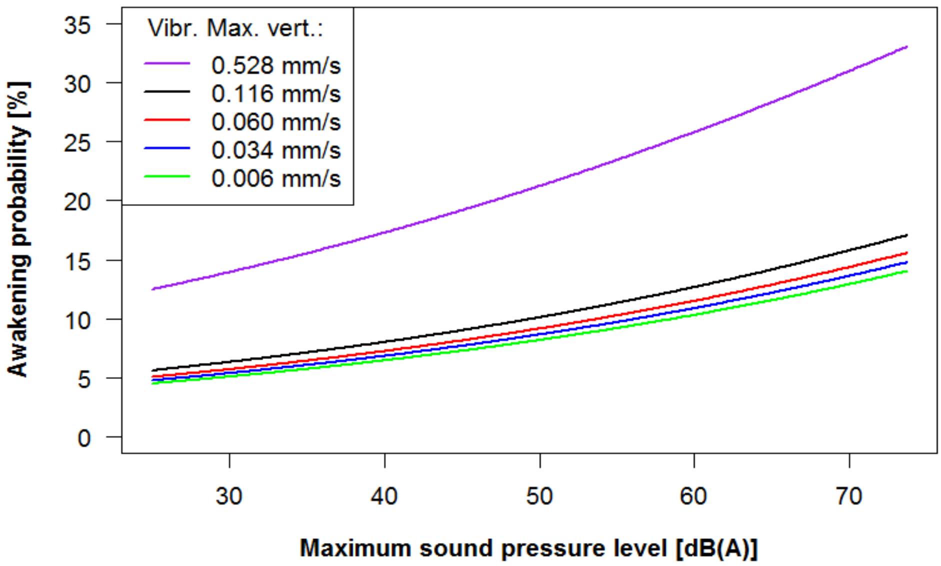


Figure 2: Awakening reactions due to noise and vibration from freight trains (vertical)

CONCLUSIONS

The results of the survey held in the Dutch rail study in 2013 indicate unfavourable effects of the exposure to vibration from train traffic on sleep disturbance. Most people living within 300 meters from the rail road are exposed to levels below the sensibility threshold of 0.1 mm/s. Around 528.000 persons are confronted with exposure levels between 0.1 – 3.2 mm/s (Vmax), the range at which vibration could cause relatively high disturbance. A relatively small proportion (some 11.000 persons) is exposed to levels above 3.2 mm/s (Vmax).

Based on the results it is estimated that in 2013 over 16% (95% Bthi 13,5 – 19,1) of the population of 16 years and older living within 300 meters of the railroad experiences severe sleep disturbance due to vibration of freight trains. The association between vibrations and these effects could not be explained by levels of noise exposure due to trains. Many situational factors seem to play a role, such as windows open and closed, location of the bedroom, perceived rattle etc. But also contextual and personal factors co-determine the level of sleep disturbance such as attitude towards the source, current policy and expansion of night time rail traffic, acceptance, fear for damage to the dwelling and expected train intensities in the future.

Secondary analysis on a German data set (2008-2009) confirms that freight trains significantly contribute to the awakening probability while accounting for noise levels, when we use the weighted Vd.max vertical as a measure.

In order to compare these findings with the survey data in the Netherlands we need to multiply them with 1,3. This means that the maximum levels measured in Germany were 0,8 mm/s. Compared to the Netherlands that is average but compared to other countries (e.g. Norway or Sweden) this is low. Exposure levels are sensitive to, among other factors, soil type and building structure. So that could explain the differences. However, the number of observations in the German data is too small and the levels of vibration measured in the bedroom were too low to draw firm conclusions.

Acknowledgement

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