Comparison of annoyance from railway noise and railway vibration

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Summary
Aim: To compare vibration exposure to noise exposure from railway traffic in terms of equal annoyance, i.e. to determine when a certain noise level is equally annoying as a corresponding vibration velocity.
Method: Using questionnaire data from the TVANE research project from residential areas exposed to railway noise and vibration in a logistic regression, the dose response relationship for annoyance was estimated. By comparing the relationships between exposure and annoyance for areas both with and without significant vibration exposure the noise levels and vibration velocities that caused an equal probability of annoyance could be determined.
Results: The comparison gives a continuous mapping between vibration velocity in the ground and a corresponding noise level that are equally annoying. For equivalent noise level at the façade compared to maximum weighted vibration velocity in the ground the probability of annoyance is approximately 20% for 58 dB or 0.29 mm/s, and about 50% for 65 dB or 1.1 mm/s.

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1. Introduction

Railway traffic can cause perceivable vibration in nearby buildings, especially for soft ground types and from heavy freight trains with high axle loads. The concept of annoyance is used throughout Europe and elsewhere in assessing the potential impact of noise on an exposed population. Annoyance curves for have existed for some time for railway noise [1] and have more recently been developed for railway vibration [2]. This paper investigates at what vibration velocity the annoyance from vibration equates to the annoyance from noise. An important complication is the interdependence of annoyance, whereby the annoyance due to noise is influenced by the presence of vibration.

2. Method

The questionnaire data were collected during the Train Vibration and Noise Effects (TVANE) project [3]. Two study sites in Sweden (Area 1, Töreboda and Falköping) were selected in areas with relatively intense railway traffic and no vibrations from railway traffic. Two separate study sites (Area 2, Alingsås and Kungsbacka) were selected in areas with approximately the same number of trains as in Area 1 but where the trains induced strong vibrations in the ground and the dwellings. Three of the study sites (Töreboda, Falköping, and Alingsås) were situated at the railway line "Västra Stambanan" between Gothenburg and Stockholm, and the fourth study site (Kungsbacka) was situated at the railway line "Västkustbanan" south of Gothenburg. The total number of train passages (and freight train passages) are presented in Table I.

Table I. Daily train passages

Site	*Total trains*	*Freight trains*
Falköping/Töreboda	124	44
Alingsås	206	48
Kungsbacka	179	22

Equivalent and maximum noise levels were calculated for all respondents in the questionnaire surveys, and in total 16 measurements were performed of both ground and indoor vibration in Alingsås and Kungsbacka. The vibration results were analysed and weighted according to the applicable Swedish standard [4], which gives a maximum vibration velocity with time weighting SLOW (1s) using a frequency weighting almost

identical to the W_m weighting from ISO 2631-1 [5].
The results in Kungsbacka were very similar for ground and outdoor vibration, and all buildings were of the same construction, a concrete slab with two floor levels. For Alingsås the results demonstrated a greater variation, and the buildings were also of many different construction types. The amplification factor from ground to indoor vibration velocity varied between 0.7 to 5.3 (0.96 to 1.1 for Kungsbacka), meaning that building resonances could increase the vibration by more than five times, but the building could also reduce the vibration velocity by 30%, depending on the details of the construction. This makes it possible to predict the indoor vibration velocity with reasonable uncertainty for all respondents from the ground vibration velocity in Kungsbacka, but not in Alingsås. In the following study we use the outdoor ground vibration during analysis, which corresponds well to indoor values for Kungsbacka, and for now accept the unknown uncertainty introduced in Alingsås with this approach.
The questionnaire data that was analysed for this study were two adjacent annoyance questions identically worded for railway noise and vibration with a 11-point numerical scale coded as 0 – 10. We consider the range 5 – 10 to correspond to "annoyed" and 8-10 "highly annoyed". The dose-response relationship is determined using logistic regression for the probability of being annoyed P according to

$$\mathrm{logit}(P) = \beta_0 + \beta_1 x, \tag{1}$$

where x is either the logarithm with base 10 of the maximum weighted vibration velocity $\log_{10}(v)$ or the equivalent noise level L_AEq and β_0,β_1 are the regression coefficients. We use the logarithm of the velocity to make it comparable to the logarithmic nature of sound pressure levels.

3. Results

The regression for the noise exposure is assessed in Area 1 only, where no vibration is present. The regression results are presented in table II. For vibration exposure there is no data without noise exposure, therefore we assess vibration annoyance in Area 2, the results are presented in table III.

Table II, regression results for annoyance from noise (Area 1, no vibration).

	Est.	*Std. error*	*z value*	
β_0	-13.85	2.04	-6.79	***
β_1	0.2136	0.036	5.934	***

Table III, regression results for annoyance from vibration (Area 2, both noise and vibration).

	Est.	*Std. error*	*z value*	
β_0	-1.876	0.1797	-10.44	***
β_1	1.656	0.3989	4.152	***

In order to get a measure of when the annoyance from vibration equates to the annoyance from noise there are several possible approaches. The most straightforward is to put the estimated probability of being annoyed by noise in Area 1 equal to the probability of being annoyed by vibration in Area 2. This gives a linear relation between noise and vibration where they give rise to the same probability of being annoyed, and the function is presented in Figure 1.
Since the model predicts 13% probability of being annoyed by vibration even at zero vibration velocity there is no possibility to compare vibration and noise annoyance for low noise levels where the probability is lower than 13%. If we instead predict the probability of being annoyed using (1) with the logarithm of the vibration velocity, $x=\log_{10}(v)$, which could be justified with the fact that the noise level is a logarithmic measure, we get the model in Table IV. Note that the intercept β_0 is not significant in this model. In Figure 2 this model is analysed as above to and compared to the linear model. The curve now has an exponential form, and in the vicinity of 20% probability of being annoyed both curves are close together, but deviates at lower and higher values.

Table IV, regression results for annoyance from vibration using the logarithm of the vibration velocity (Area 2, both noise and vibration).

	Est.	*Std. error*	*z value*	
β_0	0.1237	0.2538	0.488	
β_1	2.516	0.4143	6.073	***

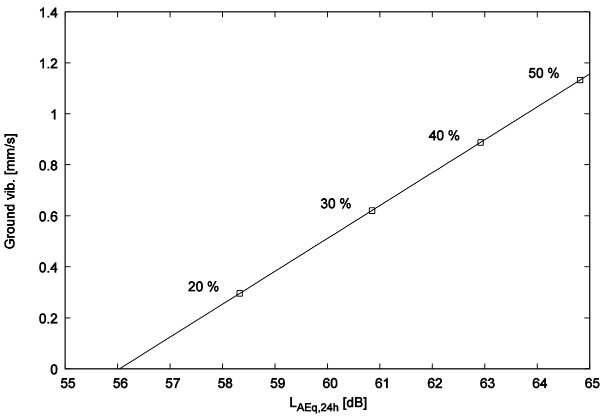

Figure 1. Function of equal annoyance for nosie and vibration, percentages indicate probability of beeing annoyed either by vibration or noise.

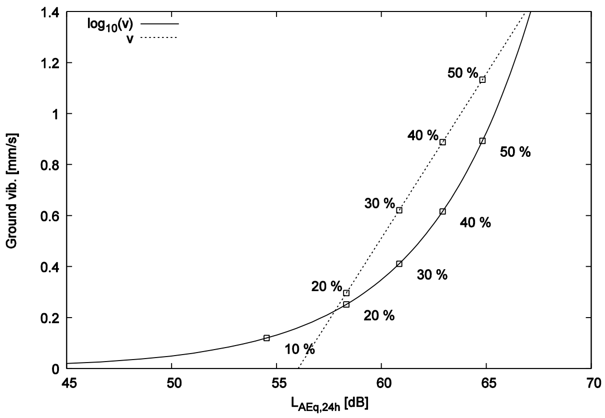

Figure 2. Function of equal annoyance for nosie and vibration both for a linera and logarithmic model, percentages indicate probability of beeing annoyed either by vibration or noise.

4. Discussion

The presented analysis gives a simple way of comparing the annoyance from vibration and noise from railway traffic. The uncertainty in predicting the indoor vibration velocity is a major concern, and future research in the field should aim at either using measured vibrations for all exposed or use advanced prediction schemes for the vibration that can take the construction details of the buildings into account.

The approach presented above ignores the fact that the respondents in Area 2 are exposed both to noise and vibration. The probability of being annoyed by noise is higher at the same noise level in Area 2 than in Area 1, which can be thought of as an interaction between noise and vibration annoyance, see Figure 3. If the reverse is also true, that the presence of noise increases the annoyance by vibration, then the effect of vibration alone is overestimated with the models presented here.

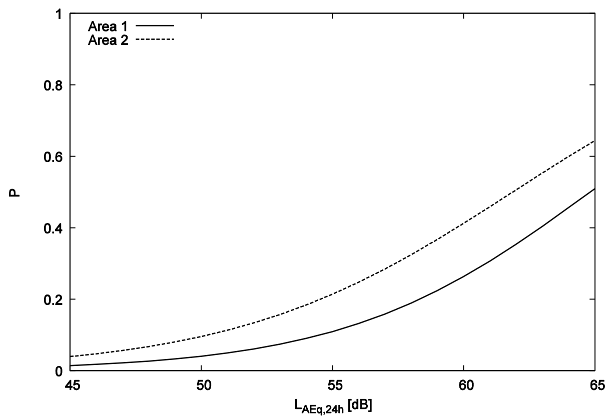

Figure 3. Estimated probability of being annoyed by noise in Area 1 (noise only) and 2 (vibration and noise).

Acknowledgments

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References

[1] H. M. Miedema, C. G. Oudshoorn: Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect 109 (2001) 409-416.

[2] S. Janssen, H. Vos, A. Koopman (2013) Cargovibes. Attenuation of ground-borne vibration affecting residents near freight railway lines. Deliverable D1.2 Exposure response relationships and factors influencing these relationships.

[3] A. Gidlöf-Gunnarsson, M. Ögren, T. Jerson, E. Öhrstrom: Railway noise annoyance and the importance of number of trains, ground vibration, and building situational factors. Noise and Health 14 (2012) 190-201.

[4] SIS (1992) SS 460 48 61 Vibration och stöt - Mätning och riktvärden för bedömning av komfort i byggnader.

[5] ISO (1997) ISO 2631-1 Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration Part 1: General Requirements. International Organization for Standardization.