Community reaction to railway vibration at different times of the day

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INTRODUCTION

Nighttime and evening time noise have a greater impact on annoyance in residential areas than daytime noise of the same level. A number of studies showed different sensitivities with respect to noise exposure during the day, evening and night in particular for air traffic (Fields 1986a, b; Miedema et al. 2000; Schreckenberg & Meis 2006). L_{den} was proven to be a good indicator for long term effects (notably annoyance). L_{den} incorporates different weighting factors for noise in the evening and night for predicting annoyance (5 dB penalty for 19-23 h, and 10 dB penalty for 23-7 h). L_{den} is one of the EU-indicators for environmental noise (EU Directive 2002/49/EC) and it is currently used to illustrate exposure-response relationships for transportation noise (Miedema & Oudshoorn 2001).

In the same way, the time of day at which vibration occurs might be a factor affecting the impact of vibration in the community. Evening and night penalties have to be investigated in order to derive a dose-response relationship for railway vibration. The current British standard BS 6472-1:2008 recommends using the Vibration Dose Value (VDV) as a vibration descriptor, which is a measure of the cumulative exposure to vibration during the measurement period and uses two frequency weighting curves for vertical and horizontal vibration, based on the human perception thresholds of vibration. VDV takes into account the number of events and their duration, but on the other hand there are no penalties determined in its calculation for different times of the day. The standard only recommends separate limit values for day and night times. Moreover, a few studies have suggested that vibration causes some rest and sleep disturbance (Arnberg et al. 1990; Klaeboe & Fyhri 1999; Öhrström et al. 2009; Ögren & Öhrström 2009) and annoyance reactions are more frequent during evening and nighttime (Öhrström 1997). However, publications tend to show both sleep disturbance and nighttime annoyance as a function of a 24-hour vibration measure.

In the present study the effects of vibration at different times of day as well as the weights for each time period are assessed performing different analyses on the survey and vibration data. In the first part the time-period annoyance ratings are related to time-period vibration levels and then the exposure-response relationships from each period are compared. The second part investigates responses to vibration using all available information about nighttime vibration levels. Finally the research findings are presented. The data used here were collected within the UK study “Human Response to Vibration in Residential Environments” by the University of Salford and funded by the Department for Environment, Food and Rural Affairs (Defra) UK.

METHODS

Study design and sample

The overall aim of the study “Human Response to Vibration in Residential Environments, UK” was to derive exposure-response relationships between vibration exposure and annoyance from railway, construction and internal sources. The data in this paper relate to response from railways only and were collected in the UK, more specifically in the North-West and the Midlands areas of England during 2009 and 2010.

The study sites were chosen to provide an overall representative and robust sample size, as well as to maximize the range of exposures to vibration and maximize the potential number of respondents. This was achieved by selecting sites within a range of distances from the railway, different railway traffic, and different kinds of properties. Mainly the sites were identified depending on the population density and distance from the vibration source. Properties within a distance of 100 meters to the railway were targeted to ensure a high enough vibration level perceptible for the respondents. Locations were also chosen to provide a representative socio-demographic sample of the UK's population.

Face-to-face questionnaires were used and the total number of completed questionnaires relating to railway vibration was 931 with associated high-quality vibration data being obtained internally in respondent's properties.

Vibration exposure

The measurement of vibration was carried out using Guralp CMG-5TD accelerometers and the measurement protocol employed consisted of long term vibration monitoring at an external position (generally a garage or a shed) along with time synchronized short-term internal snapshot measurements. By determining the velocity-ratio between the control and internal measurements, an estimation of 24-hour internal vibration exposure was obtained (Woodcock et al. 2009; Peris et al. 2011).

For each respondent, vibration dose values (VDV_b for vibration in the vertical direction and VDV_d for vibration in the horizontal direction) in accordance with BS 6472-1:2008 were calculated over three different time periods defined as: daytime between 7:00 – 19:00 h, evening between 19:00 – 23:00 h, and night between 23:00 – 7:00 h.

Questionnaire

Study respondents self-assessed their degree of annoyance in particular time periods due to railway vibration on a 5-point semantic scale, as recommended by the standard ISO/TS 15666:2003 (Condie et al. 2009). In the survey, annoyance during different time periods was assessed, from respondents who stated being somehow annoyed by vibration, and through the following question: "Thinking about the last 12 months or so, when indoors at home, how bothered, annoyed or disturbed you have been by feeling vibration or hearing or seeing things rattle, vibrate or shake caused by the railway between day (7 a.m. to 7 p.m.), evening (7 p.m. to 11 p.m.), night (11 p.m. to 7 a.m.), Would you say not at all, slightly, moderately, very or extremely?".

The annoyance response categories were converted onto a continuous annoyance scale from 0 to 100. This conversion is based on the assumption that a set of categories divides the range from 0 to 100 in equally spaced intervals. Exposure-response relationships are generally analyzed for the percentage of highly annoyed people (%HA), percentage of annoyed people (%A), and percentage of little annoyed people (%LA). According to ISO/TS 15666:2003, a person has been defined as being highly annoyed when he or she chooses "very" or "extremely" in the 5-point semantic scale. Likewise, categories including "moderately" and above correspond to annoyed whereas categories including "slightly" and above correspond to little annoyed.

The social survey questionnaire also asked respondents to state if their sleep was ever disturbed by vibration caused by railway activity. The response to this question was either “Yes” or “No”.

Statistical analyses

To examine the exposure-response relationships between vibration level and annoyance at different times of day, ordinal logit models (Klæboe et al. 2003) were used to generate parameter estimates for the annoyance thresholds (not at all, slightly, moderately, very and extremely). Equation (1) was used to obtain the estimated exposure-response relationships from the estimated parameters. The equation indicates the probability of obtaining a vibration annoyance response equal to or higher than j :

$$P(Y \geq j | \mathbf{X}_i = \mathbf{x}_i) = 1 - ((e^{\hat{\tau}_j - \hat{\beta}' \mathbf{x}_i}) / (1 + e^{\hat{\tau}_j - \hat{\beta}' \mathbf{x}_i})) \, j \in [1, ..., J-1] \quad (1)$$

where $\hat{\tau}_j$ indicates the jth estimated threshold, and $\hat{\beta}$ is the estimated parameter for the exposure value. There are J annoyance categories. $\mathbf{X}_i$ is a vector of exposure for an individual i.

Binary logistic regression analysis was used to examine the relationship between sleep disturbance (Yes/No question) and vibration exposure.

RESULTS

Vibration annoyance at different times of the day

In this section the time-period responses are related to the time-period vibration levels. Table 1 shows the results from the ordinal logit model parameter estimations. These results are used to calculate the estimated exposure-response relationship in Equation (1). For example, to calculate the proportion of respondents who are estimated to be annoyed by a VDV_b of 0.01 $m/s^{1.75}$ during the day, the estimated parameter values (Table 1) of the relevant threshold and location (exposure) parameter were inserted into the expression as follows:

$$P(Y \geq j | \mathbf{X}_i = \log_{10}(0.01)) = 1 - ((e^{2.377 - \log_{10}(0.01) \times 0.636}) / (1 + e^{2.377 - \log_{10}(0.01) \times 0.636})) \approx 0.02$$

The result shows that about 2 % of the respondents are highly annoyed at a $VDV_{b,7:00\text{-}19:00}$ of 0.01 $m/s^{1.75}$ exposure level. Figure 1 shows the exposure-response relationship for day, evening and night times. The curves indicate the percentage of residents expected to be highly annoyed by given vibration exposure levels from the railway. The grey bands indicate the 95 % confidence intervals of the relationships between exposure and annoyance at different times of day. The figure indicates that, for example, with the same vibration exposure (VDV_b) of 0.05 $m/s^{1.75}$, 4 % are highly annoyed during the day, 7 % during the evening and 15 % during the night. This means that many people are more annoyed at night compared to vibration during the day and evening at the same vibration levels.

Table 1: Parameter estimates for railway traffic vibration annoyance during the day, evening and night using ordinal logit model

Parameter Estimates	Estimates								
	Day	95 % CI		Evening	95 % CI		Night	95 % CI	
		Lower	Upper		Lower	Upper		Lower	Upper
Threshold ($\hat{\tau}$)									
Highly annoying	2.377	1.517	3.237	1.491	0.700	2.282	0.505	-0.198	1.208
Location ($\hat{\beta}$)									
$Log_{10}VDV_b$	0.636	0.139	3.237	0.820	0.364	1.276	0.931	0.512	1.350

All results are statistically significant (p<0.05); N=755; Cox & Snell R^2_{day}=0.008; Cox & Snell $R^2_{evening}$=0.016; Cox & Snell R^2_{night}=0.026.

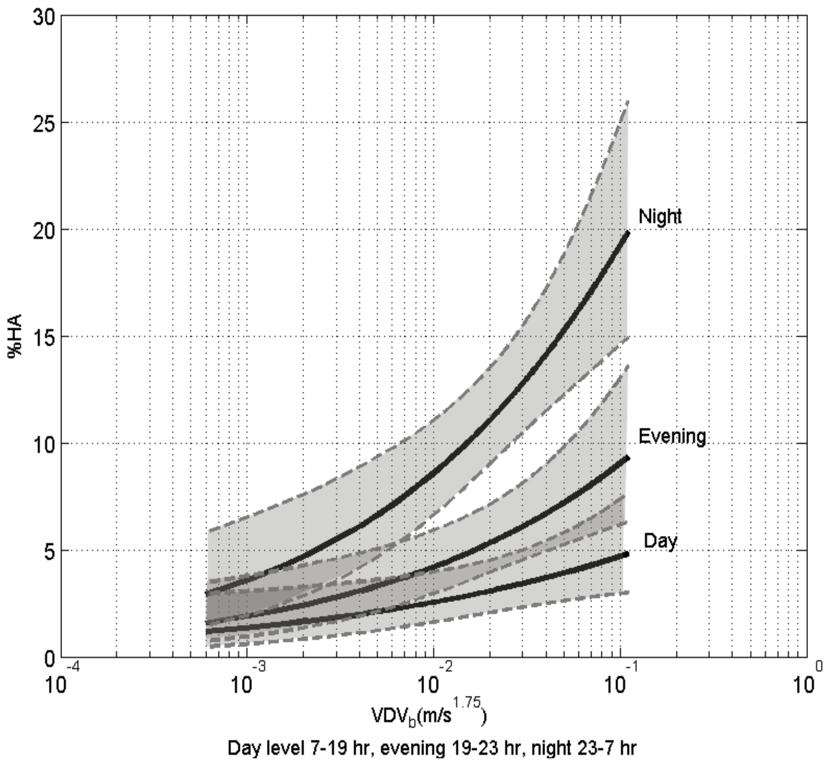

Figure 1: Comparison of the proportion of people reporting high annoyance (%HA) during the day, evening and night due to railway vibration (vertical vibration VDV_b). Curves are shown in their 95 % confidence intervals.

Figure 2 shows the distance between the annoyance responses for the day, evening and nighttime. The distance between the annoyance responses (W_e, W_n) is based on the distance between the curve for the daytime and the curve for each of the other time periods. These time period differences can be converted into time-of-day weights. For example, a VDV_b of 0.1 $m/s^{1.75}$ in the day shows the same proportion of highly annoyed respondents as a VDV_b of 0.015 $m/s^{1.75}$ during the evening. Thus, a penalty should be applied to eveningtime exposures when combining the vibration exposures in different periods into a single 24-hour descriptor. Likewise, a VDV_b of

0.1 $m/s^{1.75}$ in the daytime shows the same proportion of highly annoyed respondents as a VDV_b of only 0.002 $m/s^{1.75}$ during the night. On the basis of these results a factor of 6.7 (W_e) and a factor of 50 (W_n) for evening and nighttime exposures respectively should be applied when calculating an overall VDV descriptor as indicated in Equation 2.

$$((W_e \times 0.015)^4)^{0.25} = 0.1 \quad W_e = 6.7$$

$$((W_n \times 0.002)^4)^{0.25} = 0.1 \quad W_n = 50$$

$$VDV_{b,den} = \left[VDV_{b,7:00\text{-}19:00}{}^4 + (W_e \times VDV_{b,19:00\text{-}23:00})^4 + (W_n \times VDV_{b,23:00\text{-}7:00})^4 \right]^{0.25} \qquad (2)$$

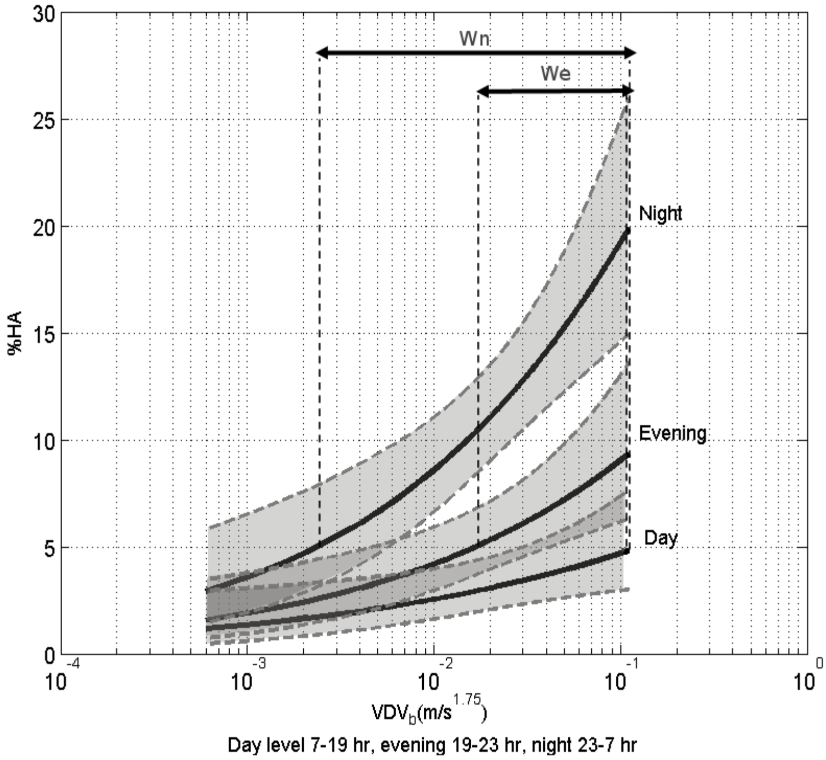

Figure 2: Comparison of the proportion of people reporting high annoyance (%HA) during the day, evening and night due to railway vibration (vertical vibration VDV_b). Curves are shown in their 95 % confidence intervals.

Night annoyance and sleep disturbance

Nighttime annoyance and sleep disturbance caused by vibration can be assumed to be somehow related as reducing sleep disturbance can be the basis for reducing nighttime annoyance. The vertical direction of vibration is dominant on the ground floor and the horizontal direction on higher floors (Madshus et al. 1996). Sleep disturbance and night annoyance caused by railway vibration can be assumed to happen where the bedroom of the respondent is located, which for typical British houses is on the first floor. From Table 2 it can be seen that the nighttime relationship is highly improved using the horizontal vibration exposure VDV_d.

This section intends to investigate responses to vibration using all available information about nighttime vibration levels. Two types of information about nighttime responses are presented.

Figure 3 relates the extent of nighttime annoyance to nighttime vibration levels $VDV_{d,23:00\text{-}7:00}$ (horizontal direction). The cumulative exposure-response curves are derived using the ordinal logit model described in the previous section. The lower curve indicates the percentage of residents expected to be highly annoyed during the nighttime by given exposure levels from the railway traffic. The upper curves indicate the cumulative percentage of respondents who are at least annoyed and at least little annoyed during the nighttime.

Table 2: Parameter estimates for nighttime railway vibration annoyance using ordinal logit model

Parameter estimates	Estimates			
	Estimates	SE	95% CI	
			Lower	Upper
Threshold ($\hat{\tau}$)				
Little Annoyed	-2.238	0.637	-3.487	-0.989
Annoyed	-1.844	0.636	-3.090	-0.598
Highly annoyed	-1.145	0.636	-2.391	0.101
Location ($\hat{\beta}$)				
$Log_{10}VDV_{d,\ 23:00\text{-}7:00}$	1.213	0.243	0.736	1.691

All results are statistically significant (p<0.05); N=755; Cox & Snell R^2=0.036.

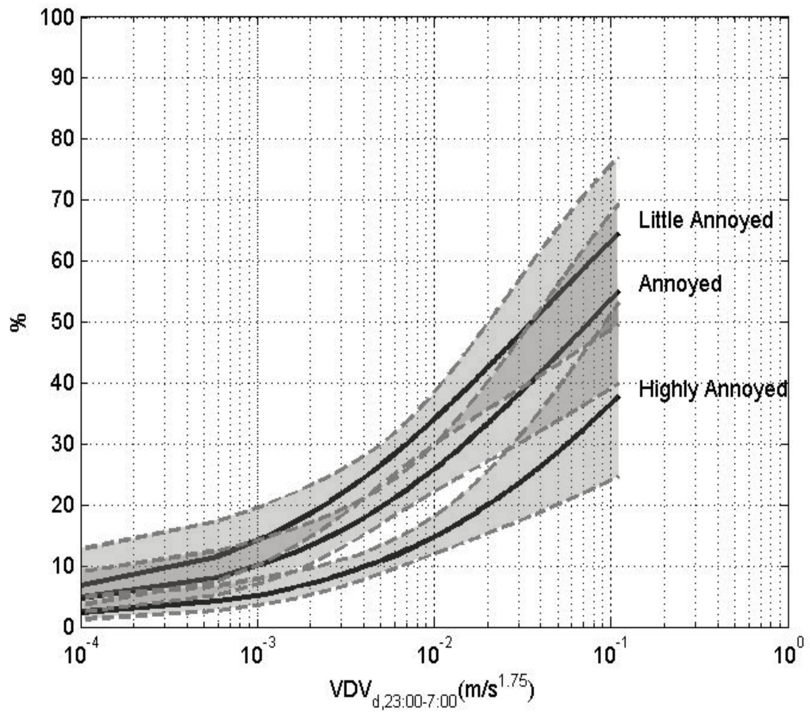

Figure 3: Cumulative exposure-response curve for $VDV_{d,23:00\text{-}7:00}$ and the proportion of respondents who express different degrees of nighttime vibration annoyance due to railway traffic

Figure 4 shows the proportion of respondents reporting sleep disturbance for a given magnitude of vibration exposure ($VDV_{d,23:00\text{-}7:00}$) and Table 3 shows the results from the logistic regression parameter estimates.

Table 3: Logistic regression results showing the relationship between sleeping disturbance and vibration exposure $VDV_{d,23:00\text{-}7:00}$

Parameter estimates	Estimates			
	Estimate	SE	95 % CI	
			Lower	Upper
Intercept	-2.547	0.686	-3.892	-1.202
$Log_{10}VDV_{d,\ 23:00\text{-}7:00}$	1.394	0.264	0.878	1.911

All results are statistically significant (*p*<0.05); N=755; Cox & Snell R^2=0.042.

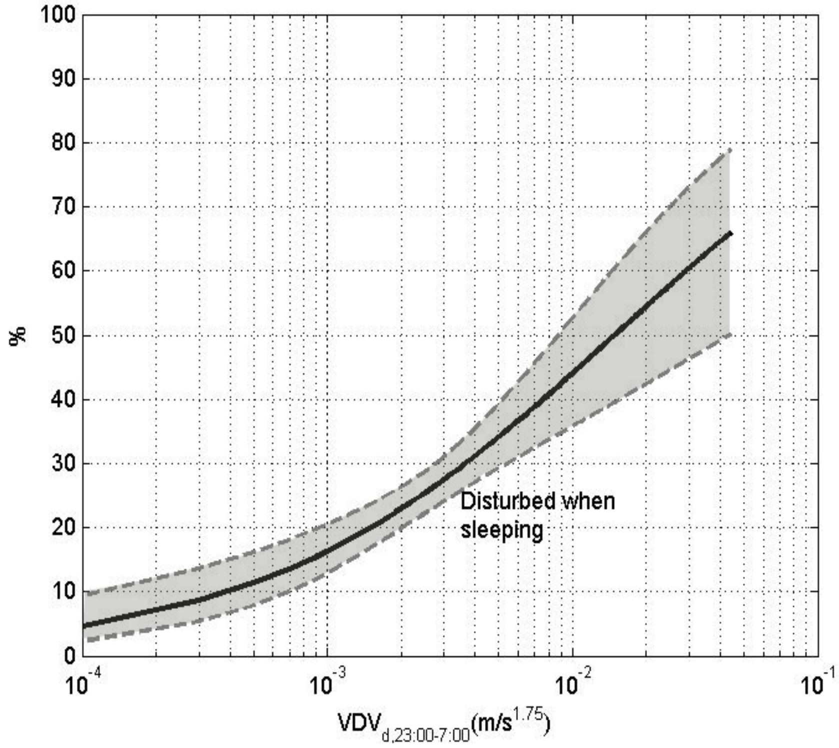

Figure 4: Proportion of respondents reporting being sleep disturbed by railway vibration for a given exposure $VDV_{d,23:00\text{-}7:00}$

CONCLUSIONS

People's reactions due to railway vibration at different times of the day have been investigated through analyses of time-period vibration levels and time-period annoyance. These analyses showed that different times of the day have a different impact on vibration annoyance, thus, separate time of day weights should be applied when considering a dose-response relationship from railway vibration in residential environments. For an optimal assessment and reduction of people annoyed by railway vibration these results should to be taken into account by policy makers, environmental health practitioners and planners.

The exposure-response relationships suggest that annoyance is greater in residential areas during evening and nighttime periods. It was found that a metric based on weights for periods 19:00-23:00 and 23:00-7:00 would be the most appropriate for predicting railway vibration annoyance.

Nighttime disturbances were better correlated with horizontal vibration exposure (VDV_d). This result highlights the importance of horizontal vibration measurements in studies and assessments involving sleep disturbance or night annoyance.

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