Human response to vibration from passenger and freight railway traffic in residential environments

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HUMAN RESPONSE TO VIBRATION FROM PASSENGER AND FREIGHT RAILWAY TRAFFIC IN RESIDENTIAL ENVIRONMENTS

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Exposure-response relationships for the human response to vibration and noise from railway activities in residential environments have been derived recently in the UK. These relationships are the outcome of a large scale field study funded by Defra (UK) in which response, mainly in terms of annoyance, was measured via face-to-face interviews with residents in their own homes and vibration exposure was determined via measurement and prediction techniques. These exposure-response relationships, which describe annoyance as a function of vibration exposure, were in terms of all activities from the railway. In this paper, data collected from this study is further explored to investigate differences in annoyance elicited by different sources of railway vibration (namely passenger trains, freight trains, and track maintenance). Consideration is given to the times of day in which freight activities occur. Preliminary exposure-response relationships are presented and compared with relationships derived for all railway activities. It is shown that there is a significant difference between annoyance responses for different sources of railway vibration (Kruskal-Wallace, $p < 0.001$).

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1. Introduction

Exposure-response relationships are vital tools for planners and policy makers to assess the human impact of an environmental stressor. From the construction of new railway lines to the operation of existing networks, environmental noise and vibration are key considerations. After decades of research, there exist internationally accepted exposure-response relationships for the human response to environmental noise[1]. These relationships are the basis of a variety of guidance documents and assessment procedures. However, unlike environmental noise there is a lack of data and fundamental research into the human response to vibration in residential environments.

A recently concluded project, the culmination of seven years of research, conducted by the University of Salford in the UK succeeded in deriving exposure-response relationships for the human response to vibration from railway and construction sources in residential environments[2]. These relationships describe the proportion of the population expected to express annoyance for a given vibration exposure. In the case of railway induced vibration, all railway activities were considered together in the derived relationships. The main aim of this paper is to provide a preliminary analysis of annoyance due to different sources of railway vibration, specifically freight and passenger traffic. This work is particularly timely given current EU policy of increasing the proportion of freight transported on rail[3].

This paper begins by giving a brief overview of the aforementioned project to provide background for the current work. Following this, data collected in the social survey carried out in this project is further analysed to highlight differences in annoyance responses to vibration from different railway activities. A recently developed algorithm to classify vibration signals from freight and passenger traffic is then employed and preliminary exposure response relationships for different sources of railway vibration are presented.

2. Field survey

2.1 Introduction

A large scale field survey has been conducted in the UK to determine both response and exposure to environmental vibration and noise in residential environments. The survey consisted of questionnaires conducted with residents in their own homes along with measurements of vibration at external and internal positions. In total 1431 questionnaires were conducted of which 931 focussed on railway as the vibration source. This section aims to give a brief overview of how this survey was implemented.

2.2 Selection of survey sites

Potential survey sites were first shortlisted via desk work using Google Maps. Sites were selected which contained dwellings within 100 m of a railway line to ensure respondents were exposed to perceptible levels of vibration. The main criteria on which sites were selected were that the site should be densely populated so as to maximize the number of potential respondents and also that the site should be subject to no confounding sources of environmental vibration. Sites which met these criteria were subject to a site reconnaissance to determine their suitability. In total, twelve measurement sites were selected across the North West and Midland regions of England.

2.3 Measurement of response

Response data were collected via questionnaires conducted with residents in their own homes. Each questionnaire took around 20 minutes to complete and collected responses on, amongst other things, annoyance due to vibration and noise from various sources. The questionnaire was presented as a neighbourhood satisfaction survey so as not to bias responses. Annoyance data were collected on both a 5-point semantic and 11-point numerical scales as per ISO 15666:2003[4]. The main annoyance question was posed as follows:

"Thinking about the last 12 months or so, when indoors at home, how bothered, annoyed or disturbed have you been by feeling vibration or shaking or hearing or seeing things rattle vibrate or shake caused by the railway including passenger trains, freight trains, track maintenance or any other activity from the railway."

Respondents who expressed annoyance due to railway induced vibration were routed to a source specific annoyance section to determine their annoyance from different railway activities. Annoyance responses were collected on a 5-point semantic scale for passenger trains, freight trains, and track maintenance.

2.4 Measurement of vibration exposure

Due to the scale of vibration measurement required to fulfil the requirement of this study, a measurement approach was developed which encompassed elements of measurement and prediction. Long term vibration monitoring was conducted at external positions for a period of 24-hours. During the long term monitoring, short term ‘snapshot’ measurements which were synchronized with the long term measurements were conducted within the properties of residents who had completed a questionnaire. By determining the transmissibility between the two measurement positions, it was possible to estimate 24-hour internal vibration exposure[5]. In total, 149 long term measurements were conducted along with 522 ‘snapshot’ measurements. This approach enabled the estimation of 24-hour internal vibration exposure in 755 dwellings.

3. Exposure-response relationship for railway vibration

The statistical model used to formulate the exposure-response relationships presented in this paper is based upon the model proposed by Groothuis-Oudshoorn & Miedema[6]. The relationships take the form of curves indicating the percentage of people expressing annoyance above a given threshold (*C*) for a given vibration exposure (*X*):

$$p_C(X) = \text{Prob}(1 - \Phi\left[\frac{C - \mathbf{X}\boldsymbol{\beta}}{\sigma}\right]) \qquad (1.1)$$

where Φ is the cumulative normal distribution function, $\mathbf{X}$ is a vector of vibration exposures, $\boldsymbol{\beta}$ are model coefficients to be estimated, and σ is the standard error. The coefficients of this model were estimated via maximum likelihood.

A major advantage of this model is that the entire annoyance distribution can be described by varying *C*. The annoyance thresholds *C* reported will be 28%, 50%, and 72% of the annoyance scale which will be referred to “*percent slightly annoyed*” *(%SA*), “*percent annoyed*” (%A), and “*percent highly annoyed*” (*%HA*) respectively. Respondents stating that they are unable to feel vibration have been recoded to the lowest category on the annoyance response scale.

Using the data collected for railway induced vibration, the exposure-response relationships presented in Figure 1 were derived. Vibration exposure is expressed in the vertical direction as frequency weighted (W_b) Vibration Dose Value (*VDV*) over a 24-hour period (see equation (1.2)) as per the guidance provided in BS 6472-1:2008[7]. It can be clearly seen from this figure that the proportion of the population expressing annoyance rises monotonically with increasing vibration exposure. The relatively narrow confidence intervals suggest that an adequate sample size was achieved along with a good quality dataset.

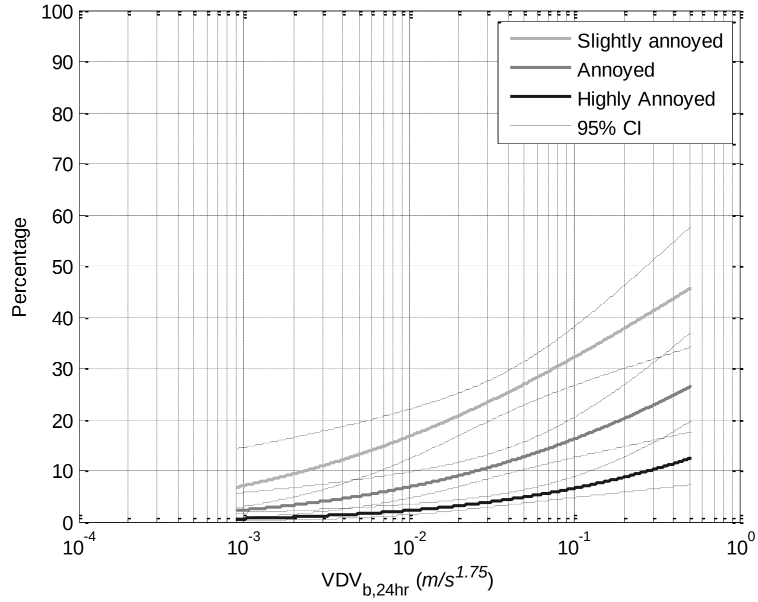

Figure 1. Exposure response relationship for railway induced vibration. (N = 752, $p < 0.001$)

$$\ddot{x}_{VDV} = \sqrt[4]{\frac{T}{N}\sum_{n=1}^{N}\ddot{x}(n)^4} \qquad (1.2)$$

Where $\ddot{x}(n)$ is an acceleration time series, N is the number of samples in the acceleration time series, and T is the duration of the event in seconds.

4. Response to different railway sources

The previous section presented an exposure-response relationship for railway induced vibration in residential environments. This relationship is in terms of vibration exposure and annoyance from all railway activities. As stated in section 2 annoyance responses were also collected for specific railway activities, namely passenger trains, freight trains, and track maintenance. Figure 2 shows the distribution of annoyance responses for different railway activities. This figure suggests that vibration from different railway activities elicits different annoyance responses.

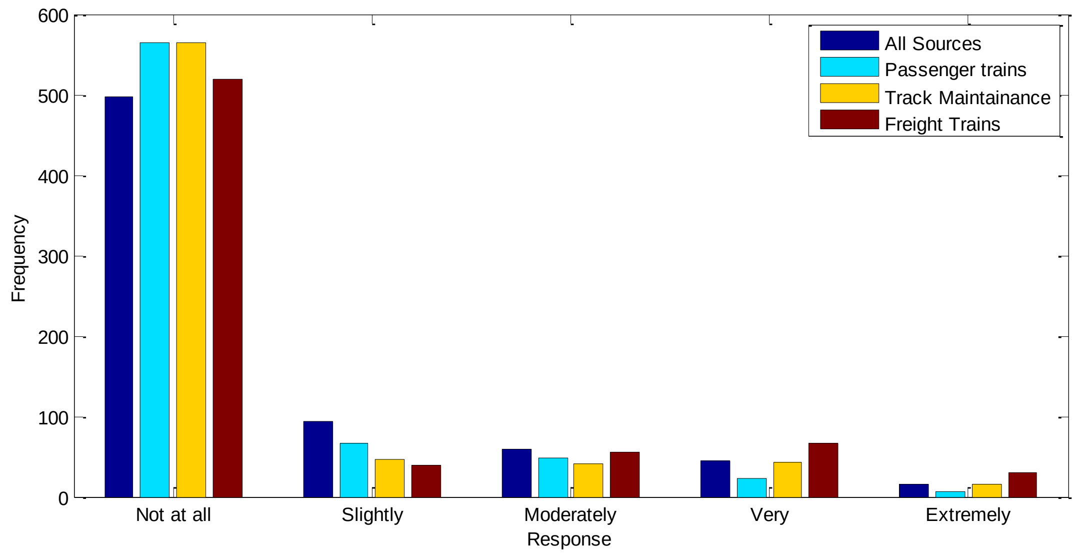

Figure 2. Distribution of annoyance responses for different railway activities (N = 711)

The data presented in Figure 2 were subject to a Kruskal-Wallace analysis which confirmed that there are significant difference between annoyance responses for different railway sources ($\chi^2 = 27.18$, $p < 0.001$). Figure 3 shows the mean rank of annoyance scores for the four different railway sources along with their 95% confidence intervals. Non-overlapping confidence intervals indicate that there is a significant difference between the mean rank annoyance scores for the different sources. It can be seen from this figure that the mean rank annoyance responses for passenger trains and track maintenance are significantly different than those for all railway sources and freight trains.

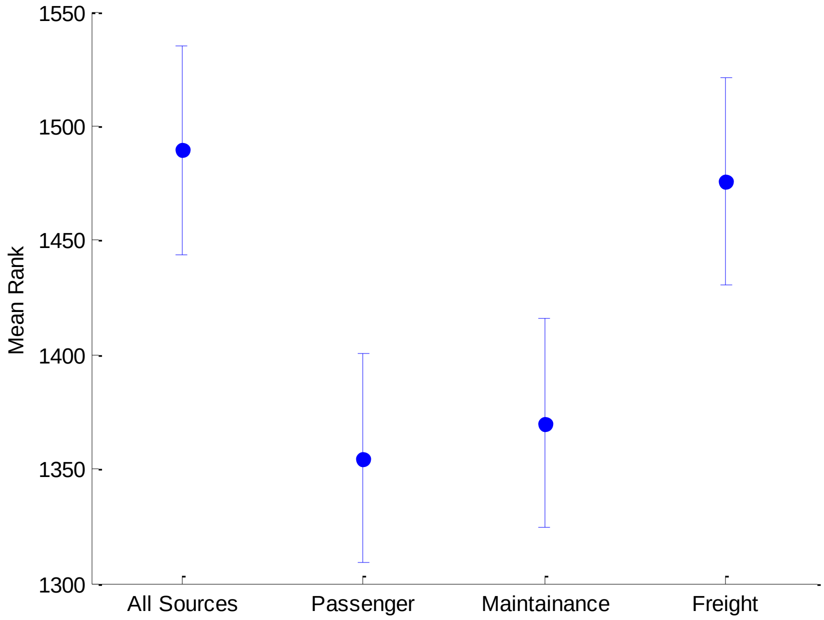

Figure 3. Multiple comparison of mean rank annoyance for different railway activities (N = 711)

Figure 4 presents the percentage of respondents reporting annoyance in the top two categories of the 5-point semantic scale for the different sources of railway induced vibration. This result suggests that a significantly higher proportion of respondents express high annoyance for freight than passenger rail activities.

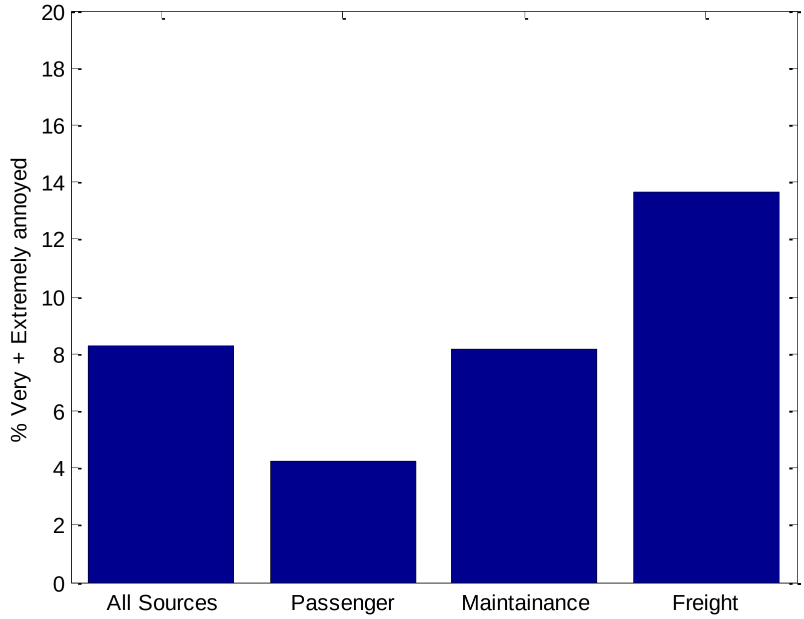

Figure 4. Percentage of respondents stating "Very Annoyed" or "Extremely Annoyed" for different sources of railway vibration (N = 711)

5. Exposure from different railway sources

The previous section highlighted the differences in annoyance responses elicited by different sources of railway vibration. An algorithm has recently been developed to classify passenger and freight trains based upon recorded acceleration time histories[8]. Preliminary results suggest that this algorithm is able to classify vibration signals from passenger and freight activities with an accuracy of 79% (+/-7%). The vibration data collected via the field survey outlined in section 2 were analysed using this algorithm resulting in vibration exposures for freight and passenger activities for each case study in the survey.

Using the statistical model presented in section 3, exposure-response relationships were derived for annoyance due to vibration from freight and passenger activities (see Figure 5). It should be noted that, due to uncertainties in the classification algorithm, these relationships should be regarded as preliminary.

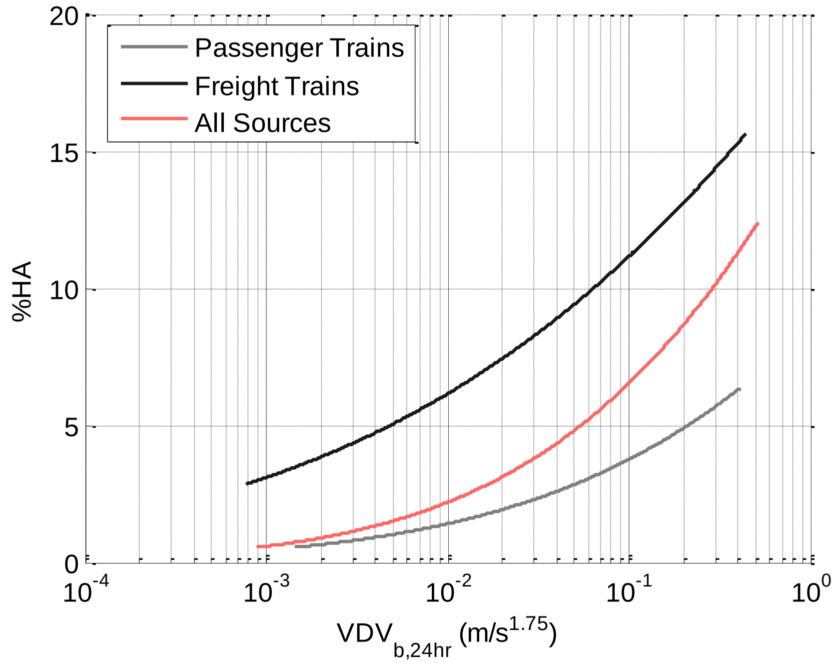

Figure 5. Preliminary exposure-response relationships for different railway sources (N = 711)

6. Discussion

The preliminary exposure-response relationships presented in Figure 5 suggest that, for the same magnitude of vibration exposure, vibration from freight traffic elicits a significantly different response than that from passenger traffic. It can be seen that annoyance increases much more rapidly with increasing vibration exposure from freight trains than it does for vibration from passenger trains.

One potential explanation for the differences in response to vibration from passenger and freight trains is the use of the Vibration Dose Value (*VDV*) as an exposure metric. As can be seen in equation (1.2), *VDV* is a cumulative measure meaning that the number of events is taken into account. The median proportion of freight to passenger traffic over a 24-hour period was 14% meaning potentially the same exposure magnitude could be measured for fewer freight events than for passenger events.

Previous research has found that the same magnitude of vibration exposure elicits a higher annoyance during the night-time (23:00 – 7:00) than during the day- (7:00 – 19:00) and evening-time (19:00 – 23:00)[9]. The median proportion of freight to passenger traffic during the day-time, evening-time, and night-time was found to be 13%, 14%, and 17% respectively. Differences in the median proportions of freight to passenger traffic were found to be statistically significant (Kruskal-Wallis, $\chi^2 = 27.18$, $p < 0.001$) with a significantly higher proportion during the night-time. The higher proportion of freight traffic during the night-time period may therefore account for the differences in annoyance responses.

7. Conclusions

This paper has presented further analysis of a dataset collected though a large scale field study designed to determine exposure-response relationships for the human response to vibration in residential environments. This analysis has revealed that there are significant differences in annoyance responses between different sources of railway induced vibration. By means of a recently developed classification algorithm, vibration exposures for each case study in the dataset have been estimated for both passenger and freight railway activities. Using these data, exposure-response relationships have been derived for different railway activities.

It should once again be noted that the exposure-response relationships relating to freight and passenger railway activities presented in this paper are preliminary. However, the observed differences in responses along with current policy themes of a modal shift from road to railway freight across Europe suggest that further work in this area could yield potentially valuable results. The results presented in this paper will help inform the current EU FP7 project Cargovibes (www.cargovibes.eu).

Acknowledgements

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