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Annoyance from railway vibration in residential environments: factors of importance when considering exposure-response relationships

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Abstract: Railway induced vibration is an important source of annoyance in residential environments. Annoyance increases with vibration magnitude. However, these correlations between annoyance and physical ratings are weak. This suggests that vibration-induced annoyance is governed by more than just vibration level, and that simple exposure-response relationships alone sometimes do not provide sufficient information for understanding the wide variation in annoyance reactions. Results of investigations made on factors coming into play when considering an exposure-response relationship between level of vibration and annoyance are presented here. Examples of these factors are time of day, situational factors, personal and attitudinal factors. This was achieved using data from case studies comprised of face-to-face interviews (N=931) and internal vibration measurements collected within the study "Human Response to Vibration in Residential Environments" by the University of Salford. This work will be of interest to researchers and environmental health practitioners involved in the assessment of vibration complaints, as well as to planners and consultants involved in the design of buildings and railways. [Work funded by the Department for Environment, Food and Rural Affairs (Defra) UK].

Keywords: Annoyance, Railway, Vibration

1. Introduction

Results of studies carried out during recent decades have shown that a higher noise exposure is responsible for an increase in annoyance (Schultz, 1978; Fields 1979; Fidell et al., 1991; Miedema and Vos, 1998; Guski, 1998; Berglund, 1998; Job, 1988; Lercher, 1998). However, research has shown that, in addition to the acoustic parameters a variety of factors might have an influence on the annoyance response. Simple exposure-response relationships alone do not provide sufficient information for understanding the wide variation in annoyance reactions. The correlations between annoyance and noise physical ratings are weak and only the 20-30% of the variation of judgments on annoyance depends on the acoustic parameters. This suggests that noise-induced annoyance is governed by more than just acoustic factors, with personal, situational and attitudinal factors coming into play.

In the same way, there are indicators showing that the percentage of people annoyed by environmental vibration is related to exposure factors such as level of vibration, frequency, duration and accompanying noise (Yonekawa, 1977; Fields and Walker, 1982; Obermeyer, 1983; Howarth, 1989; Öhrström and Skånberg, 1996; Klæboe et al., 1999). Considering that vibration is an environmental hazard as is noise, one could assume that apart from the vibration acoustic indices there are other non-physical annoyance factors linked to attitude, personality and socio-demographic variables that influence the overall vibration annoyance response. However, there is no up-to-date research regarding other factors that might explain

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the wide variation encountered in vibration reactions.

This paper aims to assess the influence of several factors on railway vibration exposure-response relationships. Examples of these factors are: personal and attitudinal factors (e.g. age, gender, sensitivity, and property damage concern), situational factors (e.g. location and visibility of the source) and time of day when the vibration occurs. The number of variables that composed the questionnaire were large, thus the selection of variables for study was based on previous findings described in the transportation noise and vibration annoyance literature. The results presented in this paper are intended to help local authorities, architects, urban planners, consultants and environmental practitioners to assess the human impact of existing railway developments.

2. Methods

2.1 Study design and sample

The data in this paper relate to measurements of, and response to, railway vibration and were collected in the United Kingdom, specifically in the North-West of England and the Midlands area during 2009 and 2010 as part of the study "Human response to vibration in residential environments" performed by the University of Salford (Waddington et al., 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 that are within a range of distances from the railway, are exposed to different railway traffic and contain different kinds of properties. Mainly, the sites were identified according to their population density and distance from the vibration source. Properties within a distance of 100 m from the railway were targeted to ensure a relatively high and perceptible vibration level for the respondents. 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 within respondent's properties.

2.2 Vibration exposure

The measurement of vibration was carried out using Guralp CMG-5TD accelerometers and the measurement protocol employed in the field consisted of long term vibration monitoring at an external position (e.g., a garage or a shed) along with time synchronized short-term internal snapshot measurements. By determining the velocity ratio between the control and the internal measurements, an estimation of 24-h internal vibration exposure was obtained. For each respondent, Vibration Dose Values (VDV), using the W_b weighting curve, in accordance with BS 6472-1:2008, were calculated over 24 h.

2.3 Questionnaire

To measure the "response" component, a social survey questionnaire was used to collect data from the respondents. The questionnaire was introduced as a survey of neighborhood satisfaction and is divided into different sections. The sections in order as they are presented in the questionnaire were : dwelling information, neighborhood satisfaction, satisfaction with home, vibration questions, noise questions, railway vibration, railway noise and personal and occupancy information.

Within the vibration questions, respondents self-assessed their degree of overall annoyance on a five-point semantic scale, as recommended by the standard ISO/TS 15666 (2003) and through the following question: "Thinking about the last 12 months or so, when indoors at home, how bothered, annoyed, or disturbed have you been by feeling vibration 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, would you say not at all, slightly, moderately, very, or extremely?"

The respondents who stated they could not feel vibration were recoded to the lowest category of the five-point semantic annoyance scale. The annoyance response categories were converted to a scale ranging from 0 to 100 and centered to the midpoints of these categories. This conversion is based on the assumption that a set of categories divides the range from 0 to 100 into equally spaced intervals.

Exposure–response relationships are generally analyzed for the percentage of highly annoyed people (%HA), which in accordance to the ICBEN recommendations (Fields et al., 2001) are the "very" or "extremely" categories in the five-point semantic scale. A total of 931 interviews were collected along with 755 estimates of internal vibration exposure. Therefore 755 case studies were available for the analysis presented in this paper.

2.4 Statistical analyses

Most of the social survey data were archived and analyzed with SPSS. The number of variables that composed the questionnaire were large, thus a first attempt was made to select a relevant set of variables. The selection was based on both the previous findings described in the transportation noise and vibration annoyance literature; and on a multivariate logistic regression analysis in which a hierarchical model was built by entering blocks of explanatory variables systematically.

To examine relationships between annoyance scores and vibration exposure featuring situational, attitudinal and personal factors, ordinal logit models (similar to Klæboe et al. 2003)were used to generate parameter estimates for the annoyance thresholds (not at all, slightly, moderately, very, and extremely). The following equation was used to obtain the estimated exposure–response relationships from the estimated parameters and indicates the probability of obtaining vibration annoyance response greater than or equal to 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 *j*th estimated threshold, and $\hat{\beta}$ is the estimated parameter for the exposure value. There are *J* annoyance categories. X_i is a vector of exposure for an individual *i*.

3. Results

3.1 Attitudinal Factors

Two attitudinal variables, sensitivity to vibration and property damage concern, were investigated.

The social survey questionnaire asked respondents to quantify on a five-point semantic scale the extent to which they felt concerned that vibration due to railway activity was causing damage to their property. The relationship for concern of damage to property and vibration exposure is presented in Figure 1. It can be seen that as vibration exposure increases, the proportion of respondents expressing concern of damage to their property increases. The effect of vibration exposure on annoyance from railway vibration mediated by property damage concern was tested in order provide and understanding of the interaction effects between property damage concern, vibration exposure and self-reported annoyance. Figure 2 shows the diagram that represents the mediation effects of the concern of damage attitude on vibration exposure and annoyance. The numbers represent the correlation coefficients. After controlling per property damage concern, the effect of vibration exposure appears to be smaller (.121 without concern; .053 with concern). Thus, property damage concern partially mediates the effect of vibration exposure on self-reported vibration annoyance It appears to be not a complete mediation, suggesting that even if property damage concern was one meditational pathway, it is certainly not the only one. The Sobel test was used in order to determine whether there was significant partial mediation. The Sobel test p-value was less than .05 and therefore we can conclude that property damage concern is a statistically significant mediator of the effect of vibration exposure on self-reported vibration annoyance.

The social survey questionnaire also asked respondents to quantify on a five-point semantic scale the extent to which they felt they were sensitive to vibration perception. Self-reported sensitivity to vibration was included in the ordinal logistic analysis as an independent variable along with the vibration exposure. However, the inclusion of sensitivity in the exposure only model did not show a significant improvement of the model fit.

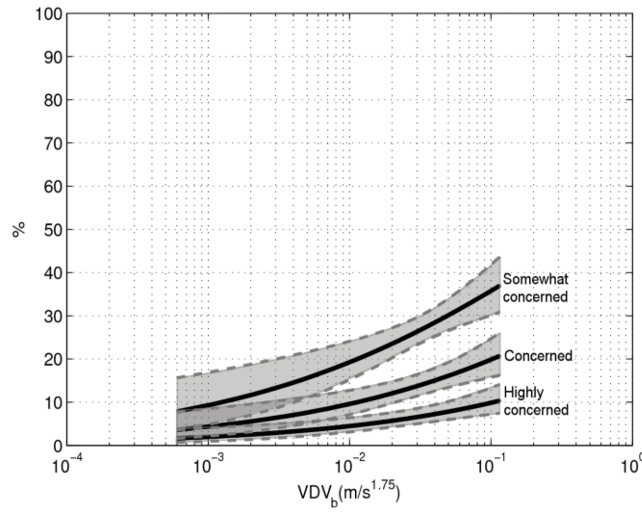

Figure 1 – Exposure-response relationship showing the proportion of people reporting property damage concern due to railway vibration for a given vibration exposure. The grey bands indicate the 95% CI (N=755). (Cox & Snell R^2=0.020, p <0.001)

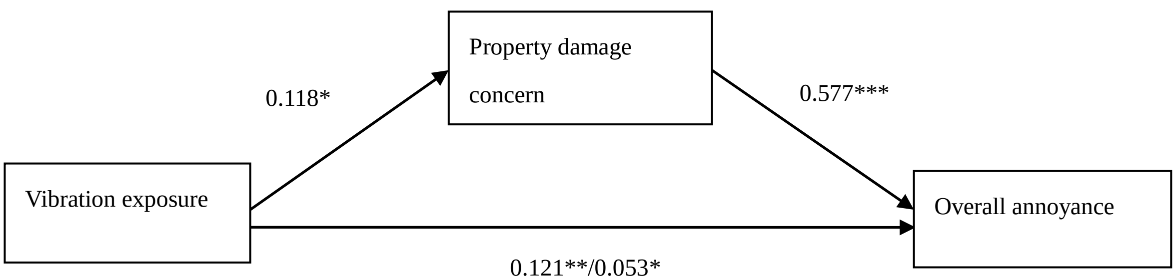

Figure 2 – A schematic overview of the mediation model between property damage concern, vibration annoyance and vibration exposure (VDV_b). The numbers represent the correlation coefficients * p < 0.1 ** p < .01 *** p < .001

3.2 Situational Factors

Respondents of the social survey questionnaire were asked to indicate in what kind of area the property they lived was located (e.g. countryside, village, small town, large town, surroundings of a city or a city). It is important to note that this question was then filled with the respondent´s perception of their living environment rather than being the interviewer who decided whether the area was urban, rural etc. Location was recoded into two categories: large town or city and small town, village or countryside. Location was included in the ordinal logistic analysis as an independent variable along with the vibration exposure. The inclusion of this variable resulted in a significant improvement from the exposure only model. Figure 3 shows the exposure-response relationship for people living in a city/ large town and a small town/village. The curves indicate the percentage of respondents expected to be highly annoyed (%HA) by a given vibration exposure from the railway. Figure 3 indicates that with the same vibration exposure of 0.1 $m/s^{1.75}$, 10% more of people are expected to be highly annoyed by vibration from railway in rural areas such a small towns or villages than in an urban area.

Moreover, the impact of the visibility of the railway on vibration annoyance was investigated. Respondents were asked to indicate if from any room in their home they could see a railway track or any type of passing train. Visibility was included in the ordinal logistic analysis as a dichotomous independent variable along with the vibration exposure. The inclusion of this variable resulted in a significant improvement from the exposure only model. Figure 4 shows the exposure-response relationship for people with visibility of the railway and for people with no visibility of the railway. The curves indicate the percentage of respondents expected to be highly annoyed (%HA) by a given vibration exposure from the railway. Figure 4 indicates that with the same vibration exposure of 0.1 $m/s^{1.75}$, 4% more of people are expected to be highly annoyed by vibration from railway in residential environments where the railway is visible than in residential environments where the railway is not visible.

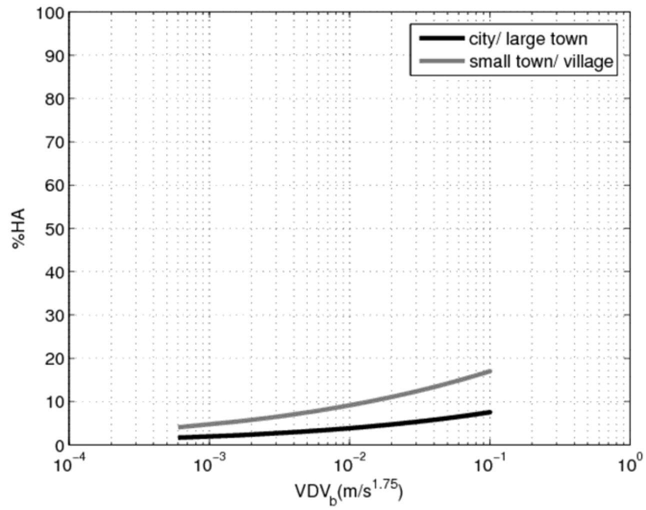

Figure 3 – Exposure-response relationship showing the proportion of people reporting high annoyance (%HA) for a given vibration exposure controlling for type of location. (N = 755). (Cox & Snell R^2=0.061, p <0.001)

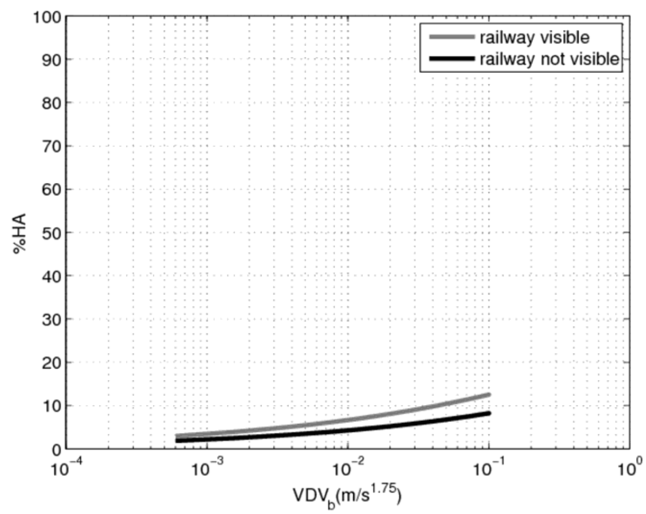

Figure 4 – Exposure-response relationship showing the proportion of people reporting high annoyance (%HA) for a given vibration exposure controlling for visibility of railway (N = 755). (Cox & Snell R^2 = 0.026, p <0.001)

3.3 Socio-Demographic Factors

The effects of age and gender to annoyance reactions due to railway vibration were investigated. Age and Age^2 were included as independent variables in the vibration exposure-response model. The inclusion of this variable resulted in a significant improvement from the exposure only model fit. For a given vibration exposure level, self-reported annoyance was highest in people of 45 years old, lowest in people of 80 years old and intermediate in people of 20 years old. That suggests an inverted U-shaped relationship between age and annoyance (the annoyance is higher for middle age people).

On the other hand, gender did not show any significant influence on annoyance reporting and therefore including this variable did not improve significantly the exposure only model. These results indicate that men and women react similarly to vibration from railway in residential environments.

3.4 Time of day

The ordinal logit regression analysis showed that vibration annoyance differs for different times of day and thus, time of day weightings should be applied when considering exposure–response relationships from railway vibration in residential environments. The analyses in time periods suggest that annoyance is greater in residential areas during evening and nighttime periods (Peris et al., 2012).

4. Conclusions

The aim of this paper was to investigate and evaluate the range of effect of several attitudinal, situational and socio-demographic factors influencing the human response to vibration from railways in residential environments. These results are intended to give to researchers, planners, local authorities, architects and environmental practitioners a better understanding of people´s reactions due to vibration from railways. Therefore, the findings can be of use for implementing regulations and optimal assessments for the reduction of people annoyed by railway vibration.

One attitude, property damage concern, was found to influence the relationship between vibration exposure and annoyance. Property damage concern showed that as vibration exposure increases, the proportion of respondents expressing concern of damage to their property increases. Moreover it was found that property damage concern partially mediates the effect of vibration exposure on self-reported vibration annoyance. There is a statistically significant indirect effect of vibration exposure on self-reported vibration annoyance through property damage concern. These results might suggest that people highly annoyed by vibrations are also highly concerned.

On the other hand, the attitudinal variable self-reported sensitivity to vibration did not show a significant improvement of the exposure only model fit. Whilst these results could indicate that the form of the question was inadequate to examine this possible relationship, these findings suggest that vibration exposure may not be related with some psychological attitudes such as nervousness and introversion that have been shown to be associated with noise sensitivity.

Situational factors such as location and visibility of the railway showed an important effect on the annoyance responses, with people being more likely to be highly annoyed if the property is located in a rural area (small town, village or countryside) and if the railway is visible from the house.

Age suggested an inverted U-shaped relationship between age and annoyance (the annoyance is higher for middle age people) and gender did not show any significant influence on annoyance reporting.

Finally, time of day when the vibration occurs plays a role in the appearance of annoyance, being evening and nighttime the most sensitive periods.

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