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Attitudinal factors as determinants of railway vibration annoyance

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The aim of this paper is to identify and understand the role of the attitudinal factors involved in annoyance reported due to railway vibration. Many non-acoustical factors have been identified with various degrees of association with annoyance due to noise exposure. In particular, attitudinal factors have shown a large effect on noise annoyance reporting. However, the novelty of this work lies in the examination of attitudinal factors on vibration annoyance reporting. This is 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. The effect on vibration annoyance of sensitivity to vibration, property damage concern and expected vibration levels is investigated using multivariate modelling and ordinal logistic regression. The conclusions are that attitudinal factors including property damage concern and the individual's opinion on future vibration levels are related to vibration annoyance, while no significant relationship is seen between self-reported vibration sensitivity and overall annoyance. The implications of these findings for the potential expansion of freight traffic on rail are discussed. [Work funded by the Department for Environment, Food and Rural Affairs (Defra) UK, and EU FP7 through the Cargovibes project]

1 INTRODUCTION

Noise annoyance research has shown that the percentage of people annoyed by noise from transportation sources is related to the noise exposure level[1-3]. Research has shown that, in addition to noise exposure, a variety of factors influence noise annoyance. Several personal,

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attitudinal and situational factors as co-determinants of annoyance as well as the causes of variation in individual reactions to exposures with equal sound level have been investigated by several authors.

Whereas demographic and situational variables (e.g. age, gender, socioeconomic status, income, education, homeownership, type of dwelling, time spent at home etc.) have shown non or little correlation with annoyance, attitudinal factors have shown a large effect on noise annoyance reporting. The main investigations on attitudinal variables were made by Fields[4]. He concluded that attitudinal variables such as fear of the source, feeling that noise is preventable and self-reported noise sensitivity had an important effect on people´s overall annoyance reactions. These findings were confirmed by Miedema and Vos[5]. Moreover, they quantified that fear and noise sensitivity had a large impact on annoyance equal to the difference caused by 11 dB and 19 dB changes in the noise exposure respectively.

Considering the existing research on factors moderating noise exposure-response relationships, it is expected that attitudinal factors will have an influence on the vibration reported annoyance. However, investigations on factors moderating vibration exposure-response are almost non-existent. Therefore there is no evidence that annoyance reactions due to railway vibration are lead by the same or other attitudinal factors that influence relations between noise and annoyance.

The aim of this paper is to identify and understand the role of the attitudinal factors involved in railway vibration annoyance reactions. The effect of sensitivity to vibration, property damage concern and expectation vibration levels on vibration annoyance are investigated here.

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[6]. 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. Only 755 measurements could be associated with railway vibration questionnaires, therefore a total of 755 case studies could be used for determining the railway relationships.

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[7](which applies to vibration in the vertical axis), 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. Several factors that could influence the response to vibration were accounted for within the social survey questionnaire. Such factors were included in order to provide data that supports a more comprehensive understanding of annoyance due to vibration from railways and also assist in the determination of exposure-response relationships. The attitudinal variables included in the analysis were asked and measured as indicated below:

- *Sensitivity to vibration*: was measured on a five-point semantic scale ranging from 'not at all' to 'extremely' and through the following question: "How sensitive would you say you are personally to vibration in general? Would you say you are not at all sensitive, slightly sensitive, moderately sensitive, very sensitive or extremely sensitive?"
- *Property damage concern*: was measured on a five-point semantic scale ranging from 'not at all' to 'extremely' and through the following question: "We would like to know if you are concerned that the vibration may damage this home or your possessions inside it in any way. Are you not at all concerned, slightly concerned, moderately concerned, very concerned or extremely concerned?"
- *Respondent´s expectation*: it was assessed using a three-point categorical scale (better, same, worse) and through the following question "In the future, do you think the level of vibration you experience whilst indoors at home will get worse, get better or remain the same?" The responses were dichotomized into individuals who reported expecting worse levels versus those expecting levels to get better or remain the same.

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)[8] 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[9] are the "very" or "extremely" categories in the five-point semantic scale. The same approach was used for attitudinal items measured on a five-point semantic scale.

2.4 Statistical Analyses

Most of the social survey data were archived and analyzed with PASW. To examine relationships between annoyance scores and vibration exposure featuring attitudinal factors, ordinal logit models[10] 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:

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

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

3 RESULTS

3.1 Self-reported Sensitivity to Vibration

The social survey questionnaire 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. The inclusion of sensitivity in the exposure only model did not show a significant improvement of the exposure only model fit.

3.2 Property Damage Concern

This section aims to provide new information about the impact of property damage concern due to railway vibration on annoyance and a better understanding of the working mechanism through which property damage concern acts. 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 mediational pathway, it is certainly not the only one. The Sobel test[11] 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.

Finally, the relationship between ownership and self-reported property damage concern was investigated. Ownership appeared to be correlated significantly with property damage concern. Concern is not moderating the relationship between annoyance and ownership but ownership is related to damage property concern in the way that property damage concern is more likely when the property is owned than when it is rented. Ownership it is not related to vibration annoyance. Figure 3 shows the proportion of people reporting high property damage concern for a given vibration exposure controlling for ownership. It can be seen from Figure 3 that for a given magnitude of vibration exposure, the proportion of highly concerned people is higher for owners than for renters.

3.3 Expectation

Respondents of the social survey questionnaire were asked to indicate if in the future they thought the level of vibration they experienced whilst indoors at home would get worse, get better or remain the same. Expectation was recoded into two categories: vibration will get worse and vibration will get better or remain the same. Expectation 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 ($p < 0.001$) improvement from the exposure only model. The product term (expectation*exposure) was found not to contribute significantly to the prediction of annoyance and so expectation does not interact with vibration exposure (i.e. it doesn´t influence the effect of vibration exposure).

Figure 4 shows the exposure-response relationship for people expecting the vibration levels to get worse and for people expecting the vibration levels to remain the same or get better. 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 at the same exposure level of 0.1 $m/s^{1.75}$, whereas 8% of people believing levels of vibration will remain the same or get better are expected to be highly annoyed, more than three times this proportion is expected for people believing levels of vibration will get worse.

4 DISCUSSION AND CONCLUSIONS

Due to the increasing mobility needs of the population, sustainable means of transport such as railways are being promoted. This fact will imply the development of new railway lines and the upgrading of existing ones in order to allow higher volumes of railway traffic. However, railways are a major source of vibration and projects will face opposition from people living in the vicinity of new and existing railway paths. Generally, reducing physical levels of exposure is costly; the knowledge and understanding of attitudinal factors to reduce or avoid adverse reactions might be in some cases more cost-effective than reducing only exposure levels.

Some attention has given to investigations on people's reactions to noise and attitudinal factors. One could assume that the same factors influencing the relationship between noise exposure and annoyance are factors that influence the relationship between vibration exposure and annoyance. Some of these non-acoustical attitudinal factors that proved to have an influence on noise annoyance responses (e.g. fear of the noise source, sensitivity to noise) might for example not have any influence on vibration annoyance reporting and therefore factors influencing noise reactions have to be distinguished from factors influencing vibration reactions.

The aim of this paper was to investigate and evaluate the range of effect of several attitudinal factors influencing the human response to vibration from railways in residential environments. Exposure-response relationships were shown as a function of exposure and attitudinal factors using ordinal logit regression. Other aspects have been investigated such as the working mechanism of the attitudinal factor "property damage concern" and the relation between this variable and ownership of the property.

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.

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.
Ownership appeared to be correlated significantly with property damage concern but not with vibration annoyance. These findings might explain the non-conclusive results obtained in past noise studies. Ownership may be a factor influencing the response when the source induces not only noise but also vibration since property damage concern is a specific reaction due to vibration from the source.

People's expectations to the vibration levels were found to strongly influence their annoyance response. At the same vibration level more people are expected to be highly annoyed by vibration from railway if they think that vibration levels will get worse than if they think they will get better or remain the same. These results suggest that the believing of the residents in terms of future exposure have much more influence than the vibration exposure levels and that effort have to be made on positivize people´s attitudes to railway traffic.

5 ACKNOWLEDGEMENTS

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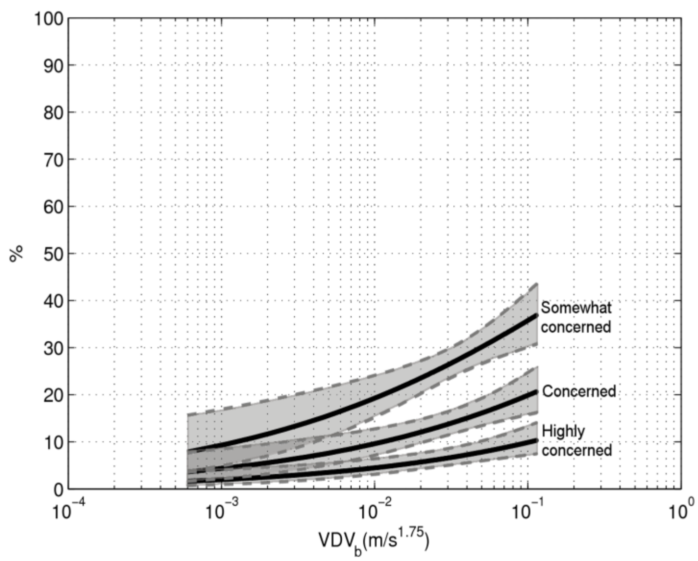

Fig. 1 – Exposure-response relationship showing the proportion of people reporting property damage concern due to railway vibration for a given vibration exposure. The grey bands indicate the 95% CI (N=755). (Cox & Snell R^2=0.020, p <0.001)

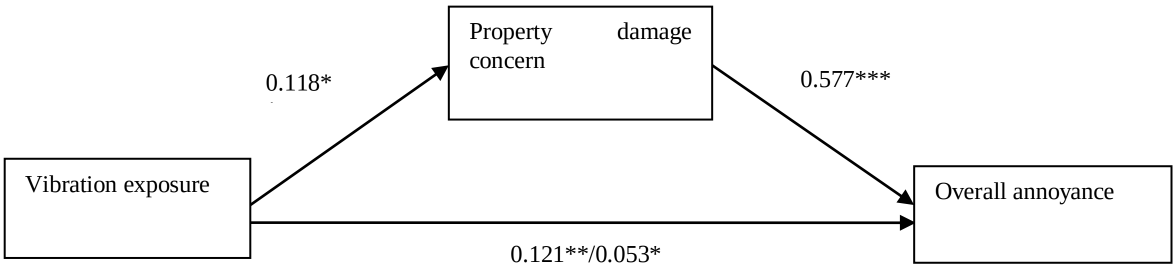

*Fig. 2 – A schematic overview of the mediation model between property damage concern, vibration annoyance and vibration exposure (VDV_b). The numbers represent the correlation coefficients. The difference between 0.121 and 0.053 is that 0.121 refers to the correlation coefficient when exposure predicts annoyance on its own, whereas 0.053 refers to the regression coefficient of exposure on annoyance when concern is also a predictor in the regression equation. * $p < 0.1$ ** $p < .01$ *** $p < .001$*

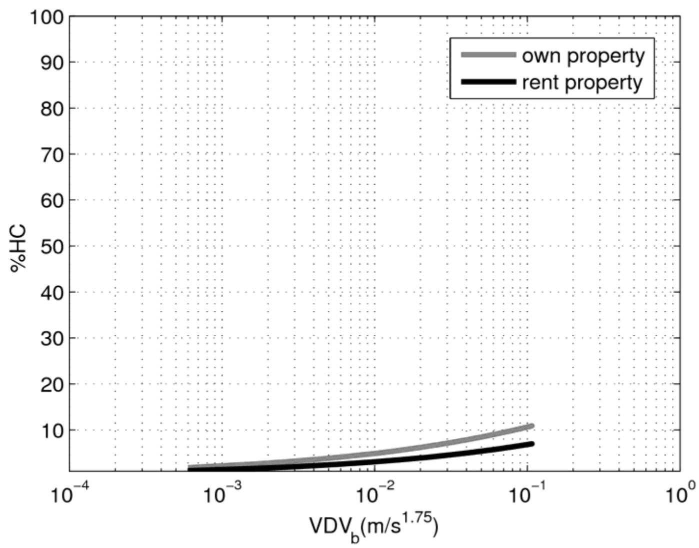

Fig. 3 – Exposure-response relationship showing the proportion of people reporting high property damage concern (%HC) for a given vibration exposure controlling for type of occupation (N=754). (Cox & Snell R^2=0.026, p <0.001).

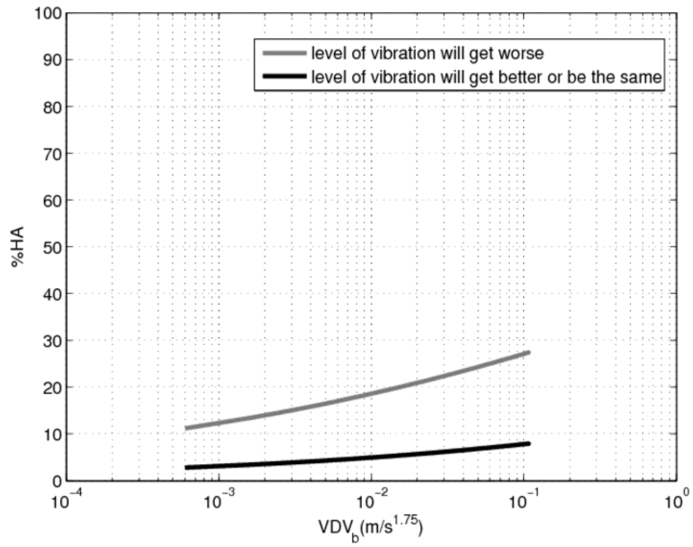

Fig. 4 – Exposure-response relationship showing the proportion of people reporting high annoyance (%HA) for a given vibration exposure and controlling for expectation (N=617). (Cox & Snell R^2=0.103, p <0.001).