Annoyance and Acceptability of Construction Vibration

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Abstract
The human response to environmental stressors such as vibration and noise is often expressed in terms of exposure-response relationships that describe annoyance as a function of the magnitude of the vibration. This paper examines measures other than annoyance by expressing exposure-response relationships for vibration in terms of self-reported acceptability and of non-exposure factors. The results presented in this paper are derived from data collected through a socio-vibration survey (N = 321) conducted for the construction of an urban Light Rail Transit (LRT) system in the United Kingdom. It is concluded that exposure-response relationships expressing acceptability as a function of vibration exposure could usefully complement existing relationships for annoyance in policy decisions regarding environmental vibration.

Keywords: Vibration, Construction, Acceptability, Concern, Annoyance, Exposure-Response Relationship, Light Rapid Transport (LRT)

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1 Introduction

Self-reported annoyance as a response to a stimulus is often used in the field of acoustics to form exposure-response relationships. The annoyance of vibration has been studied in the laboratory and this has gone on to inform national and international standards (e.g. BS6472-1:2008 [1]; ISO 2631-2:2003 [2]). As is it more difficult to measure vibration annoyance in the field, less research has been completed in residential environments. More recently studies have been carried out regarding the annoyance of vibration from transport in residential areas ([3], [4]). It has been shown that acoustic parameters do not fully account for the annoyance reported ([5], [6]), a finding that also applies to annoyance from noise [7].

Public acceptance has been studied for sustainable energy technologies because it is crucial for their successful introduction into society [8]. Public acceptance is recognized as an important issue shaping the widespread implementation of renewable energy technologies and the achievement of energy policy targets [9]. The work argues for inter-disciplinary research combining qualitative and quantitative approaches, using social research methods with emphasis on the symbolic, affective and discursive nature of beliefs about these technologies. Huijts [10] puts forward a framework of acceptance based on a review of psychological theories and on empirical studies. In that framework, attitude is influenced by the perceived costs, risks and benefits, positive and negative feelings in response to the technology, trust, procedural fairness and distributive fairness. Public acceptance is considered the most important barrier in studies of urban road pricing [11].

With regard to noise, public acceptance has long been an approach favoured by aircraft and the rotorcraft industries [12]. Acceptance through public engagement measures have also been carried out for wind farms. Toke [13] emphasizes the benefits of sensitivity to a local community by the developer and of a more open and proactive dialogue between the wind industry and local communities. To increase public acceptance of sustainable transportation systems, Pridmore and Miola [14] recommend measures such as gaining trust from the public, informing the public in a transparent manner, seeing operations in action, improving the perception of benefits and enhancing positive media coverage.

Recent work by the authors [15] establishes baseline models relating construction vibration exposure to response. Here we extend those models by looking at the influence of different non-exposure factors, specifically attitudinal, behavioural and situational. Non-exposure factors, such as future expectations of the vibration levels and concern of property damage, are found to constitute the most important parameters for railway vibration annoyance, and indeed these parameters have a greater weight than exposure [16]. It is clear that engineering measures alone will not solve pressing problems of concern about the consequences of unwanted vibration. Peris et al. [16] suggests that knowledge and understanding of attitudinal factors can potentially be a way to reduce or avoid adverse reactions in a more cost-effective way than reducing only exposure levels. For example, residents could be educated how low vibration levels are not likely to cause damage to their property, therefore increasing the public acceptance of the vibration source.

In this paper, the subjective human response to vibration from the construction of an urban LRT system is investigated in terms of self-reported acceptability and of non-exposure factors. This is achieved through further analysis of the dataset reported in [15]. Firstly the paper briefly outlines the methods used to collect the data using field measurements of vibration exposure and responses from face-to-face questionnaires. Next the statistical analyses are described and the results expressed as exposure-response relationships for exposure-annoyance and exposure-acceptability. The effects of the various non-exposure factors at different VDV levels are also examined. The results are then discussed with a particular emphasis on their proposed application to address contemporary challenges involving environmental vibration.

2 Methodology

2.1 Study Design

The data used in the paper were collected for the Defra project: Human Response to Vibration in Residential Environments ([4], [17]). The two components needed for this paper were the exposure data and the response data for the construction operations. All measurements presented here were made in the North-West of the England in 2010 during the construction/extension of an LRT system. The construction/extension of an LRT was chosen since a repeated cycle of activities was carried out at each point along the line. This was important as residents at one end of the line experienced the full construction cycle and could be surveyed without introducing a bias from the vibration survey. Vibration measurements of the full construction cycle were at the same time undertaken further down the line. It was important that case studies did not have other significant sources of vibration and were at appropriate stages of the construction process. It was also important that there was a mix of construction activities and that there were enough residences within 100 m. Three locations were found to meet the requirements. There were 350 dwellings in the sample.

2.2 Vibration Exposure

Vibration exposure was estimated using a technique combining measurements and estimation, due to the number of responses case studies. For preference, vibration would have been measured over a 24-hour period at the centre of the room where the greatest vibration magnitude is perceived, as recommended by [1] and [2]. The vibration measurement instrumentation used are Guralp CMD-5TD three axis force feedback accelerometers, synchronised using GPS signals. Long-term measurements captured the full life cycle of the construction as it passed by residences over approximately two months. Short-term measurements were made at various distances from the line and at one position inside the residence. From the long and short-term measurements, the ground attenuation was characterised using the Bornitz equation [18] and so the long-term internal vibration exposures were estimated.

2.3 Survey Data

Responses were collected from 350 residences across the three locations, A (161 residences), B (124 residences) and C (65 residences), with 133 male, 216 female and 1 not recorded. Respondents ranged in age between 16 and 88 years of age. All three locations were on the outskirts of a large city and therefore relatively urban. The same LRT lines were being constructed at each location but intrinsic differences between each location resulted in some differences in construction activities. The light-railway lines were being constructed along disused railway cuttings behind residences at locations A and C but along the main road at location B. As a result of these differences the disruption to residents may have differed between locations.

2.4 Questionnaire

Surveys were conducted face-to-face to avoid self-selection bias and only one person per household was interviewed. Respondents had to have been living at the residence for more than 9 months. To avoid bias regarding vibration, the survey was introduced as a neighbourhood satisfaction survey so the first few sections were about their neighbourhood and home. The wording of the questions regarding annoyance, concern about property damage and acceptability were of particular importance and are outlined below. Further details can be found in [19].

2.4.1 Annoyance

The questions relating to levels of annoyance used a five point semantic scale and the question: “Thinking about the time you have been living here, 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 construction activity, including demolition, piling road works, drilling, surface activity such as bulldozers and loading trucks and any other construction activity? Would you say not at all (1), slightly (2), moderately (3), very (4) or extremely (5)?”.

2.4.2 Acceptability

The question used to measure how acceptable residents found vibration was: “Looking at this scale and given all that you have said, in the time you have been living here, how acceptable have you found the level of vibration you have experienced in this home. Would you say it has been very acceptable, acceptable, neither acceptable nor unacceptable, unacceptable or very unacceptable? Very acceptable (1), Acceptable (2), Neither acceptable nor unacceptable (3), Unacceptable (4), Very unacceptable (5)".

2.4.3 Non-exposure factors

Questions were included to investigate the influence of different non-exposure factors, specifically attitudinal, behavioural and situational. For example, the question used to ascertain levels of concern about property damage was: "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: No - Not at all (1), Yes - Slightly (2), Yes – Moderately (3), Yes - Very (4), Yes - Extremely (5)".

2.5 Statistical Analyses

The programme SPSS (IBM SPSS Statistics v.20) was used to archive and analyse the survey data. Following the work of [16] and [3] an ordinal logistic regression was used to model the data and generate parameter estimates for each dependent variable threshold (e.g. not at all, slightly annoyed, moderately, very and extremely annoyed). Parameters were estimated using a Maximum Likelihood Estimation (MLE) and they are consistent and asymptotically multinomial. In using ordinal logistic regression the assumption of proportional odds is implicitly made. The validity of this assumption was tested via the test of parallel lines. Each model was judged by the change in the pseudo R^2. In particular the Cox & Snell R^2_{pseudo} and Nagelkerke R^2_{pseudo} were used. For linear regression the R^2 value describes the proportion of variance in the dependent variable that is described by the predictor variable, however this is not the same for logistic regression. Instead only the relative improvement of one model over another can be judged using the pseudo R^2 values.

3 Results

3.1 Exposure Relationships

The exposure-response for construction annoyance is shown in Figure 1. It shows the percentage highly annoyed (%HA) as a function of construction vibration exposure. This curve is derived using ordinal logistic regression as detailed above. For the construction source, the %HA category is formed by combining the Very and Extremely categories; this means that the curve represents the proportion of respondents expressing annoyance in the upper 40% of the scale. For comparison, also shown in Figure 1 are exposure-response relationships for freight and passenger railway vibration [5]. The statistical model used to formulate these exposure-response relationships is an ordinal probit model and the curves represent the proportion of respondents expressing annoyance in the upper 28% of the scale. Also, railway vibration is here Wb weighted while the construction vibration is Wb weighted, a difference factor of around 1.15. This means that these results do not provide a strict comparison. Nevertheless, this figure serves to illustrate that, for a given vibration exposure, vibration from construction is significantly more annoying than vibration from either freight or passenger railway.

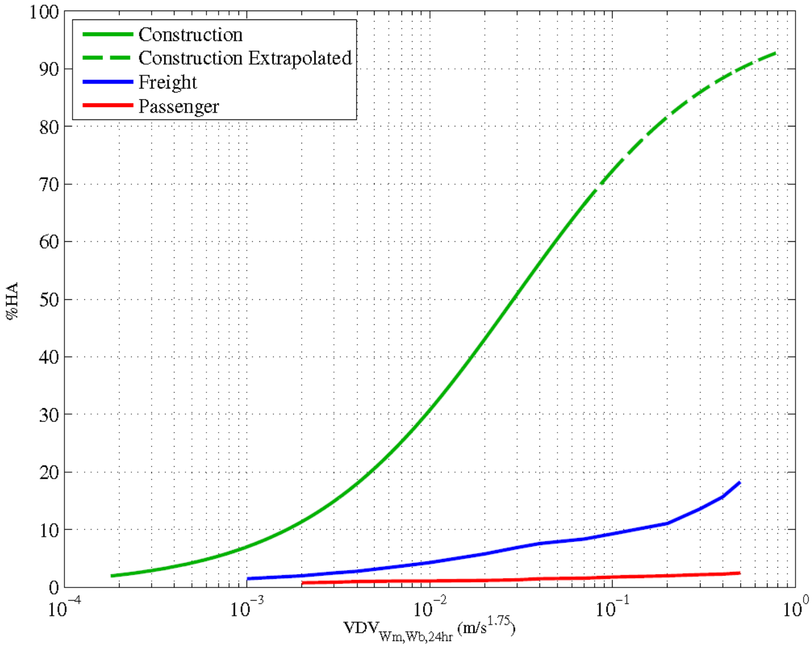

Figure 1: Exposure-response relationships showing percentage highly annoyed (%HA) as a function of vibration exposure for construction (ordinal logistic, Wm), freight railway (ordinal probit, Wb) and passenger railway (ordinal probit, Wb)

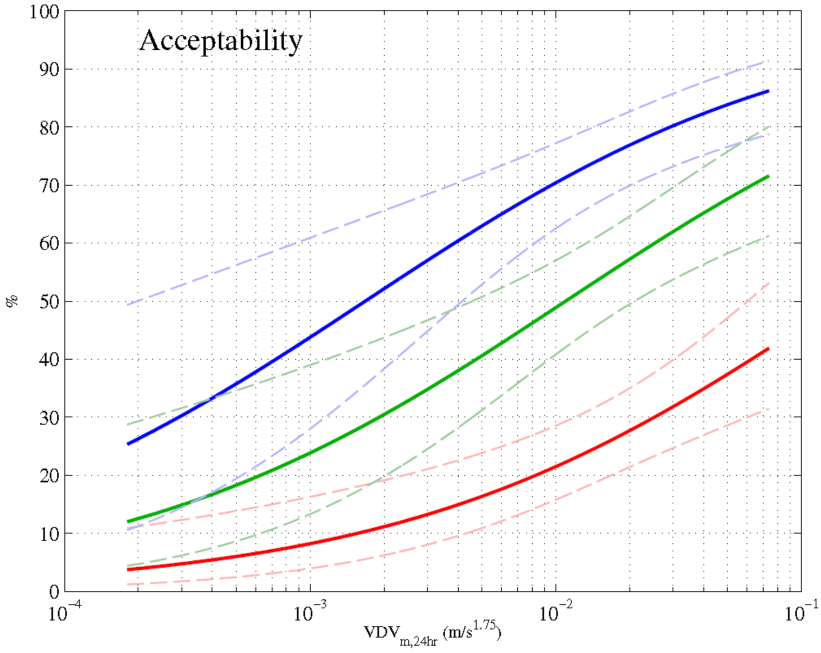

Figure 2: Exposure-Response curves showing the probability of people finding the construction vibration Neither Acceptable nor Unacceptable (Blue), Unacceptable (Green), or Very Unacceptable (Red).

Exposure-response curves showing the probability of people finding the vibration Neither Acceptable nor Unacceptable, Unacceptable, or Very Unacceptable are presented in Figure 2. The proportion of people reporting construction vibration as Unacceptable is found to increase with exposure. For example, for a construction vibration exposure $VDV_{m,24hr}$ of $2x10^{-4}$ $m/s^{1.75}$ it is seen that ~5% of respondents find the level to be Very Unacceptable, ~10% find it Unacceptable, and ~15% find it Neither Acceptable nor Unacceptable. The remainder find this level to be Acceptable or Very Acceptable. For a construction vibration exposure $VDV_{m,24hr}$ of 10^{-2} $m/s^{1.75}$ it is seen that ~20% of respondents find the level to be Very Unacceptable, ~30% find it Unacceptable, ~20% find it Neither Acceptable nor Unacceptable. Comparable curves for Annoyance and for Concern are presented in [15]. Of the three measures Acceptability has the broadest confidence intervals. The Cox & Snell R^2_{pseudo} value is ~0.17 for Annoyance, ~0.11 for Concern, and ~0.10 for Acceptability.

3.2 Non-exposure factors

A summary of the results of the different non-exposure factors is presented in Table 1. The centre column presents a ratio of the maximum and minimum VDV values at 10% HA. For the binary variables the ratio is between each situation, e.g. visible or not. For the ordinal variables the ratio is taken between the level 1 and level 3 cut-off values, e.g. slightly concerned and highly concerned. It should be noted that within the range of VDV measured in this study those reporting as highly sensitivity did not reach 10% HA and the VDV range was extended lower to attain the value in Table 1.

Table 1 – Summary of the different modifying factors examined

Factor	**VDVmax/VDVmin at 10%HA**	**Comment**
Sensitivity	69.3	How sensitivity affects annoyance. NB VDV range extended lowered for this statistic
Concern	45.7	Mediates the exposure-annoyance
Age	7.0	Inverted `U' shape relationship, middle-aged most annoyed.
Neighbourhood Satisfaction	5.0	
Home Satisfaction	2.8	
Visibility	6.0	Mediates exposure-annoyance
Ownership	3.6	Mediates exposure-annoyance
Expectation	2.9	No improvement to model

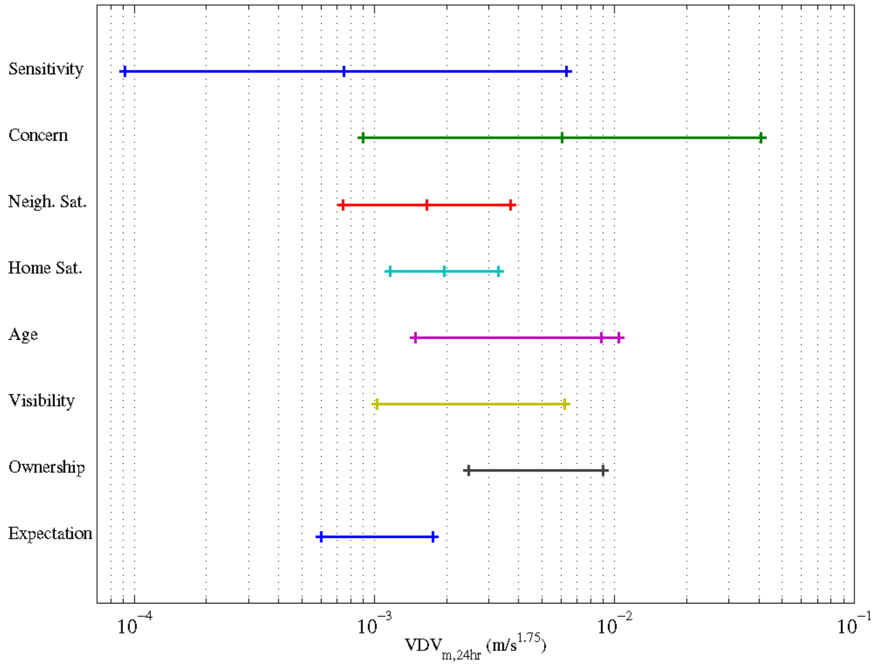

Figure 3: Range of influence of different non-exposure factors at different VDV levels.

Figure 3 presents a summary of the different ranges of VDV covered by the different non-exposure factors. Each of the different factors is listed on the left and the VDV corresponding to 10% HA for the different levels within that factor are plotted. For example, from the exposure-response curves for self-reported sensitivity there are three values for VDV depending on which category a respondent lies: slightly sensitive, sensitive or highly sensitive. These three values of VDV are plotted on the graph to provide for comparison between different factors. Note that the VDV axis is on a log scale.

4 Discussion

The results of this study show annoyance to have more precise relationship with exposure than does acceptability. This may in part be a feature of the study design, specifically the differences in questionnaire wording and scales used. Annoyance was measured using a semantic scale running from “Don't notice” through to “Extremely”, i.e. levels of being annoyed, while acceptability was measured on a semantic scale passing through neutral from “Unacceptable” to “Acceptable”.

Another consideration is how acceptability is judged compared to annoyance. In the model investigated, individuals report how annoyed they are in response to vibration by considering the vibration alone, regardless of other factors. However it is known that many other factors influence the exposure-annoyance relationship ([16], [20]), yet the respondent is being asked about (and therefore supposedly only considering) the vibration. For acceptability, on the other hand, the respondent is likely to be considering a far wider range of factors balancing the negatives of living with the construction vibration (e.g. annoyance, damage) against the potential positives of the construction site's outcome, i.e. a nearby convenient transport link.

This finding presents an interesting dichotomy for the management of the human response to vibration from construction. On the one hand, the equivalence of annoyance and acceptability as a predictor of community response suggests that vibration limit values may be set based on the derived annoyance exposure-relationships curves without the need for consideration of a complex framework of psychological factors. On the other hand, acceptability presents the possibility of the management of these psychological non-exposure factors, such as perceived costs, risks and benefits, and outcome efficacy, to improve the community response.

There is significant knowledge gap on how measures directed to manage acceptability might be more cost-effective than physical interventions alone. Further work might therefore be directed towards the development of guidance on management of annoyance and related behaviours such as acceptability. The guidance could give knowledge about expected outcomes when applying the various mitigation measures and describe the limits of its applications. These outcomes are likely to be economic and this means that it is essential for industry to partner on such work. Likewise outcomes might be societal, so policy makers and planners too need to be key participants.

5 Concluding Remarks

The results indicate that the next steps in research should aim to identify the benefits of the different self-reported metrics for assessing the human response to environmental vibration in terms of improved community response and economic cost. Of particular importance are gaps regarding possible measures and interventions, accompanying costs, benefits of avoided effects, determinants of acceptance, influence of other personal and contextual aspects including policy and governance, and communication. This requires a multidisciplinary approach that will bring together experts on modelling and mitigating vibration, as well as experts on human response, including annoyance, sleep disturbance and health effects. Standardization, establishing and sharing high quality databases, and the harmonisation of methods, which so far is much more advanced in the noise field, would likewise enable significant progression in the innovative management of vibration.

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