

A social survey questionnaire has been developed to determine human responses to vibration in residential environments. The overall aim was to produce a robust methodology for obtaining responses that could be combined with vibration measurements so as to investigate dose-response relationships for vibration in residential buildings. The sources of vibration considered include those outside the control of residents (e.g., from road, rail, industrial, construction). This paper describes the development of the questionnaire and explains its structure and content. Social surveys of responses of residents to vibration and noise are reviewed. Methods of analysing responses obtained with the questionnaire are summarised.

1 Introduction

Vibration produced by external sources, such as road and rail traffic, industrial machinery and construction activities can be transmitted through the ground to nearby buildings. Building vibration can also be caused internal sources such as domestic equipment and footfalls, and from acoustic excitation, such as the sounds of aircraft or road traffic.

Residents may perceive building vibration by feeling the motion transmitted to them from a supporting surface, such as the floor or a chair. Responses may vary from mild dissatisfaction to annoyance or anxiety depending on the characteristics of the vibration and individual factors such as expectation, experience, and personal traits. Vibration of a building may also be perceived by seeing movement, such as the swaying of pendulum lights, or hearing movement, such as the rattling of objects. The vibration of floors and walls may also radiate noise that can be heard. The reactions of residents to vibration in a building may therefore be complex due to the multiplicity of means of perceiving the vibration. Furthermore, responses to vibration can be increased or decreased by the presence of simultaneous noise, depending on the relative magnitudes of the two stimuli [1]. When interviewed, residents may be uncertain of the differences between noise and vibration. A questionnaire intended to reveal causes of subjective responses to vibration in buildings should be phrased so as to minimise unreliable interpretations of terminology and recognise the different means of perceiving vibration.

This paper provides an overview of the development, structure, and content of a social survey questionnaire designed to obtain responses from the occupants of buildings that could be combined with vibration measurements so as to determine dose-response relationships applicable to vibration in residential buildings. The various means of perceiving vibration, alternative response terminologies and ratings scales, the effect of questionnaire filters, and the order of questions are considered. The questionnaire is published in full elsewhere [2].

2 Response terminology, ratings scales, filters and order of questions

2.1 Response terms

Vibration can provoke a range of reactions in residents, depending on various factors including the activities being conducted at the time of the vibration event. Those sleeping may be disturbed by vibration from traffic, whereas other residents may be annoyed by vibration if it distracts from tasks such as reading or watching television.

Questions designed to gather information on the reactions of residents to building vibration must include response terms that most appropriately describe the range of possible responses to the various types and effects of vibration.

Previous noise and vibration questionnaires have used combinations of the terms “bother”, “annoyance” or “disturbance”. Klæboea, Öhrström, Turunen-Risec, Bendtsen and Nykänen [3] proposed the use of “annoyance” scales with a lower anchoring point “Do not notice” in surveys of responses to road and rail traffic. Grimwood, Skinner and Raw [4] asked residents to indicate whether they were “bothered, annoyed or disturbed” in a survey of community response to environmental noise. Stansfeld, Brown, Haines and Cobbing [5] asked respondents to indicate how “bothered, annoyed or disturbed” they were by domestic noise. Öhrström and Skånberg [6] employed the terms “observe” and “annoy” to obtain ratings of the effects of exposure to noise and vibration from railway traffic. Woodroof and Griffin [7] asked residents near railway lines to rate their “annoyance” from railway-induced building vibration. Watts [8] asked residents to provide ratings of “bother” caused by noise and vibration from road traffic. Fields and Walker [9] asked residents to rate their “bother” and “annoyance” from railway noise and vibration. In the current questionnaire, respondents were asked to provide ratings of “bother, annoyance and disturbance”. These response terms were selected as encompassing most likely reactions of residents to building vibration from common sources. Use of these terms allows comparison of gathered questionnaire data with findings from the environmental and domestic noise surveys of Grimwood *et al.* [4] and Stansfeld *et al.* [5] that obtained ratings of bother, annoyance and disturbance.

2.2 Rating scales

The questionnaire employs both numerical and semantic rating scales. A 7-point numerical rating scale is used to indicate satisfaction with the home or neighbourhood, and to rate bother, annoyance or disturbance caused by vibration and noise. A 5-point semantic is employed for other questions on bother, annoyance or disturbance. The use of the two scales enables the results to be tested for consistency and reliability by correlating the responses obtained with the 5-point and 7-point scales.

The 5-point semantic scale is the same as that employed by Grimwood *et al.* [4]. The 7-point numerical scale is similar to that used in the noise survey reported by Stansfeld *et al.* [5] and the same as that employed by Woodroof and Griffin [7] in a study of responses to railway-induced building vibration. The use of similar scales makes it possible to compare responses with those obtained in these other surveys.

2.3 The use of filter questions

The use of filter questions in social surveys, for example asking about responses to a specific event only if respondents report perceiving it, has been reported to bias the results of social surveys. Skinner, Grimwood and Raw [10] compared the results of two surveys of attitudes to environmental noise. One of the surveys employed a questionnaire that made extensive use of filter questions. They concluded that if responses to a specific noise source were requested only when the respondents reported they "had heard" that noise, responses were biased, with a greater proportion indicating they were affected because the question was not asked of those who had not "heard" it. The authors suspected that "heard" may have been interpreted variously as either "noticed", "affected" or "bothered", in which case some responses from those who heard but were unaffected by the noise may have been filtered out inadvertently. Skinner *et al.* conclude that filter questions may introduce errors if there are several possible interpretations of the filter question and so recommend that filtering should be kept to a minimum and the phrasing and consequences of any such routing should be considered carefully. The current questionnaire makes minimal use of filter questions. No filter questions are employed in questions that might be used to determine exposure-response relationships.

2.4 Means of perceiving vibration

Building vibration may be perceived as a result of vibration being transmitted to the body from surfaces supporting the body, such as floors, chairs, or beds. For this type of stimulus, respondents are asked to rate

annoyance, bother or disturbance caused by feeling vibration of the floor, chair or bed using a 5-point semantic scale (Figure 1). If the response is "not at all", "don't know" or "don't feel", further questions follow to ascertain whether vibration is ever felt. A "don't feel" option is selected if the response to the additional questions is that the respondent never feels vibration. Hence, ratings are obtained only if vibration is perceived. This avoids contamination of the results by the inclusion of the lowest rating when vibration is not perceived.

The perception of vibration other than by feeling the vibration (e.g., as a result of the rattling of objects, the swaying of lights, or the noise caused by the vibration of surfaces) is addressed separately from feeling vibration. Respondents are asked whether they ever hear things rattle or see things vibrate, shake or sway, what they think this is caused by, whether it interferes with aspects of their home life, and the associated degree of bother, annoyance, or disturbance (see Figure 2). In these questions, "hear or see" is in bold and underlined text to ensure that the respondent distinguishes these perceptions from the feeling of vibration transmitted to the body from the floor, chair or bed. Elsewhere, where appropriate, "feel" is in bold and underlined text.

2.5 Order of questions

Skinner *et al.* [10] suggest that differences in the order of questions in two questionnaires employed in surveys of environmental noise may have contributed to differences in responses. They suggest that awareness of environmental noise issues may increase during the interview resulting in higher responses in later questions. They also suggest that a general noise question may elicit

27.A Thinking about the last 12 months (or over the period of occupancy if less than 12 months), when you are in your home; how bothered, annoyed or disturbed are you by **feeling vibration** or shaking of the floor, chair or bed caused by **cars, lorries, buses or other road vehicles**? Show card 8:

Not at all	<input type="checkbox"/> ₁	Please clarify, you never feel or sometimes feel this kind of vibration?	Never	<input type="checkbox"/> Go to Q27B	Sometimes	<input type="checkbox"/> Go to (i)			
A little	<input type="checkbox"/> ₂								
Moderately	<input type="checkbox"/> ₃	Go to Q27 B							
Very	<input type="checkbox"/> ₄								
Extremely	<input type="checkbox"/> ₅								
Don't feel	<input type="checkbox"/> ₆	Please clarify, you never feel or sometimes feel this kind of vibration?	Never	<input type="checkbox"/> Go to Q27 B	Sometimes	<input type="checkbox"/> Go to (i)			
Don't know	<input type="checkbox"/> ₇	Please clarify, you never feel or sometimes feel this kind of vibration?	Never	<input type="checkbox"/> Go to Q27 B	Sometimes	<input type="checkbox"/> Go to (i)			
(i) So, can you confirm whether you are bothered, annoyed or disturbed by feeling vibration from cars, lorries, buses or other road vehicles ? Show card 8									
not at all	<input type="checkbox"/> ₁	a little	<input type="checkbox"/> ₂	Moderately	<input type="checkbox"/> ₃	Very	<input type="checkbox"/> ₄	Extremely	<input type="checkbox"/> ₅

Fig. 1 Example question on the perception of vibration by feeling.

more accurate responses when preceded by questions on specific noise sources which may act as a prompt or reminder about past experiences. In the present questionnaire, a general question on the degree of bother, annoyance or disturbance from vibration or noise is placed after questions on specific aspects of vibration or noise. Questions on sensitivity to noise and vibration are placed after questions on ratings of vibration and noise so as to avoid any influence of sensitivity questions on the ratings of noise and vibration.

3 Questionnaire structure and content

The questionnaire begins with a section in which the interviewer reports on dwelling and location information. Section 2 consists of questions concerning personal characteristics, ownership or tenancy of the dwelling, duration and hours of occupancy, and number of occupants. The third and fourth sections consist of questions on likes and dislikes about aspects of the neighbourhood and home. In the fifth and sixth sections, questions focus on feeling vibration, followed by questions on the perception of vibration other than by feeling. The seventh and eight sections focus on noise. In Section 9, respondents are asked to indicate their preference for a reduction in either noise or vibration and to provide ratings of their response to combined noise and vibration.

Respondents are also asked to rate their sensitivity to vibration and noise. In the final section, interviewers are asked to provide information on their experience during the interview of either feeling vibration or perceiving it by other means.

4 Questionnaire analysis methodology

Statistical analyses of responses from the questionnaire can test the reliability of the responses and examine relationships between subjective responses and objective measures of vibration exposure.

Spearman's rank correlation coefficient may be applied to test for consistency between ratings of bother, annoyance or disturbance, to test for agreement between ratings on different annoyance scales and between questions on perception and annoyance. The Wilcoxon matched-pairs signed ranks test may be employed to test for differences between noise and vibration ratings for the same source, and to test for differences between ratings of annoyance caused by the perception of vibration by feeling and by hearing or seeing. To determine whether questions on annoyance caused by vibration or noise produced different responses for different sources of vibration or noise, the Friedman test may be applied.

Factor analysis may be employed to assist the

31. Thinking about the last 12 months (or over the period of occupancy if less than 12 months), how bothered, annoyed or disturbed are you by **hearing or seeing vibrating**, rattling, shaking or swaying of things caused by.....? *Show card 8*

	not at all	A little	Moderately	very	extremely	don't hear or see
a. Cars, lorries, buses or other road vehicles	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆
b. Aircraft	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆
c. Overground trains	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆
d. Underground trains	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆
e. Quarrying or mining	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆
f. Construction	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆
g. Road works	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆
h. Footfalls, slamming doors, domestic appliances inside your home	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆
i. Footfalls, slamming doors, domestic appliances in neighbouring homes	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆
j. Other (<i>specify</i>)	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄	<input type="checkbox"/> ₅	<input type="checkbox"/> ₆

Fig. 2 Example question on the perception of vibration by hearing or seeing.

identification of underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. The Kaiser-Meyer-Olkin and Bartlett tests may be applied to responses from specific questions to determine whether the data are suitable for factor analysis. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy tests whether the partial correlations among variables are small. Bartlett's test of sphericity indicates whether the correlation matrix is an identity matrix, which would indicate that the factor model is inappropriate.

Explorations of the relationships between subjective responses and objective measures of vibration and noise may involve partial and multiple correlation analyses. Logistic regression may also be employed to investigate the relationships between variables, for example, to model the probability of feeling annoyed by vibration from predictor variables such as the distance from the source of vibration, or a measure of the vibration magnitude, or dose. Simple logistic regression (univariate analysis) and multiple logistic regression (multivariate analysis) may be conducted to investigate relationships between single dependent variables and one or more independent variables.

5 Conclusions

A social survey questionnaire has been developed to obtain human responses to vibration in residential environments. The questionnaire development process involved consideration of the key objectives: to obtain response data which are psychometrically reliable for feeling and otherwise perceiving vibration in residential environments. The effects of different response terms, ratings scales, filter questions and order of questions were taken into account. The requirements for statistical analyses of the questionnaire data and of combined questionnaire and vibration data were considered in the questionnaire development.

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