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INSTITUTE OF SOUND AND VIBRATION RESEARCH

Community Response to Multiple Noise Sources

by

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ABSTRACT

FACULTY OF ENGINEERING AND APPLIED SCIENCE
INSTITUTE OF SOUND AND VIBRATION RESEARCH

Doctor of Philosophy

Community Response to Multiple Noise Sources

by Ian Harry Flindell

A series of studies were conducted to investigate the degree of correspondence between laboratory and field community noise annoyance responses, and how selected aspects of these responses differ in situations where more than one noise source is present.

A good correspondence was obtained between laboratory and field responses to road traffic noise by using a simulated domestic living room listening laboratory, realistic tape recordings recorded at the appropriate distances from the noise sources for the simulated reproduction levels, numerical category scaling with ten point annoyance scales in the field and similar home projection annoyance scales in the laboratory with instructions specifically related to the evening period, and indoor laboratory reproduction levels at 18 dB below outdoor facade 24 hour L_{Aeq}'s, to correspond to typical open window outdoor/indoor attenuation, as measured in the field. This result supported the value of the laboratory method.

A laboratory study was conducted using combinations of road traffic and railway noise. This study found that the average noise intensity concept (L_{Aeq}) was not satisfactory in explaining subjects' overall reported annoyance. Completely new noise exposure measures, pressure L_{Aeq} and pressure sum (pL_{Aeq} and psum) were then developed based on average r.m.s. pressure. These new measures gave good quantitative agreement with mean reported annoyance ratings.

Re-analysis of other field and laboratory data supported the psum as a measure for multiple noise source environments. However, source specific field annoyance data relating to aircraft noise considered as a separate noise source was not consistent with pL_{Aeq}. A suggestion is made that new field research might overcome this discrepancy by concentrating on overall annoyance responses to the total noise environment, rather than on reactions to specifically identified noise sources. It is hypothesised that pL_{Aeq} and psum might then constitute significant advances in the search for a unified noise scale.

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INTRODUCTION

There is currently a need for improved community noise assessment procedures that can take proper account of multiple noise source environments. To a certain extent, the Equivalent Continuous A-weighted Sound Level (L_{Aeq}) is such an appropriate measure of noise exposure. However, the value of predictions of general community annoyance based on measured or predicted L_{Aeq} is limited. Contrary to Schultz's synthesis [1] of social survey data, community annoyance response is different for different noise sources at the same L_{Aeq} (or L_{DN}) [2]. Further, as Powell [3] has shown, community annoyance responses to multiple noise source environments may be significantly higher than the overall L_{Aeq} of the multiple noise source environment implies.

In this thesis, new procedures are proposed which take account of these limitations. Pressure L_{Aeq} (pL_{Aeq}) and corrected L_{Aeq} are suggested in order to take account of annoyance response differences between different noise sources, whilst the pressure sum (psum) procedure is suggested in order to take account of the enhanced annoyance potential of multiple noise source environments. pL_{Aeq} and the psum procedure involve a modification to the formula for conventional L_{Aeq} in order to take account of average r.m.s. pressure rather than average intensity. For example, noises having only occasional peak level events interspersed with periods of relative silence have lower pL_{Aeq}'s than conventional L_{Aeq}'s. The psum of a combination of noise sources is higher than the overall conventional L_{Aeq} (or energy sum) of the combination. Corrected L_{Aeq} involves the addition of empirically derived source specific correction factors to measured or predicted L_{Aeq}'s in order to take account of annoyance response differences between different noise sources.

These factors can be further illustrated by a consideration of a noise environment having both road traffic noise and railway noise, where evidence is presented in support of the hypotheses that the psum of separate noise source pL_{Aeq}'s (pL_{Aeq}, psum) or the psum of corrected L_{Aeq}'s have higher correlations with reported annoyance than overall conventional L_{Aeq}.

pL_{Aeq}, psum is not a decibel quantity in that it is not directly related to power ratios. However, it has been treated as a quasi-decibel quantity in comparison with true decibel quantities, such as SPL, in order to simplify the exposition in this thesis.

The new procedures are considered in the context of laboratory experiments carried out in a simulated domestic living room listening facility. Competing models exist and are discussed in detail. A calibration of the laboratory techniques was carried out by comparing laboratory and field annoyance responses to road traffic noise using the same subjects in both the laboratory and field phases. The new procedures were then tested against other sets of data available in the literature.

1.1 A Caveat

Corrected L_{Aeq} can by definition take account of any non-acoustic factors that mediate overt response. However, the appropriate correction factors are necessarily situation dependent as well as noise level dependent. Pressure L_{Aeq} and the psum procedure are completely objective but are necessarily limited in the number of factors that they can take into account. pL_{Aeq} differs from conventional L_{Aeq} solely in the extent to which numbers and durations of noise events are taken into account. The psum procedure differs from the energy sum procedure solely in the extent to which the numbers and relative levels of contributing noise sources are taken into account. pL_{Aeq} and the psum procedure are proposed merely in order to overcome certain limitations of overall conventional L_{Aeq}.

There are a number of factors which may mediate overt response which are not taken into account by pL_{Aeq} or the psum procedure. For example, the attitudinal and situational factors that may influence annoyance responses in field surveys are not taken into account. Further, special acoustic factors such as corrections for impulsiveness or tonality are not taken into account. Of course none of these factors is taken into account by overall conventional L_{Aeq} either.

It is recognised that administrative recognition of any new procedures is unlikely without new field research. A strong recommendation is made in Chapter 7.6 that any such new field research should place a considerable emphasis on overall annoyance response to the total noise environment. In that way certain inconsistencies between the pL_{Aeq} concept and observed differences in annoyance responses between aircraft noise and other noise sources might be resolved.

2. MEASURES OF ANNOYANCE POTENTIAL

2.1 Introduction

This chapter describes the fundamental objective of community noise research to develop methods of evaluating annoyance potential. Annoyance potential is defined as an objectively measurable quality of the noise environment that is related to the average response of a reasonable and representative exposed population. The average response is measured in terms of mean reported annoyance in the laboratory since in this way many of the attitudinal and situational parameters that mediate overt response can be ignored. The advantages of the laboratory study in terms of precise control of experimental variables and the use of repeated measures experimental designs are described. The terms 'models', 'scales', 'procedures' and 'criteria' are defined. A case is made for a unified noise scale based on the A-weighted sound pressure level.

2.2 Annoyance Potential

When people are exposed to community noise sources they are likely to be affected in some way. They may suffer activity interference, they may be prevented from resting or sleeping, they may have to modify their behaviour in order to adapt to the noise, or they may just feel annoyed. Eventually, they may complain or take some other form of action, or they may have to resign themselves to living with the noise.

Although noise nuisance can take many forms, this thesis has adopted annoyance as the dependant variable of interest. The effects of noise on general health and on mental health are not proven [4]. It is difficult to evaluate the importance to the community of the various autonomic and physiological responses to noise which have been reported in the literature [5]. Complaint studies and behavioural investigations depend very much upon specific situations. However, a direct measure of annoyance provides each individual with the opportunity to make his own assessment or subjective weighting of the relative importance to him of each type of nuisance or disturbance, when forming an overall judgement of the quality of his environment. Annoyance ratings have thus been described as judgements of "perceived environmental quality" [6].

In the field, annoyance ratings are measures of actual annoyance, and are thus strongly influenced by many attitudinal and situational variables. The degree of noise exposure is only one of those many variables. In the laboratory, mean reported annoyance ratings do not represent actual annoyance at all, but rather, they represent relative rankings of a set of noise exposures in terms of their annoyingness, or perceived *annoyance potential*. In this context, annoyance potential refers to some objectively measurable quality of the noise environment that is related to the average response of a reasonable and representative exposed population having no vested interest. Providing that care is taken to ensure that any set of laboratory subjects is "reasonable and representative" and "having no vested interest" then whatever measure of noise exposure is found to be most highly correlated with average response could be taken as a measure of annoyance potential.

Then in any noise assessment problem, the appropriate question would not be, "Would these particular people be annoyed?" The appropriate question would be, "Would these particular people be annoyed if they were reasonable and representative and had no vested interest?" It is not the business of noise control to influence all those attitudinal and situational variables that mediate overt response. Noise control usually involves cost and inconvenience, and the producer of the noise should not necessarily have to incur extra cost because of any particularly noise-sensitive exposed individuals. It would not be equitable for the position of a new airport to be decided merely on the relative strengths of local public opposition at each proposed site. Opposition can be whipped up by organisation, and can appear minimal if the population is inarticulate or poorly organised.

Annoyance potential offers an equitable method for defining acceptability. A good measure of noise annoyance potential enables proper comparisons to be made between alternatives. Of course, this thesis only attempts to measure annoyance potential through the attribute of reported annoyance. It must be recognised that if some other attribute, such as the degree of sleep disturbance, were to be used, then the form of the measure of annoyance potential might turn out differently. However, in terms of general community annoyance potential, then mean reported annoyance is probably the best dependant variable to use.

2.3 Laboratory Studies

Community response to noise can be investigated by means of field studies or in the laboratory. Field studies have the compelling advantage of face validity. However, they are expensive, cumbersome, and may not be sufficiently powerful to answer the research questions properly because of high residual levels of response variance [7]. Laboratory studies have major advantages due to the possibility of using repeated measures experimental designs, which are inappropriate for field studies. The repeated measures experimental design enables mean responses to a series of noise exposures to be compared in order to derive direct relative rankings of annoyance potential. Such relative rankings can only be inferred from field study data by assuming that the mean responses of each homogeneous noise exposure group are directly related to noise annoyance potential and that the mediating effects of attitudinal and situational variables can be ignored.

The laboratory study offers precise control over the experimental variables. Such control is not possible in the field because noise exposure varies from day to day and from dwelling to dwelling. It is normally simple to construct particular noise exposures in the laboratory that might be almost impossible to find in real-life, especially in the light of the usual requirement for homogeneous samples of some 20 to 100 residents. However, the question of the appropriateness of any particular laboratory exposure to simulate any particular real-life exposure can only be resolved by calibration studies. A calibration study of response to road traffic noise was carried out. People were interviewed in their own homes and then tested in the laboratory. It was concluded that an 18 dB attenuation factor was appropriate between outdoor facade noise levels in the field and indoor noise levels in the laboratory in order to achieve a close correspondence between field and laboratory annoyance responses [8]. This study is fully described in Chapter 5.

Social surveys of community response to noise generally conceal their true purpose by being ostensibly about other environmental matters. Questions on noise will only be introduced unobtrusively. This is in order to avoid bias by drawing the respondent's attention to a noise problem, which he may have previously ignored. Nevertheless, a social survey conducted during a period of widely reported public debate on a relevant issue will generally be viewed with suspicion, as it can only measure actual reported annoyance and not annoyance potential.

The laboratory study provides an ideal opportunity for measuring the response of a group of representative, reasonable persons having no vested interest. Any variations in individual noise sensitivity will be unimportant in terms of the relative rankings of the different noise exposures. Providing that the sample has no vested interests, there is no reason to assume that they will respond with any bias towards any one noise source in a multiple noise source experiment. The 18 dB attenuation factor described above may be assumed as taking account of the normal range of tendencies towards over- or underestimating projected home annoyance from laboratory exposures, subject only to the proviso that this attenuation factor could be different for noises other than road traffic.

2.4 Definitions of Terms

As the Noise Advisory Council Working Party on Noise Units noted [9] there is confusion in the literature over the use of terms, particularly with respect to noise scales and indices. It is therefore worthwhile to define certain terms as they are used in this thesis.

A *model* of community response to noise is understood to refer to a mathematical description of the relationship of human responses to the noise exposure. For this purpose the actual noise exposure must be measured in terms of a defined noise *scale* which takes account of all objective parameters of interest. Such models may or may not be based on psychological or acoustical theory but it is generally desirable that they should be as simple as possible. The noise exposure measure or scale would normally be defined in such a way as to give the simplest relationship possible between response and exposure. In this context the community response must be related to the reasonable and representative exposed population mentioned in Chapter 2.2 above in order to determine appropriate measures or scales of annoyance potential.

Where a noise exposure measure requires that a relatively complex calculation of the final scale values be made, this is termed a *procedure*, as in the pL_{Aeq}, psum procedure, as discussed in this thesis. The objective of all noise exposure measures is to reach a single figure descriptor that bears a strong relationship with annoyance potential. Such measures, scales or procedures can be used in the setting of *criteria* against which acceptability or entitlement to compensation, etc., can be judged. This thesis has no objectives in terms of the selection of appropriate criteria, but is restricted to a consideration of models, scales and procedures.

The Noise Advisory Council Working Party on Noise Units [9] made an admirable attempt to reserve the term *index* for those measures that are intended to be related to actual community response, whereas the term "scale" could relate to any measure. This distinction has not been followed rigorously by all recent authors, and confusion as to the meaning of the term "index" remains. Further, the objective of this thesis is not to measure actual dose-response relationships in the field, but to find improved measures of annoyance potential. Accordingly, the term "index" is not used elsewhere in this thesis.

2.5 A Unified Noise Scale

The Noise Advisory Council Working Party on Noise Units [9] gave a clear recommendation for the adoption of the A-weighted sound level as an appropriate measure for all noise sources. This recommendation is consistent with research results [10, 11] which found no real advantage by using other frequency weightings or the available more complex frequency band level summation techniques.

Accordingly, the A-weighting is either assumed or applied throughout this work. However, it should be noted that one of the two major recommendations for the adoption of the pL_{Aeq}, psum procedure is the potential elimination of response differences between different noise sources at similar noise exposure levels. It is possible, although unlikely, that future developments could improve on the A-weighting and eliminate the response differences at similar conventional L_{Aeq} levels. Therefore, should a superior successor to the A-weighting ever be devised, then this work will have to be critically reviewed.

The working party recommended the adoption of L_{Aeq} as a common measure for all noise sources in the light of the current United Kingdom practice of having different and incompatible noise indices for each major noise source. They recognised some limitations of L_{Aeq} and suggested further research on alternatives although their optimism concerning Noise Pollution Level (L_{NP}) |12| as an alternative has not been borne out by events. The current United Kingdom practice is unsatisfactory as the proper assessment of any complex noise environment is impossible when using different measures for each noise source. Further, it is very difficult for a layman to make his own judgements of the validity of professional assessments whereas with a proper unified measure noise assessment need no longer be a "black art" and many disagreements between professionals could be avoided.

This thesis can be considered as part of that research on alternatives to conventional L_{Aeq} in the search for an improved unified noise scale.

3. MODELS

3.1 Introduction

Strictly speaking, the models refer to the mathematical description of the relationship of community response to defined measures of noise exposure. Each noise scale or procedure depends upon an underlying model. For example, in the case of conventional L_{Aeq} as a scale, the underlying model in which it is used assumes that response is related to the average intensity of the sound. The underlying model need not be explicitly stated although the value of any measure or procedure depends upon the underlying model being plausible. This chapter discusses the available models, scales and procedures under the generic term 'models', recognising that in some cases, for example, L_{NP}, the underlying model can only be described in operational terms.

The A-weighted sound pressure level, L_A, is assumed throughout to be a necessary and sufficient descriptor of the instantaneous auditory magnitude of any sound. Possible corrections for impulsiveness and tonality, for time-of-day, and for receiver circumstances are not considered here, although of course full records would always enable such factors to be taken into account.

This thesis is concerned with methods of taking into account fluctuations of sound level with time and the numbers and levels of contributing and separately identifiable noise sources or groups of noise sources.

The existing United Kingdom measures - the Noise and Number Index (NNI); the L_{10}(18 hour) index; and the Corrected Noise Level (CNL) - are specific to single noise sources and are not appropriate as unified noise scales. They have obvious shortcomings were they to be used as unified noise scales and require no further discussion here.

A selection of remaining scales and models are discussed in this chapter each in a separate section. Some are rejected on theoretical considerations leaving conventional L_{Aeq} and corrected energy sum; pL_{Aeq} and pL_{Aeq}, psum; and the Powell [3] model. There is a whole plethora of other measures which could be devised but pL_{Aeq}, psum is supported because of its simplicity.

3.2 The Equivalent Continuous Sound Level (Conventional L_{Aeq})

The Noise Advisory Council have published a comprehensive guide [13] to the measurement and prediction of annoyance potential using this scale. It is the average A-weighted intensity expressed in decibels relative to the standard threshold level:

$$L_{Aeq} = 10 \log_{10}\left[\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \frac{p_A^{\,2}(t)}{p_{ref}^{\,2}}\, dt\right] \qquad (1)$$

where $p_A(t)$ is the A-weighted sound pressure as a function of time,

p_{ref} is 20 micropascals,

$T_2 - T_1$ is the time interval of interest.

The A-weighted sound pressure level, L_A, is related to the A-weighted sound pressure, p_A, by the following definition.

$$L_A = 10 \log_{10}\left[\frac{\overline{p_A^{\,2}}}{p_{ref}^{\,2}}\right] \qquad (2)$$

where $\overline{p_A^{\,2}}$ is the mean square value of the A-weighted sound pressure. There is an averaging time associated with the mean square value. It is determined by the time constant of the sound level meter dynamic response characteristic. For the "fast" and "slow" meter characteristics the time interval $T_2 - T_1$ (equation (1))above) is generally large compared with the averaging time associated with L_A. The alternative formula for L_{Aeq} given below is then convenient.

$$L_{Aeq} = 10 \log_{10}\left[\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} 10^{\frac{L_A(t)}{10}}\, dt\right] \qquad (3)$$

where L_A is the A-weighted sound pressure level.

Equations (1) and (3) may not be equivalent if fast attack slow decay sound level meter response dynamic characteristics such as "impulse" are used. In such cases the L_{Aeq} derived according to equation (3) will normally be higher than the true L_{Aeq} derived according to equation (1).

It is elementary to calculate the overall L_{Aeq} of any multiple noise source environment from the contributing noise source L_{Aeq}'s, providing that the time intervals $T_2 - T_1$ are in all cases equivalent. This is because the overall sound energy is the sum of the energy contributions of the contributing noise sources. Energy is simply the product of intensity and time. The relationship between intensity and sound pressure squared is dependent on the characteristic impedance of air which varies with atmospheric conditions but under normal circumstances this variation can be ignored.

The overall L_{Aeq} is given by

$$L_{Aeq} \text{ overall} = 10 \log_{10} \sum_{i=1}^{n} 10^{\frac{L_{Aeqi}}{10}} \qquad (4)$$

where L_{Aeqi} is the L_{Aeq} of the i^{th} noise source and all time intervals $T_2 - T_1$ are the same.

The single event noise exposure level, L_{Ax}, is a convenient concept for use in the calculation of L_{Aeq} but it is not important from the point of view of the matters under discussion here.

L_{Aeq} can be employed in the assessment of multiple noise source environments. The separate noise source L_{Aeq}'s are evaluated according to equations (1) or (3) and then the overall L_{Aeq} can be calculated according to equation (4) above. The underlying model is simply that annoyance potential is related to average intensity regardless of the type and number of noise sources.

3.3 Corrected Energy Sum

This procedure is intended to describe the annoyance potential of multiple noise source environments. Rice [14] proposed subjective correction factors in order to equalise responses to different noise sources at the same A-weighted sound pressure levels. The concept of correction can be readily applied to separate noise source L_{Aeq}'s. It involves the addition of empirically derived source specific correction factors to measured or predicted L_{Aeq}'s.

The overall L_{Aeq} of the multiple noise source environment can then be calculated by taking the energy sum of the corrected contributing noise source L_{Aeq}'s. This procedure is based on the model that annoyance potential is directly related to average intensity, providing only that noise source specific correction factors have been applied to the contributing noise source L_{Aeq}'s. Correction factors can be level dependent if that is found to be appropriate empirically.

$$L_{Aeq} \text{ overall} = 10 \log_{10} \sum_{i=1}^{n} 10^{\frac{L_{Aeqi} + D_i}{10}} \qquad (5)$$

where D_i is the appropriate correction factor to the L_{Aeq} of the i^{th} noise source, and providing that all time intervals $T_2 - T_1$ are the same.

The corrected energy sum procedure conveniently resolves the source dependent response limitation associated with conventional L_{Aeq}. Unfortunately, it is unsatisfactory in three respects: first, the appropriate correction factors must be determined empirically. This could well involve the considerable expense of new field surveys. Secondly, there is no theory which predicts the magnitude of such correction factors (with the exception of Pressure L_{Aeq}, Chapter 3.4). Indefinable attitudinal differences between noise sources could be invoked by way of explanation, but such explanations may not be satisfactory in the long term. Thirdly, the energy sum procedure does not take account of Powell's [3] observation that community response to multiple noise sources may be significantly higher than the overall L_{Aeq} of the multiple noise source environment implies.

3.4 Pressure L_{Aeq} (pL_{Aeq})

A generalised expression for the A-weighted noise measure, X, is given by:

$$X = k \log_{10}\left[\frac{1}{T_2 - T_1}\int_{T_1}^{T_2}\left(\frac{p_A^{2}(t)}{p_{ref}^{2}}\right)^{10/k} dt\right] \qquad (6)$$

where k is a parameter

$p_A(t)$ is the A-weighted sound pressure

p_{ref} is 20 micropascals

$T_2 - T_1$ is the time interval of interest.

The alternative formula below will normally be equivalent, providing that $T_2 - T_1$ is large compared with the averaging time associated with L_A:

$$X = k \log_{10}\left[\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} 10^{\frac{L_A(t)}{k}} dt\right] \qquad (7)$$

where

$$L_A = k \log_{10}\left[\frac{\overline{p_A^{2}}}{p_{ref}^{2}}\right]^{10/k} \qquad (8)$$

Conventional L_{Aeq} is defined by a k value of 10 in equations (6) and (7). pL_{Aeq} is defined by a k value of 20 in equations (6) and (7). pL_{Aeq} can be defined as the equivalent continuous r.m.s. A-weighted sound pressure (level), whereas conventional L_{Aeq} is the equivalent continuous r.m.s. A-weighted sound pressure squared (level).

pL_{Aeq} gives less emphasis to peak noise level events than conventional L_{Aeq} within any given time history of events. Hence, pL_{Aeq} is always lower than conventional L_{Aeq} for time varying noise. The difference is reduced as the percentage on-time of the noise increases until there is no difference for noise having a steady A-weighted sound pressure level.

The most useful expression for pL_{Aeq} is given below:

$$pL_{Aeq} = 20 \log_{10} \left[\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} 10^{\frac{L_A(t)}{20}} dt \right] \qquad (9)$$

The pL_{Aeq} can be readily determined from a measured or predicted probability distribution of sample A-weighted sound pressure levels.

Two examples of how the difference between conventional L_{Aeq} and pL_{Aeq} depends upon the time history of the noise are given below:

(a) Consider two events lasting 60 seconds each, of peak level 100 dB(A) in a one hour period. Then the conventional L_{Aeq} is given by

$$L_{Aeq} = 10 \log_{10} \left[\frac{1}{3600} (60 \times 10^{\frac{100}{10}} + 60 \times 10^{\frac{100}{10}}) \right]$$

$$= \underline{\underline{85}}$$

The pL_{Aeq} is given by:

$$pL_{Aeq} = 20 \log_{10} \left[\frac{1}{3600} (60 \times 10^{\frac{100}{20}} + 60 \times 10^{\frac{100}{20}}) \right]$$

$$= \underline{\underline{70}}$$

(b) Consider 60 events lasting 59 seconds each, of peak level 70 dB(A) in a one hour period. Then the conventional L_{Aeq} is given by:

$$L_{Aeq} = 10 \log_{10} \left[\frac{1}{3600} (60 \times 59 \times 10^{\frac{70}{10}}) \right]$$

$$= \underline{\underline{69.93}}$$

The pL_{Aeq} is given by:

$$pL_{Aeq} = 20 \log_{10} \left| \frac{1}{3600}(60 \times 59 \times 10^{\frac{70}{20}}) \right|$$

$$= \underline{\underline{69.85}}$$

These two examples are illustrated in Figure 3.1.

Evidence is presented in this thesis to suggest that the use of pL_{Aeq} may eliminate the need for correction factors to conventional L_{Aeq}'s by taking account differently of the number and duration of peak noise level events. pL_{Aeq} is not proposed as a suitable measure for multiple noise source environments. These would require the pressure sum procedure to be used, as discussed in Chapter 3.5 below.

3.5 Pressure Sum Procedure (psum)

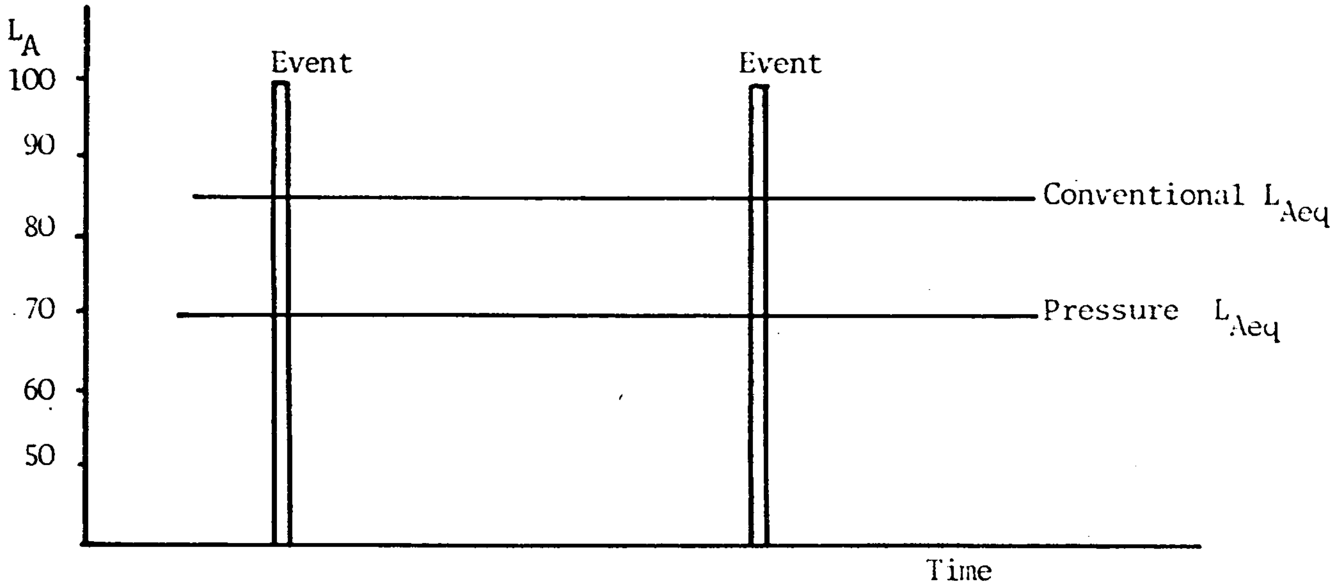
This procedure is intended to enable the annoyance potential of multiple noise source environments to be described. It is proposed as an alternative to the energy sum procedure implied by conventional L_{Aeq}. The pressure sum procedure is based on the model that annoyance potential is directly related to the calculated sum of the contributing noise source average r.m.s. sound pressures, rather than the sum of the average intensities.

The model only applies where the two or more contributing noise sources are clearly and separately identifiable and distinguishable. Otherwise, the measured or predicted average sound level for each confusable group of contributing noise sources is appropriate. This is because the pressure sum model is intended to account for a psychological rather than a physical phenomenon. The overall annoyance potential of two separately identifiable and distinguishable contributing noise sources may be greater than their physical sum would imply. However, if two noise sources are confusable, i.e., not separately identifiable and distinguishable, then there is no information present for such a psychological effect

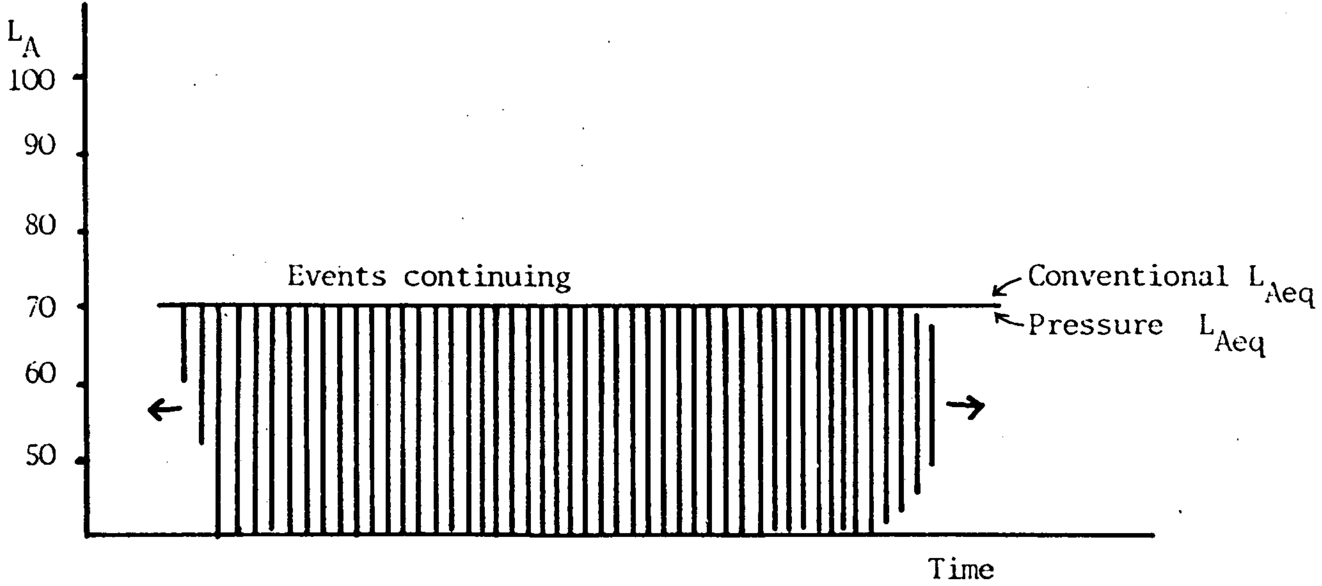
Figure 3.1

Examples of the difference between conventional L_{Aeq} and pressure L_{Aeq}.

Example a)



Example b)



to operate. Then the annoyance potential of the confusable group of noise sources must be related solely to their physical sum.

The pressure sum is given by:

$$\text{psum} = 20 \log_{10} \sum_{i=1}^{n} 10^{\frac{L_i}{20}} \tag{10}$$

where L_i is the equivalent continuous level for the i^{th} separately identifiable and distinguishable group of contributing noise sources.

In this context the equivalent continuous level can be expressed in terms of pL_{Aeq}, conventional L_{Aeq}, corrected conventional L_{Aeq} or on any other appropriate scale. The psum model is intended to take account of the observed higher level of community response to multiple noise sources than overall conventional L_{Aeq} would imply [3]. It does not take account of differences in community response to different noise sources at the same equivalent continuous level, and therefore is not a complete procedure, whereas pL_{Aeq}, psum described in Chapter 3.6 is a complete procedure.

The psum procedure implies that the overall annoyance potential of two subjectively equivalent and separately identifiable and distinguishable groups of noise sources is some 6 dB greater than the annoyance potential of either source alone. The overall conventional L_{Aeq} is only 3 dB greater than the annoyance potential of either source alone, under the same circumstances. It may at first sight be confusing, yet the overall pL_{Aeq} of the same two noise sources might only be 3 dB greater than the pL_{Aeq} of either source alone, whereas the psum is 6 dB greater than the pL_{Aeq} of either source alone.

Two examples may help to make this clear.

(a) First, consider two separately identifiable and distinguishable noise sources, Source A and Source B, both having steady levels of 70 dB(A). Both the conventional L_{Aeq}'s and pL_{Aeq}'s of each noise source would be 70 . The overall conventional L_{Aeq} would be 73 and the overall pL_{Aeq} would also be 73 , as there are no fluctuations in noise level. However, the psum would be 76 .

(b) Secondly, consider two separately identifiable and distinguishable noise sources, Source C and Source D, both having fluctuating levels such that a peak noise level of 80 dB(A) occurs for 10% of the time. When combined, the peak noise level events do not overlap. The conventional L_{Aeq} of each noise source would be 70 as before, but the pL_{Aeq} of each noise source would be only 60 . The overall conventional L_{Aeq} would be 73 and the psum of the conventional L_{Aeq}'s of each noise source would be 76 . However, the overall pL_{Aeq} would be only 66 , and the psum of the pL_{Aeq}'s of each noise source would also be 66 .

The important point to note is that overall pL_{Aeq} is not the same thing as psum. Overall pL_{Aeq} is a physical descriptor of any noise environment, whereas psum is merely a procedure to account for enhanced annoyance potential due to multiple noise sources.

3.6 Pressure L_{Aeq}, Pressure Sum (pL_{Aeq}, psum)

This procedure attempts to take account of both response differences between noise sources at similar conventional L_{Aeq}'s and the enhanced annoyance potential due to multiple noise sources, when compared to the annoyance potential implied by the energy sum procedure. The procedure is applied in the following way. First, the separately identifiable and distinguishable groups of noise sources must be identified. Secondly, pL_{Aeq}'s must be measured or predicted for each of these separate groups of contributing noise sources. Finally, the separate pL_{Aeq}'s are summed to yield a final scale value which is then taken as the measure of overall annoyance potential of the environment under consideration.

Pressure L_{Aeq}, pressure sum (pL_{Aeq}, psum) is given by:

$$pL_{Aeq}, \text{psum} = 20 \log_{10} \sum_{i=1}^{n} 10^{\frac{pL_{Aeqi}}{20}} \qquad (11)$$

An alternative formula is given below:

$$pL_{Aeq}, \text{psum} = 20 \log_{10} \left[\frac{1}{T_2 - T_1} \sum_{i=1}^{n} \int_{T_1}^{T_2} \left(\frac{p_{Ai}{}^2(t)}{p_{ref}{}^2} \right)^{\frac{1}{2}} dt \right] \tag{12}$$

where $p_{Ai}(t)$ is the A-weighted sound pressure of the i^{th} separately identifiable and distinguishable group of noise sources. It is not a directly measurable quantity in any multiple noise source environment, but is dependent upon the contribution of each separately identifiable and distinguishable group of noise sources.

The pL_{Aeq}, psum procedure does not reflect the physical summation of the contributing noise sources. As such it could only be expected to apply to any single assessment of community noise. The procedure is not necessarily cumulative over many changes in or additions to any particular noise environment. Each new actual or projected noise environment should be reassessed from actual pL_{Aeq} measurements or predictions for each separately identifiable and distinguishable group of contributing noise sources.

The examples given in Chapter 3.5 above should suffice by way of illustration of the procedure, referred to in these examples as the psum of the separate source pL_{Aeq}'s.

3.7 Noise Pollution Level (L_{NP})

The noise pollution level, L_{NP}, was proposed by Robinson [12] as a unified noise index. It was intended to take account of assumed increases in annoyance potential when fluctuations of noise level occur. L_{NP} was defined according to the expression below:

$$L_{NP} = L_{eq} + k\sigma \tag{13}$$

where L_{eq} is the equivalent continuous sound level

σ is the standard deviation of the instantaneous sound pressure level, considered as a statistical time series over the same period as the time interval for L_{eq}

k is a constant which was provisionally assigned as 2.56.

The concept has had limited support [15, 16] but has not been found generally useful and is not used in any Standards or Regulations. This is presumably because fluctuations in instantaneous sound pressure level do not affect annoyance potential in the way that such fluctuations are taken into account by L_{NP}.

Consider a hypothetical noise source having occasional peak noise level events interspersed between periods at a much lower steady background level. As the background level is reduced, the L_{eq} may remain relatively constant, as it is likely to be determined primarily by the peak noise level events. In this situation, reductions in background level will increase the standard deviation in instantaneous sound pressure level, σ, and thus imply increased annoyance potential according to the L_{NP} concept. Greater reductions in background level imply still greater increases in annoyance potential. There rapidly comes a limit where the concept breaks down, as there is every reason to believe that, once the background level has dropped below a certain level, further reductions in background level can have no effect.

Robinson's recent suggested modification to the L_{NP} concept [17] to take account of different rates of change of noise level, do not eliminate this logical flaw in the concept. This flaw may be one of the main reasons why L_{NP} can only be shown to fit certain data sets but not many other data sets. In particular, L_{NP} plainly does not apply to railway noise annoyance potential, a noise source which should be found grossly annoying if the L_{NP} concept were correct.

The pL_{Aeq} concept, described in Chapter 3.4 above, does not suffer from this logical flaw. pL_{Aeq} implies that, in our hypothetical example, reductions in background level will slightly reduce annoyance potential at first and then have no further effect, with further reductions in background level. Background level is taken account of by conventional L_{Aeq} to an extent, providing that the steady background level is within about 10 dB or so of the overall L_{Aeq}, and it is taken account of by pL_{Aeq}, providing that the steady background level is within about 20 dB or so of the overall pL_{Aeq}.

Matschat and Müller [18] devised a consistency criterion which stated that two non-overlapping noises with the same scale value Q and durations t_1 and t_2 should be equivalent to a single noise with scale value Q and duration $t_1 + t_2$. L_{NP} fails this reasonable criterion as any particular value of L_{NP} can be made up of a noise having a low L_{eq} and a high standard deviation, or a high L_{eq} and a low standard deviation. The overall L_{NP} of two consecutive noises having these opposite characteristics will not be related in any obvious way to the L_{NP} of each noise considered separately.

It is readily apparent that the L_{NP} concept is not in qualitative agreement with much of the data considered in this thesis, mainly because of the effect of the steady background level becoming more and more important as it gets lower and lower. Further, L_{NP} is not a convenient scale owing to its failure to comply with Matschat *et al*'s consistency criterion. Accordingly, L_{NP} is given no further consideration in this thesis.

3.8 Response-summation Model

A response-summation model was proposed by Ollerhead [19] to take account of correction factors when using conventional L_{eq}. The overall annoyance potential of a multiple noise source environment can be described by the quantity L_{eff} (overall effective level) which is defined according to the expression given below:

$$L_{eff} = L_{eq} + \sum_{i=1}^{n} D_i \, 10^{(L_i - L_{eq})/10} \tag{14}$$

where L_{eq} is the overall conventional L_{eq}

L_i is the i^{th} source conventional L_{eq}

D_i is the i^{th} source correction factor

This model has the major advantage that the D_i factors associated with each contributing noise source can be evaluated by multiple regression analysis. It is not necessary to evaluate separate dose-response relationships for each contributing noise source. However, the response summation model was formulated only to satisfy the boundary condition that the overall annoyance potential of a hypothetical environment having one very dominant noise source should be the same as the annoyance potential of that noise source alone.

The response summation model is often thought of as being the same as the corrected energy sum procedure described in Chapter 3.3 above. In fact, it is not the same. The response summation model gives different results if the D_i factors are first added to the L_i contributing source L_{eq}'s before the summation according to equation (14) above. If the D_i factors are added in first, then D_i in equation (14) above becomes zero, leaving the corrected energy sum procedure. This exposes a serious logical flaw in the response-summation model which implies that if the response-summation model is correct then the D_i factors do not actually represent the differences between the separate noise source dose-response relationships.

Because of this difficulty, the response-summation model is given no further consideration here.

3.9 Powell's Summation and Inhibition Model [3]

Powell proposed a model to predict the annoyance potential of multiple noise sources based on the summation of mutually inhibited annoyances of the contributing noise sources. This model took account of Stevens' [20] theory of power group transformations in the presence of inhibiting stimuli. Hence the model necessarily assumes that Stevens' general psychophysical power law is valid.

Powell's model is open to criticism on several counts. First, there are much simpler models available which fit empirical data as well as Powell's model, as will be shown in following sections of this thesis. Secondly, Powell's model requires the experimental determination of a number of constants. Values for these constants must either be assumed, or much experimental work would be required in order to determine them with any precision. Thirdly, Powell's model is actually expressed by three formulae, appropriate to different degrees of inhibition. These formulae are discontinuous, leading to "cusps" in any graphical plots of the effects of the model. These cusps are unlikely to be representative of actual response and for this reason Powell's model may only be approximate in the regions of the cusps. Fourthly, Powell's model necessarily assumes that conventional L_{eq} is an adequate descriptor of the annoyance potential of any single noise source but not of the annoyance potential of any multiple noise source. This is contradictory without an adequate definition of what constitutes a single noise source as opposed to a multiple noise source. Finally, Powell's model does not explain the differences in annoyance reaction between different noise sources at the same conventional L_{eq} levels.

Powell produced a graphical plot showing an increment of annoyance potential for multiple noise sources over and above the annoyance potential predicted by overall corrected conventional L_{eq}. Despite the above criticisms of Powell's model it is nevertheless possible to apply the model purely as an empirically derived correction to overall conventional L_{eq}. None of the above criticisms actually rule out Powell's model as a plausible model. Accordingly, Powell's model is further considered in this thesis, and is illustrated in Figures 3.2, 3.3 and 3.4, along with the other considered models. The mathematical expression of Powell's model is not given here on the grounds that it is complex, and Powell's model is not supported by the evidence discussed in the following chapters.

It will be shown in Chapter 3.11 below, that Powell's model is not very different from the psum procedure. The assumption of the overall annoyance potential of two contributing noise sources being related to the sum of their average r.m.s. sound pressures is much simpler than the power law transformation assumptions made in the development of Powell's model.

3.10 Mean Annoyance Level $\bar{Q}$ (Störindex)

This noise scale is used in German and Austrian noise control procedures. It is discussed here because it is a special case of the generalised expression written in section 3.4 above, equation (7). It could be thought of as an intermediate scale between conventional L_{Aeq} and pressure L_{Aeq}. Rathe and Muheim [21] give the following expression:

$$\bar{Q} = \frac{10q}{3} \log_{10}\left(\frac{1}{T} \sum_{k} 10^{3Q_k/10q} . t_k\right) \qquad (15)$$

where $\bar{Q}$ is the noise exposure scale value

Q_k is the maximum sound level of event k

t_k is the duration of event k

q is a weighting parameter

T is the time interval of interest.

$\bar{Q}$, the noise exposure scale, is defined as the constant noise level which leads to the same total noise exposure over a time interval T as the sum total of all events during the time interval T considered. It is not a true average sound level as there is no integration of time varying instantaneous sound levels within each event k, but it would normally be a close approximation to a true integration. The weighting parameter, q, is 4, thus implying that a doubling of duration is equivalent to a 4 dB increase in noise level for non-overlapping noises. This value appears to have been chosen on the basis of a perusal of the literature pertaining to the effects on annoyance or noisiness ratings of increases in noise event duration [22, 23].

A q value of 4 corresponds to a k value of 13.3 in equation (7) in section 3.4 above. Such a k value is intermediate between k values of 10 for conventional L_{Aeq} and 20 for pressure L_{Aeq}. It is doubtful whether any empirical test could be devised which could actually distinguish between the $\bar{Q}$ scale and either conventional or pressure L_{Aeq} with any high degree of statistical certainty. Accordingly, the $\bar{Q}$ scale cannot be rejected from consideration as a potential unified scale on the basis of empirical tests. However, it is possible to approach the matter from a different direction, as below.

The weighting parameter q was assigned a value of 4 on the basis of a perusal of the literature available at the time. It must be recognised that that literature was not consistent. Were the pL_{Aeq}, psum procedure to be adopted, this would imply that a change of weighting parameter q would be appropriate, to a new value of 6. Then the $\bar{Q}$ scale would be consistent with pL_{Aeq}.

Therefore the $\bar{Q}$ scale is not considered further in this thesis as a candidate unified scale. Rather, it is considered as a noise scale which is open to modification in the light of the results of this investigation.

3.11 A Comparison of Models

Certain available models have been rejected on the basis of the above discussion, and other models remain for consideration. The models to be considered are:

Conventional L_{Aeq} and corrected energy sum;

Pressure L_{Aeq} and pressure L_{Aeq}, pressure sum;

Powell's model.

pL_{Aeq} has been proposed as an alternative to conventional L_{Aeq} in order to eliminate correction factors to contributing noise source levels. The psum procedure has been proposed as an alternative to the energy sum procedure in order to account for the enhanced annoyance potential of multiple separately identifiable and distinguishable contributing groups of noise sources.

The considered models are illustrated in Figures 3.2, 3.3 and 3.4, in respect of the predicted annoyance potential of multiple noise sources. These figures do not take account of the differences between conventional L_{Aeq} and pL_{Aeq}, as scales for single noise sources. That difference has been illustrated in Figure 3.1. Rather, Figures 3.2, 3.3 and 3.4 show the different effects of the energy sum and psum procedures and the Powell model, all compared against overall conventional L_{Aeq} at three values of correction factor for the first of the two noise sources considered.

Figure 3.2

Multiple noise sources   D of source 1 = 10dB

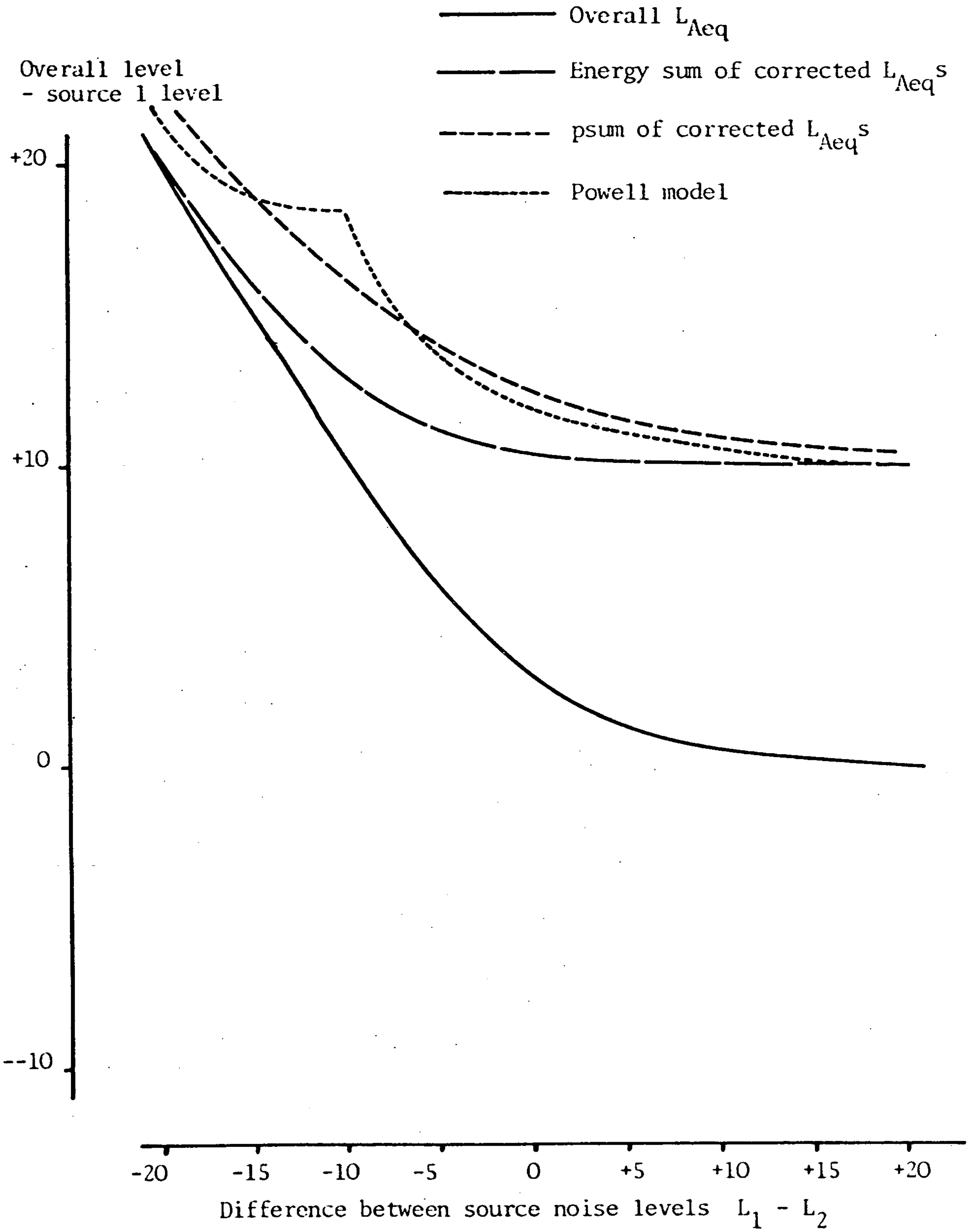


Figure 3.3

Multiple noise sources D of source 1 = 0

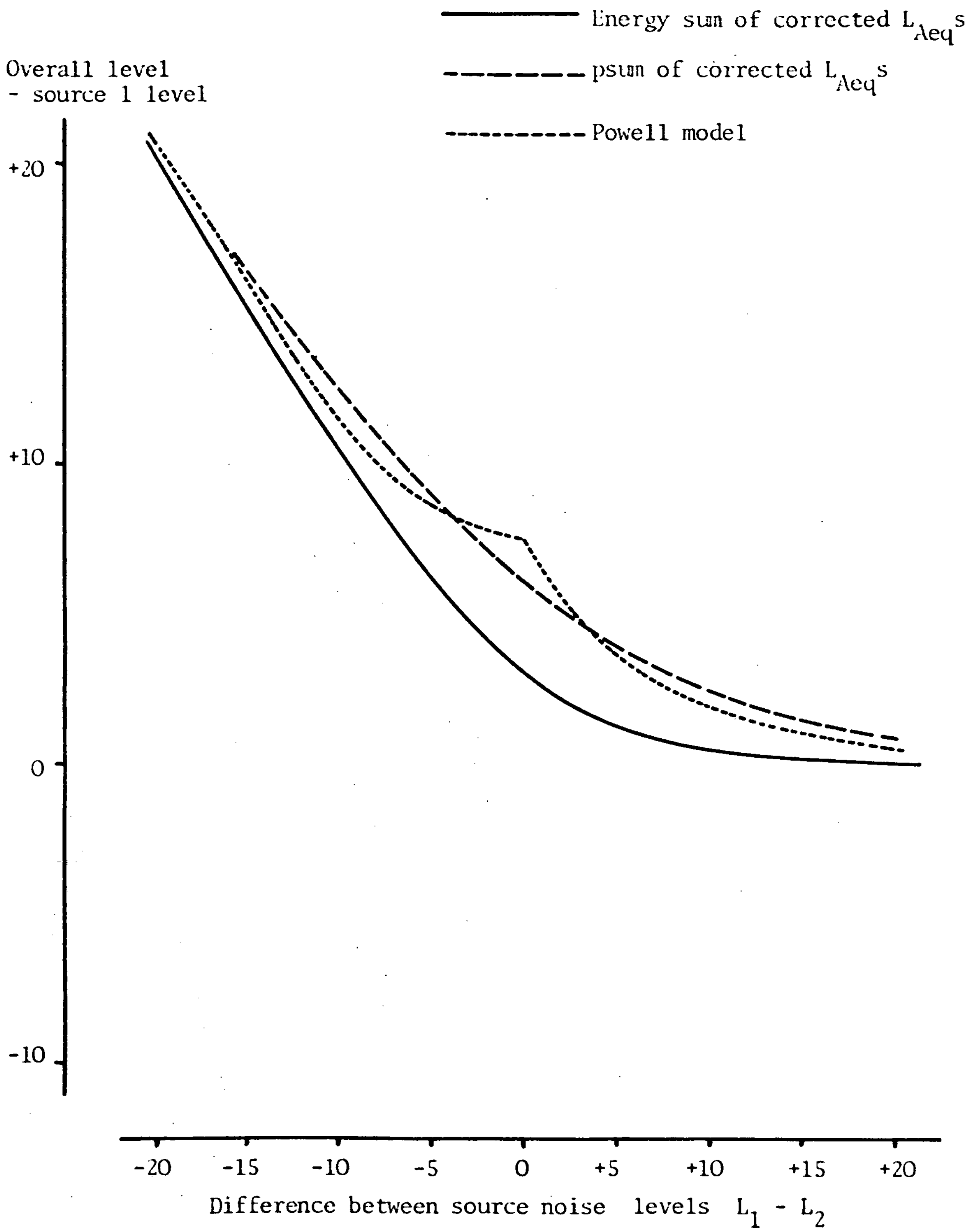
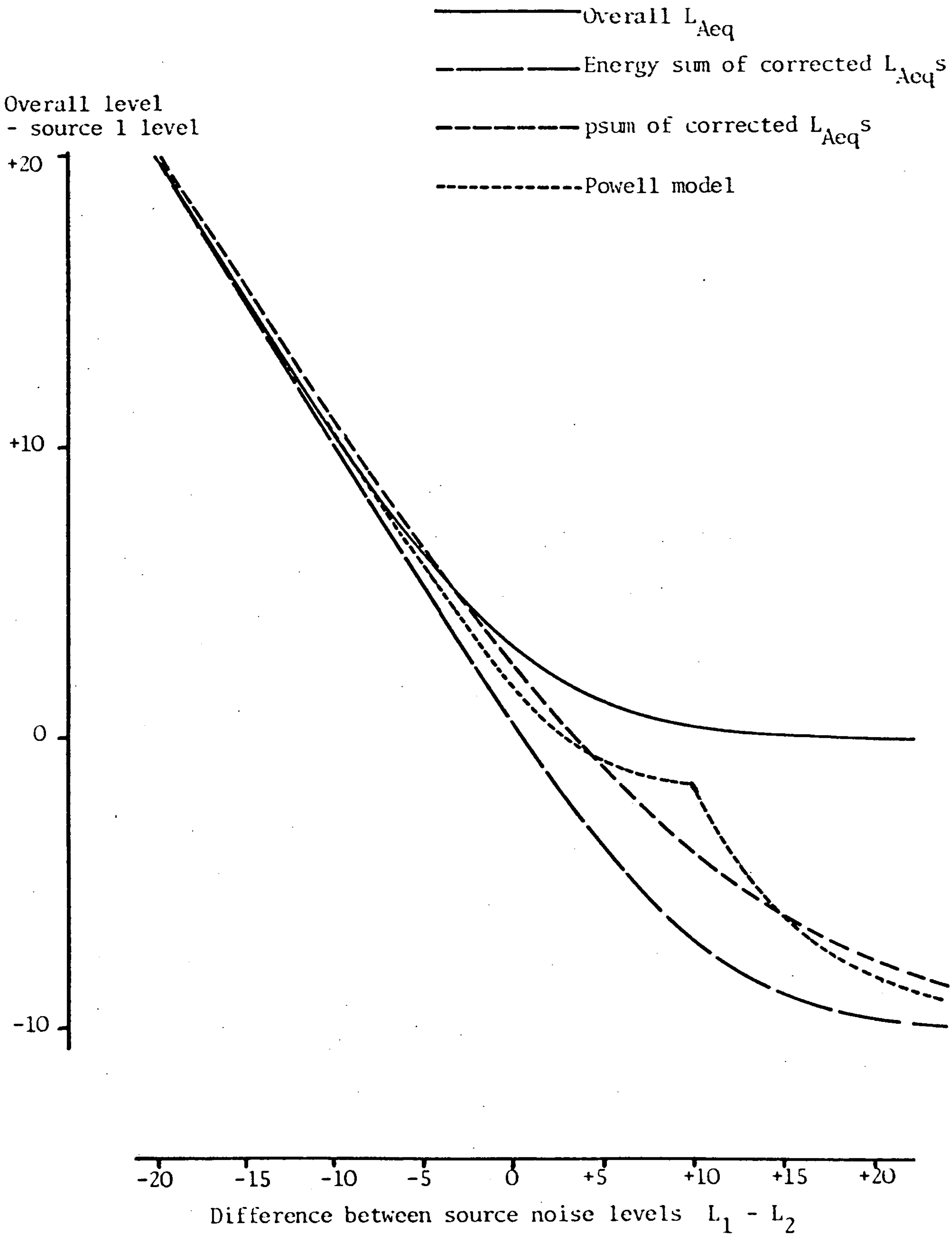


Figure 3.4

Multiple noise sources D of source 1 = -10dB



It is apparent that first, large errors may ensue if correction factors (or pL_{Aeq}) for single noise sources are not taken into account; secondly, the energy sum and psum procedures differ by a maximum of 3 dB at the point where the noise sources are subjectively equivalent; thirdly, that the Powell model (corrected to take account of subjective differences) is very little different from the psum procedure. The psum procedure follows the mean trend of the Powell model without the cusps.

3.12 pL_{Aeq}, psum and the Physical Correlate Theory

pL_{Aeq}, psum does not normally reflect the physical summation of two contributing noise sources. Rather it reflects the psychophysical phenomenon that the psychological summation of response to multiple noise events or multiple noise sources may not follow the physical summation of those events or sources.

In terms of the loudness of short duration sounds or susceptibility to noise induced hearing loss, it is possible that the ear responds either to average r.m.s. pressure, or to average intensity, or to a combination of both. However, these matters are outside the scope of this thesis. A factor of greater immediate relevance is a consideration of the increase in noise level appropriate to a doubling of perceived noisiness, or annoyance, and the true meaning of such concepts.

Conventional L_{Aeq} implies that a doubling of duration of events, or a doubling of numbers of events or sources, is equivalent to a 3 dB increase in noise level. pL_{Aeq} implies that a doubling of duration, or of noise events or sources, is equivalent to a 6 dB increase in noise level. There may be a conceptual link between these doublings of duration, noise events or sources, and the doublings of perceived magnitude of classical psychophysics.

Warren [24] proposed the physical correlate theory of judgements of sensory intensity. Judgements were considered as "learned estimates of physical magnitudes correlated with changes in sensory stimulation rather than built-in neural functions". According to Warren's theory, perceptual magnitudes have no absolute meaning in themselves, i.e., there is no internal perceptual continuum having magnitude properties. Warren hypothesised that perceptual magnitudes derive their meaning only in terms of the stimulus intensities that they are associated with. Hence a doubling of loudness, for example, only has meaning in terms of some learned physical correlate such as a halving of apparent distance.

Warren, Sersen and Pores [25] carried out experimental tests on half-loudness and double distance judgements and satisfied themselves as to the usefulness of the physical correlate theory. However, the theory predicts that a doubling of loudness is equivalent to a 6 dB increase in noise level (assuming, of course, point sources, spherical spreading, no excess attenuation, and no undue influence of loudness constancy effects). Stevens [26] maintained that 10 dB (later 9 dB [27]) was an appropriate increase in noise level for a doubling of loudness. Warren considered that Stevens' higher value for a doubling of loudness could have been due to experimental artefacts such as the avoidance of reverberation in headphone and anechoic room listening tests, and stimulus range and context effects (see, for example, Poulton [28]).

Accordingly, Warren carried out a set of very cumbersome experiments [29] using only one judgement of loudness by each of many hundreds of naive subjects, relative to a standard sound. Subjects could switch between the comparison and standard sounds at will, for as long as they wished, before making a judgement. These experiments supported the physical correlate theory.

How is the physical correlate theory related to the pL_{Aeq}, psum procedure? It is reasonable to relate a doubling of numbers of events or sources to a doubling of reported annoyance or annoyance potential. It may still be reasonable to relate a doubling of duration to a doubling of annoyance potential. So far, the perceptual meaning of "doubling" has been defined operationally, rather than measured empirically. If the physical correlate of a doubling of annoyance potential is a halving of source to receiver distance, all other things being equal, then under most circumstances a doubling of annoyance potential would occur for an increase in noise level of about 6 dB. This logic would then enable a doubling of duration, events or sources to be equated with a 6 dB increase in level. This 6 dB increase is consistent with the concept of pL_{Aeq}, psum.

The physical correlate theory suggests that the appropriate increase in physical level for a doubling of annoyance potential is learnt on the basis of experience. This means that under typical outdoor conditions with point sources, normal attenuation rates, and no screening, 6 dB per doubling would be appropriate. Under different conditions, for example road traffic noise from a busy road, noise levels attenuate at less than 6 dB per doubling of distance and so lower physical correlates would be appropriate. For noise sources normally heard at relatively large distances, for example aircraft noise, noise levels attenuate at more than 6 dB per doubling of distance and so higher physical correlates would be appropriate.

The generalised expression for the A-weighted noise measure, X was given above (Chapter 3.4, equation (7)).

$$X = k \log_{10} \left[\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} 10^{\frac{L_A(t)}{k}} \, dt \right]$$

A physical correlate of 3 dB per doubling of distance implies a k value of 10, i.e., conventional L_{Aeq}. A physical correlate of 6 dB per doubling of distance implies a k value of 20, i.e., pL_{Aeq}. A physical correlate of 10 dB per doubling of distance implies a k value of 33. Any k value greater than 20 implies averaging in terms of some root of the r.m.s. sound pressure.

The physical correlate theory provides a basis on which to justify any particular k factor, dependent upon the conditions under which the noise in question is normally heard. The proposal made in this thesis for pL_{Aeq}, psum is made in the belief that it is a superior alternative to conventional L_{Aeq}. That does not mean that it is the only alternative. It may be that the best correlation between noise exposure levels and response could be obtained in any particular circumstances with k factors other than 20. These k factors other than 20 would imply non-integer power r.m.s. sound pressure averaging.

However, the blanket adoption of a k factor of 20 in any unified scale could well be a satisfactory compromise. It is very difficult to conceptualise any satisfactory annoyance potential assessment procedure that had variable k factors dependent upon noise source. On the basis of the limited amount of data examined in this thesis, a k factor of 20 certainly seems to be more appropriate than a k factor of 10.

4. EXPERIMENTAL TECHNIQUES

4.1 Introduction

This chapter describes the simulated domestic living room listening facility in which volunteer experimental subjects were exposed to tape-recorded simulations of community noises. The self-completion questionnaires which were used to obtain mean reported annoyance ratings are described. The projection technique which was used to encourage experimental subjects to relate their annoyance ratings to their own experience at home, is described. A major compromise in experimental design is the trade-off between session length and number of treatments. Session length is discussed.

4.2 The Laboratory

The simulated domestic living room listening facility at ISVR (see Appendix A) was used for all the experimental work carried out by the author of this thesis. The purpose of this laboratory is to enable experimental subjects to relax and to feel as "at home" as possible whilst being exposed to a range of different levels of tape-recorded noises. The laboratory was initially set up by Rice [30], to whom the concept of a simulated domestic living room must be attributed. Several modifications to the sound reproduction systems were made by the author, in order to improve the fidelity of the simulation.

The laboratory is furnished as a typical domestic living room with four comfortable chairs, bookcases, tables, a television, a coal-effect fire, pictures on the walls, a table lamp, a standard lamp and a carpet. Loudspeakers are concealed in the walls and ceiling, although, of course, no attempt is made to actually deceive experimental subjects. Three stereo channels are normally provided. Tape-recordings can be reproduced through the ceiling loudspeaker arrays in order to simulate overflying aircraft, and through the two pairs of wall loudspeakers in order to simulate moving ground noise sources such as road traffic, trains, airport ground noise, etc.

Every attempt was made to obtain the maximum realism in the tape-recorded simulations. Accordingly, only the highest quality equipment was used, with dBX type tape noise reduction systems. Effective signal-to-noise ratios in excess of 100 dB are achievable with these systems but in practice the limit on signal-to-noise ratio is defined by the difficulty of finding low background noise locations at which to make the master tape recordings. Whenever possible, the master tape-recordings were made at locations which closely approximated the simulations in the laboratory. This was to ensure that the duration characteristics and frequency spectra of the simulations were appropriate to the reproduced noise levels. This technique is a significant improvement over the traditional technique of merely varying the level of recordings made close to the noise sources.

4.3 Questionnaires

As mentioned in Chapter 2.1, mean reported annoyance was used as the dependant variable. This was measured by means of a self-completion questionnaire administered immediately after each exposure or session in the laboratory. These questionnaires included items of the form:

(a) How annoying are these noises?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

and of the form:

(b) Would you say you are 'highly annoyed' or not by these noises?

Yes, highly annoyed .... ☐

No .... ☐

Normally, these items would be repeated on the same questionnaire form but reworded in order to encourage the experimental subjects to make *projections* to their own home environments. A typical form of words would be:

Now thinking about when you are at home, indoors, in the evenings:

How annoying would these noises be in your own living room, in evenings?

The actual questionnaire forms used in each experiment are reproduced in the relevant appendices which give technical details of those experiments. It is appropriate here to discuss the philosophy behind the particular choice of scaling technique used in the work.

The 0 to 9 numerical category scale of reported annoyance was developed by Rice [14] as a convenient and reasonably reliable measure. The various alternative scaling techniques have been covered in great detail by other authors [31, 32] and mere repetition of their arguments would not be appropriate here. It should be noted that agreement has not been reached in the scientific community as a whole on any preferred scaling technique. This may be partly due to disagreements concerning the objectives that scaling is intended to fulfil.

In this case, the 0-9 numerical category scale is considered merely as an instrument to enable relative annoyance ratings for each exposure treatment to be obtained, in comparison with all the other relative annoyance ratings for the other exposures within any experiment. Stevens and others [33, 34, 35, 36] have debated the existence of an underlying perceptual magnitude scale, which may or may not be related to the logarithm or some power of the stimulus intensity. However, purely operational treatment of the mean reported annoyance ratings enables such underlying philosophical questions to be disregarded. As such, the 0-9 numerical category scale has been assumed to be an equal interval scale merely in terms of the corresponding increments of stimulus intensity, and not necessarily in terms of any underlying perceptual magnitude scale. Noise assessment research cannot wait for a psychophilosophical consensus to be reached.

The yes/no high annoyance dichotomy was included in order to be able to determine the percentages describing themselves as highly annoyed (see, for example, Schultz [1]). Percent highly annoyed is not a powerful measure from the statistical point of view, but it does have the advantage of a more obvious immediate meaning when compared to any particular rating on a numerical category scale. Results on these yes/no high annoyance questions were not used directly in the statistical comparisons of the different noise scales but rather as supporting information.

The home projection technique attributable to Rice [30] and adopted in this work is a difficult task for experimental subjects. Nevertheless, experimental subjects are always prepared to attempt the projection. The results of the laboratory field calibration experiment (Chapter 5) tend to support the value of the projection technique. Of course, it is likely that individual subjects will tend to either over- or underestimate how they would respond under the same conditions at home. The taking of group means cancels such individual bias, leaving an overall effect which is taken into account by the empirically derived 18 dB attenuation factor discussed in Chapter 5.

4.4 Session Length

The session length is the length of time for which volunteer subjects are exposed to tape-recorded noises in the simulated domestic living room listening facility before making each annoyance judgement. Each session, or exposure, defines one treatment in the experimental design and represents a particular degree of noise exposure in the field. Under normal circumstances a set of sessions or exposures would be chosen in order to cover the range of noise exposures of interest in order that simulated dose-laboratory response relationships might be established.

A major compromise in the experimental design is that between session length and the number of treatments. Obviously, a one-minute session length is too short to enable subjects to distinguish between treatments having two or four events per hour. On the other hand, it would be unreasonable to expect volunteer subjects to cooperate in experiments for more than two or three hours on each visit to the laboratory. Therefore, the choice of the shortest session length that will still give useful results is important in order to ensure that each experiment includes the maximum number of treatments for each group of subjects.

Unfortunately, it is very difficult to conceptualise any simple experiment that would investigate the ideal session length properly, since if session length is varied, then stimulus duration is introduced as another variable. The experiments carried out for this thesis used ten-minute and five-minute session lengths, for the following reasons: first, it was assumed that if the session length was in fact too short, then any errors would be uniform throughout the experiment and could thus be ignored from the point of view of the relative ranking of treatments; secondly, the number of events from each noise source was kept constant, such that at least two events from each noise source occurred in each session; and thirdly, there was no evidence in the literature that longer session lengths were necessary.

There are precedents in the literature for session lengths ranging from 7½ minutes to 2 hours [15, 30, 38, 39, 40, 41, 42, 43, 44, 45]. Borsky [38] found no differences between reported annoyance ratings to aircraft noise sessions having three, four or five flyovers per session, and concluded that three events per session was adequate. Rylander, Sjostedt and Bjorkman [42] found that 2-hour sessions led to fatigue and concentration difficulties amongst their subjects. Other authors do not comment on the effects of the session length that they actually used.

Fuller and Robinson [45] concluded that in experiments where the reaction of a subject to the total noise environment is to be measured, then exposure times (session lengths) of greater than 15 minutes are advisable. It is possible to show that the results of Fuller and Robinson's experiment are not applicable to the present work on the basis of fundamental differences in objectives and techniques.

First, Fuller and Robinson used traffic noise at a constant level of 85 dB(A) which is fully some 25 dB higher than normal experience indoors in the noisiest of dwellings. Secondly, the subjects were kept fully engaged at pencil and paper tasks whereas in the present work, subjects were allowed a free choice of relaxation, reading, conversation, or private work. Thirdly, they actually used a constant session length of one hour and presented their noise for either the last 5 minutes, the last 15 minutes, the last 30 minutes, or the whole hour. Their subjects were specifically requested to base their judgements on the last 5 minutes of each session, which of course, was in noise for all treatments. In the present work, subjects were expected to make overall judgements of complete sessions. Fourthly, the home projection questionnaire item was discarded from their analysis because that item showed signs of saturating the scale, presumably because of the excessive noise level.

Fuller and Robinson also found that direct ratings for the four noise duration treatments were all significantly correlated together except for the 5 minute and 60 minute treatments. They assumed that the 60 minute treatment gave the "best" results and then concluded that there was something odd about the 5 minute treatment. However, it is possible to show that the 5 minute and 30 minute treatments had the highest intercorrelations with the other treatments and that the 60 minute treatment had the lowest. This would imply that the 60 minute treatment was, in fact, the odd man out.

In addition, these authors noted a trend for direct ratings to increase with noise on-time. The increase was barely significant and was not linear. However, there was no basis for assuming that either the higher or the lower direct ratings were the "correct" scores. There was a low correlation between direct ratings and semantic differentials for the 15 minute treatment. Bearing in mind the list of semantic differentials used in the study, it is difficult to place any confidence in the semantic differential scores, when compared with the direct rating scales used.

Thus it can be reasonably concluded that Fuller and Robinson's study does not lessen the validity of the 10 minute and 5 minute session lengths used in the present work.

4.5 Session Length Pilot Study

This pilot study was carried out in order to investigate subjects' own preferred session length when exposed to road traffic noise recordings in the laboratory. University Open Day (1977) visitors were recruited for the experiment and the instructions shown at Appendix B were read out to them. They were then ushered into the simulated domestic living room, while a recording of road traffic noise was being reproduced. They were instructed to use the questionnaire shown at Appendix B to record their annoyance and to take as much time as they liked in order to select an annoyance rating. As soon as they had made a response they were asked to leave the room and the time they had spent in the room was noted.

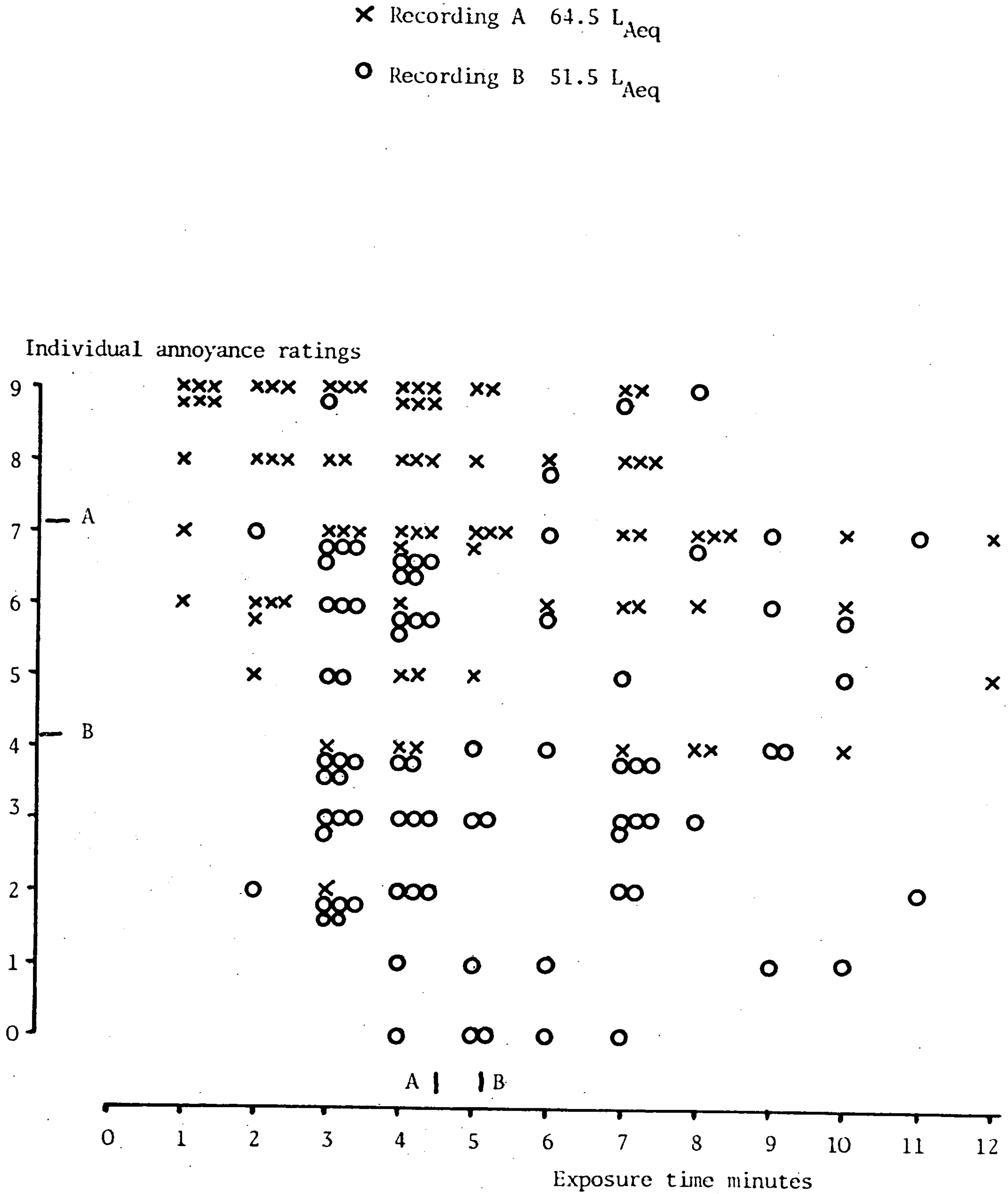
Two road traffic noise recordings were used, recorded at 5 m and 100 m from a busy intersection in Southampton. These recordings were reproduced at L_{Aeq}'s of 64.5 and 51.5. The recordings were alternated between successive groups of subjects.

The results are shown at Figure 4.1. This figure illustrates the wide spread of individual responses typical in this type of work. The mean reported annoyance ratings for the 64.5 L_{Aeq} and 51.5 L_{Aeq} recordings were significantly different ($p = 0.001$). There was a non-significant trend for subjects to spend less time in the noisier recording. There was no relationship between exposure time and annoyance ratings, although a non-significant trend is apparent from Figure 4.1, for subjects who spent less time in the noisier recording to report higher annoyance.

The results of this pilot study implied that, for road traffic noise recordings, relatively short session lengths of only a few minutes would be perfectly adequate for meaningful annoyance ratings to be obtained. Annoyance ratings were much more sensitive than voluntary exposure times in differentiating between the two road traffic noise levels used in the experiment.

Figure 4.1

Session length pilot study



5. LABORATORY-FIELD CALIBRATION

5.1 Introduction

Mean reported annoyance ratings in the laboratory have to be related to annoyance ratings in the field in order to be of value. It is reasonable to assume that the same relative ranking of noise exposures applies in the laboratory as in the field. It is of great interest to determine whether or not the annoyance ratings obtained in the laboratory are the same as those obtained in the field in an absolute sense. Unfortunately, there are a number of possible effects which could be influencing the laboratory mean reported annoyance ratings in comparison with field annoyance ratings. These are:

(a) Subjects could be using annoyance rating scales differently in the laboratory and in the field.

(b) Subjects could tend to over- or underestimate their projected annoyance ratings from the laboratory to their own homes in comparison to their actual annoyance ratings in the field.

(c) Measurements of noise levels in the field are usually made outdoors for purely practical reasons. Measurements of noise levels in the laboratory are made indoors by definition. The typical outdoor/indoor attenuation of dwellings is of great importance in selecting the appropriate level at which to reproduce tape recorded noises in the laboratory.

It is necessary to assume that effect (a) does not apply, i.e., that people use the annoyance rating scales in the same way in the laboratory and in the field. Effects (b) and (c) could be interactive in that laboratory-to-field projection over- or underestimation might depend upon the particular conditions being simulated, (for example, with respect to open or closed windows). It was not possible to separate out effects (b) and (c) empirically and therefore an experiment was carried out in order to determine the combined effect of (b) and (c) together.

5.2 Laboratory-to-Field Projection Errors

Perceptual constancy

Perception is organised, in order that any person's surroundings might appear relatively stable, or behave in an orderly fashion, regardless of constantly changing and often conflicting sensory information. For example, people do not appear to shrink in size as they walk away from an observer, even though the size of the retinal image shrinks. In relation to the perception of sound there is a tendency for subjective impressions of noise sources to remain constant even though the actual loudness at the ear might change because of changes in distance, or other intervening attenuation factors. These effects are examples of perceptual constancies.

This effect is of considerable importance in offering a theoretical explanation of the reason for people's apparently greater sensitivity to noise indoors than outdoors [46,47,48]. Robinson, Bowsher and Copeland described the effect as a "projection effect" and suggested that it was due to their subjects making an unconscious allowance for the typical sound reduction of building structures when inside. In relation to this effect they further noted that noises from distant aircraft flyovers were rated more harshly than noises from nearby aircraft flyovers. It is interesting to note that the difference in dB terms between outdoor and indoor noise levels to result in the same annoyance ratings outdoors and indoors was usually less than the actual sound reduction of the buildings used in the various tests. This observation is consistent with the perceptual constancy theory, which is a tendency only and does not always completely compensate for changes in sensation level.

Kryter [49] suggested an alternative explanation for the "projection effect". He suggested that it was due to indoor activities being more sensitive to noise interference than outdoor activities, thus leading to a lower threshold of acceptability indoors. This explanation would require, for example, that outdoor conversations are conducted at speech levels some 15-20 dB higher than indoors. This does not take place and implies that Kryter's suggestion is unlikely to be the correct explanation.

Perceptual constancy can operate to a greater or lesser extent. On the one hand, a constant output sound source could be judged equally noisy regardless of its distance from the listener and thus its received noise level. On the other hand, a sound source could be judged equally noisy at different distances from the listener if its sound output were adjusted to give a constant received noise level. Which of these two situations applies (or any intermediate situation) depends upon the amount of information available to the listener, and upon the particular noisiness rating procedure adopted.

The relevance to the laboratory experiment is this. It is not sufficient merely to reproduce field indoor noise levels accurately in the laboratory. It is also necessary to reproduce the character of the noises accurately with respect to apparent source distances and apparent sound reduction due to the building structure.

Complete constancy implies that any sound would be rated exactly the same whether heard outdoors, indoors and attenuated by the building structure, or indoors in the laboratory at the same level as it would be heard indoors in the field. If constancy applies to a different extent in the laboratory to indoors in the field then different annoyance ratings could be expected between the laboratory and indoor field situations, all other things being equal. The only way to reduce the likelihood of constancy operating to a different extent in the laboratory to indoors in the field is to make the simulations as accurate and realistic as possible. This philosophy was followed in all the experimental work carried out for this thesis.

In particular, the use of a simulated domestic living room with a representative reverberation time is much to be preferred over anechoic room listening tests. Even the use of headphones, with perhaps binaural recordings, is likely to alter the apparent distance characteristics of the simulated noise sources, in comparison with reproduction through high quality loudspeakers into a realistic environment.

Concentrated attention effects

Research techniques using questionnaires necessarily concentrate subjects' attention on to any noise being rated. This concentrated attention could have the effect of increasing the annoyance ratings above the noise's true annoyance potential. This effect is guarded against in field surveys by concealing questionnaire items of interest among a number of other questionnaire items such that respondents would not become aware of the true purpose of the questionnaire until a considerable portion of the questionnaire had been completed. However, there is evidence available from a recent survey of response to railway noise [2] that such concealment of purpose has no effect. Fields and Walker compared the results obtained from a dissatisfaction rating scale near the beginning of their questionnaire with the results from an identical dissatisfaction rating scale near the end of their questionnaire. They found no difference.

There is another possible effect of concentrated attention in field surveys. This is that source specific annoyance rating scales might in certain circumstances overstate the importance of that noise source within the context of respondents' overall reactions to their environment as a whole. The major noise surveys that have been carried out in the U.K. [2, 50, 51, 52, 53, 54] have tended to concentrate on source specific annoyance rating scales and did not simultaneously attempt to measure the importance of those topics to respondents. For example, aircraft flyovers might well be judged very annoying *when they occur* but might nevertheless be unimportant in an overall context because the events occur infrequently. This point is crucial to a reconciliation of the pL_{Aeq} concept with certain field survey data concerning responses to aircraft noise and road traffic noise. It will be returned to in the discussion in Chapter 7.

Concentrated attention in laboratory studies can be assumed to be unimportant in terms of relative rankings of treatments within any experiment but may be important in an absolute sense. It is partially guarded against in the laboratory by using questionnaire items relating both to laboratory experience and to projections to the home environment. These items are explained to subjects by pointing out that they might feel that they would get used to noises at home that they might find annoying in the laboratory, or conversely, that they might find noises at home annoying that are acceptable in the laboratory because they know they do not have to live in the laboratory.

In relation to multiple noise source laboratory exposures, the noise sources are not identified specifically on the questionnaires. Subjects are asked for their overall reactions. In this way, the relative contributions to overall annoyance from different noise sources can be assessed.

Nevertheless, there might still be an overall concentrated attention effect, which cannot be separated from the effect of outdoor/indoor attenuation, in terms of laboratory-field calibrations. Fortunately, it is not necessary to separate out these effects in order to achieve laboratory-field calibration.

5.3 Outdoor/Indoor Attenuation

The sound reduction of typical dwellings to community noise is of great importance in selecting appropriate levels at which to reproduce indoor noise levels in the laboratory. There is a general consensus that the difference in dB(A) noise levels between outdoor facade measurements and indoor room centre measurements will normally be in the range from 10 to 25 dB dependent upon individual circumstances and whether or not the windows are open for ventilation. The higher sound reductions achieved by fitting special windows and other measures need not concern us here.

The sound reduction of typical dwellings depends on the type of windows fitted and whether or not they are opened for ventilation, on the area of the windows in relation to the areas of the building envelope, on the internal acoustics of the room, and on the angle of incidence of the noise source to the windows. Attenuations in terms of dB(A) levels further depends on the frequency spectra of the noise sources as all structures have differing attenuations at different frequencies.

There are a limited number of reports available [55-60] which suggest open window attenuations of from 10 to 17 dB on A-weighted levels and closed window attenuations of from 19 to 24 dB on A-weighted levels, for typical dwellings and aircraft and road traffic noise sources. These attenuation ranges are too wide to define the appropriate levels at which to reproduce indoor noise levels in the laboratory. Accordingly, a limited number of measurements were made in dwellings occupied by participants in the laboratory-field calibration study, described in Chapter 5.4, below. These measurements were of outdoor-indoor attenuation to road traffic noise.

It is not a simple matter to obtain the high degree of cooperation required from local residents as outdoor/indoor measurements necessarily involve gross intrusion into the home, with cables being run out through side windows and under doors. Moreover, in several dwellings where consent was obtained, the data was rendered useless by a disinclination of the residents to avoid noisy activities for a long enough period. Eventually, worthwhile measurements were obtained at four representative dwellings. The outdoor/indoor attenuation was defined as the difference in L_{Aeq}'s due to road traffic noise at microphone positions at 1 m from the facade and approximately in the centre of the front ground floor principal room. Microphone heights were at the standard 1.2 m. Extended measurements at the author's own premises demonstrated that the attenuation in terms of L_{Aeq} closely matches the average attenuation to individual peak levels (A-weighted) when great care is taken to exclude extraneous noise from affecting the indoor data.

The mean attenuation for open windows was 18 dB (range 17 to 19 dB) and for closed windows was 23 dB (range 20-26 dB). In terms of linear (non-frequency weighted) levels the attenuations were less. For these purposes, an open window was defined as having one casement or sash opened by 10-12 cm. This was considered to be a typical amount by which windows are normally opened for ventilation purposes. At first sight, 18 dB might appear to be more attenuation than one might expect through an open window. However, moving sources are only opposite the opening for a small proportion of the time that the noise event is audible within the room. An open window would not be expected to give 18 dB attenuation against a stationary noise source opposite the opening.

18 dB attenuation for open windows and 23 dB attenuation for closed windows was taken as a guide to the typical attenuations against road traffic noise, for dwellings of the types included within the laboratory-field calibration study.

5.4 Pilot Studies

Two further pilot studies were carried out in order to take advantage of University Open Day (1978 and 1979) visitors in helping to resolve certain methodological questions. The first pilot study (1978) was intended to investigate the effect of simulated indoor open window or indoor closed window conditions on mean reported annoyance ratings. The second pilot study was intended to investigate the effect of simulated indoor open window or outdoor facade conditions, on mean reported annoyance ratings. Both studies used road traffic noise. The self-completion questionnaires used are shown at Appendix C.

The open or closed window pilot study used two road traffic noise recordings, made at 5 m from a road with occasional fast vehicles, and at 30 m from a road with heavy semi-congested traffic flows. The measured L_{Aeq}'s at the two recording positions were within 2 dB. These recordings were reproduced at the noise levels shown in table 5.1. With hindsight, it is reasonable to assume that the open window condition L_{Aeq}'s were too high for realistic simulations. The levels were chosen on the assumption that open windows would have hardly any attenuation. This assumption was incorrect - see Chapter 5.3 above, and Chapter 5.5 below.

The open window simulation was made without frequency response shaping. The closed window simulation was made with a fall-off in response at the higher frequencies. A dummy openable window in the simulated domestic living room was demonstratively opened and closed to coincide with the open and closed window simulations and the difference was further reinforced in the questionnaire wording. Open Day visitors volunteered at random and were first instructed in the task and then shown into the simulated living room in groups. Each group was exposed to an open and a closed window condition according to a complete factorial design for open/closed windows, order, and road traffic noise recording. Each exposure treatment lasted for four minutes only in order not to take up too much of the visitor's time.

The mean reported annoyance ratings for each exposure treatment are shown at table 5.2. 127 subjects took part, each subject rating an open and a closed window condition. The difference in mean reported annoyance ratings between the two tape recordings was significant (0.1%)

under the open window condition but not under the closed window condition. The difference in mean reported annoyance ratings between the open and closed window conditions was highly significant for both tape recordings. There was a significant order effect on the open window conditions but not for the closed window conditions.

The highly significant difference between mean reported annoyance ratings between the open and closed window conditions could have been due to any of the following reasons:

(a) Subjects made reported annoyance ratings on the basis of the absolute noise level in the simulated living room without regard to window condition cues.

(b) The open window condition was simulated at too high noise levels.

(c) Subjects may have had difficulty distinguishing between the intended questionnaire projection from the laboratory conditions as experienced and the possible misinterpretation of a projection to home environments having those conditions.

Accordingly, the findings of this pilot study could not be unequivocally interpreted.

The indoor or outdoor conditions pilot study (1979) was carried out after the laboratory-field calibration study (described in Chapter 5.5 below). The 70 L_{Aeq} outdoors road traffic noise tape recording from that study was reproduced at levels of 70 L_{Aeq} and 52 L_{Aeq} in the simulated living room in order to simulate indoor and outdoor conditions. Two versions of the self-completion questionnaire were used, seeking projections to: "at home, indoors, in the evening"; and "outside your front door, at home, in the evening". Subjects were exposed to one of the four treatments only, for four minutes, in order not to take up too much of the visitor's time.

The results are shown at table 5.3. Only 66 University Open Day (1979) visitors took part. Attendance at the Open Day was low that year. The mean reported annoyance rating for the 52 L_{Aeq} indoor projection questionnaire treatment was in very close agreement with the mean reported annoyance rating for the corresponding treatment in the laboratory-field calibration study. The mean reported annoyance ratings for the 70 L_{Aeq}

Table 5.1 Open/Closed Windows Pilot Study - L_{Aeq}'s

Window Condition	Tape Recording 5 m low flow	 30 m heavy flow
Open	64	62
Closed	51	49

Table 5.2 Open/Closed Windows Pilot Study - Mean Reported Annoyance Ratings

Window Condition	Tape Recording 5 m low flow	 30 m heavy flow
Open	7.25	6.00
Closed	3.68	3.44

Table 5.3 Indoor/Outdoor Conditions Pilot Study - Results

L_{Aeq}	Questionnaire Version	Mean Reported Annoyance	Percent Highly Annoyed
70	Indoors	8.29	100
70	Outdoors	7.19	63
52	Indoors	5.71	44
52	Outdoors	5.00	13

and 52 L_{Aeq} treatments were significantly different but the effect of the questionnaire versions was not significant. However, there was a trend for the indoor questionnaire version to yield higher mean reported annoyance ratings.

These results could have been due to a combination of the following reasons:

(a) Subjects made reported annoyance ratings on the basis of absolute noise levels in the simulated living room without regard to indoor or outdoor simulations.

(b) Subjects may have made a slight allowance for their experience of higher noise levels outdoors than indoors.

(c) Subjects may have had especial difficulty in making a projection from the laboratory conditions to 'just outside their front doors'.

The results of both pilot studies are shown at Figure 5.1.

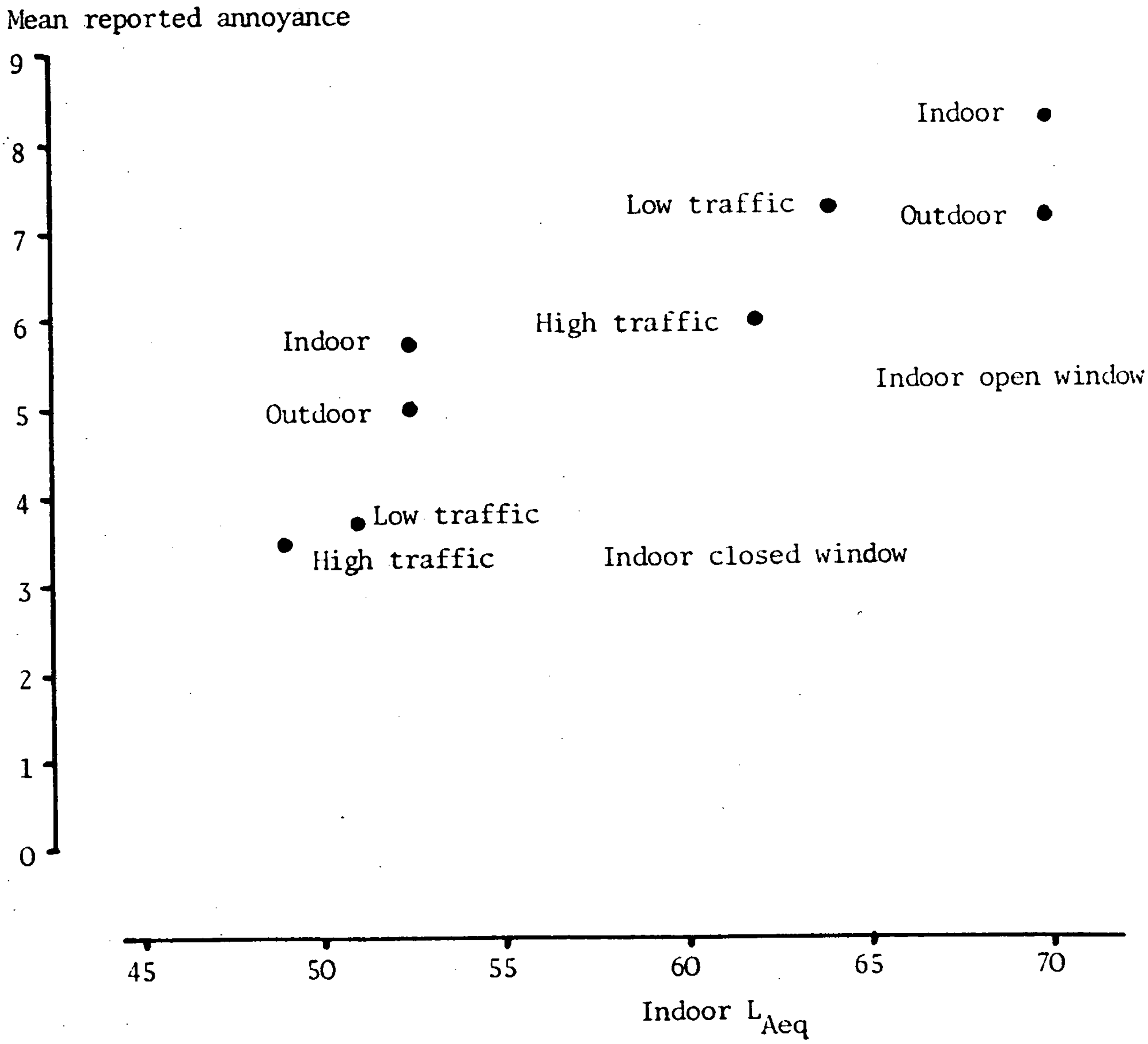
Taken together, the results of both pilot studies imply that laboratory reported annoyance ratings are relatively insensitive to simulation condition cues and mainly depend on the absolute noise level alone. They do not indicate whether indoor open window, indoor closed window, or outdoor simulations are the most appropriate. The laboratory-field calibration study described in Chapter 5.5 was necessary in order to examine this question.

5.5 Laboratory-field Calibration Study [8]

This study was carried out in order to compare road traffic noise annoyance ratings obtained in the field and in the laboratory using the same subjects for both phases. 60 randomly selected subjects were recruited from three sections of a district in Southampton having reasonably homogeneous high, medium and low levels of road traffic noise exposure. A 20-30 minute interview was given to each subject by professional interviewers from Social and Community Planning Research. The questionnaire is shown at Appendix D. It included items taken directly from previous major road traffic noise social surveys [52-54] for response comparison purposes. Noise measurements were made throughout the district in order to be able to extrapolate 24 hour L_{Aeq}'s outside

Figure 5.1

Pilot studies (1978 and 1979)



every dwelling. It was not known before the survey which dwellings would be of interest because of uncertainties in subject recruitment.

Stereo tape recordings were made in order to simulate an average road traffic noise exposure for each of the three noise level areas. These recordings were reproduced in the simulated domestic living room at nominal levels 10 dB lower than outdoor levels in order to simulate open window indoor conditions [61]. The outdoor/indoor attenuation measurements discussed in Chapter 5.3 were carried out *after* the laboratory-field calibration study. The outdoor/indoor attenuation measurements implied that the nominal laboratory levels were in fact 8 dB too high for an accurate simulation of typical open window indoor conditions. This topic is discussed below in this chapter under the heading "laboratory-field comparisons".

Subjects visited the laboratory within three days of being interviewed and each rated four ten-minute sessions. The experimental design is given at Appendix E. As a subsidiary to the main experiment subjects also individually matched the reproduction level of a tape recording in the laboratory against the level of road traffic noise audible at precisely specified locations in their own homes.

The sample

A plan of the sample district is shown at Figure 5.2. High road traffic noise exposure dwellings faced onto the main thoroughfares. The low road traffic noise exposure dwellings were in quiet roads remote from the main thoroughfares. The medium road traffic noise exposure dwellings were in between. The distribution of facade 24 hour L_{Aeq}'s obtained over the sample of 60 dwellings is shown at Figure 5.3. The bi-modal distribution evident for the medium exposure group is an artefact of the random sampling.

Figure 5.2

Plan of sample district showing 24 hour outdoor facade L_{Aeq}s

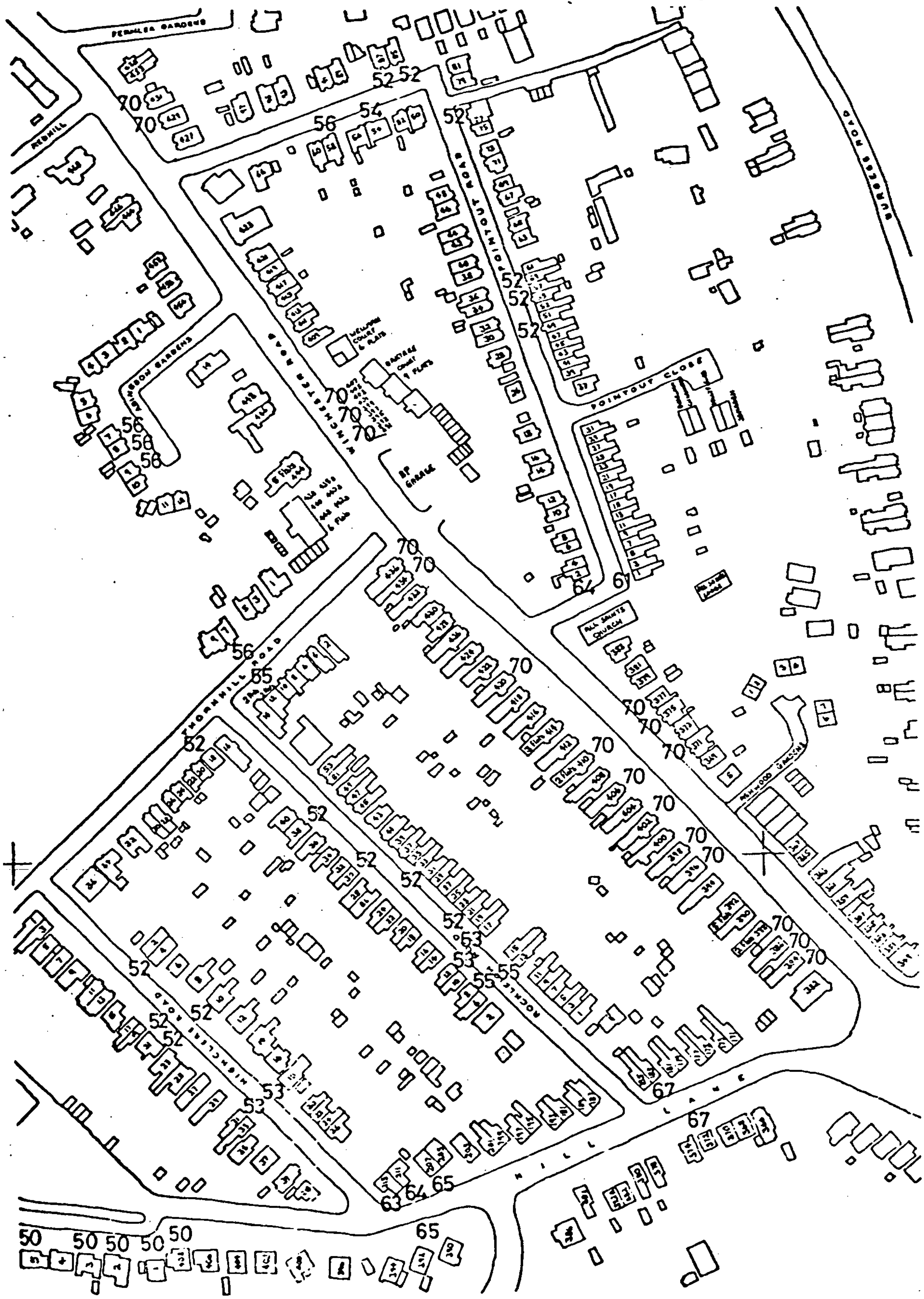
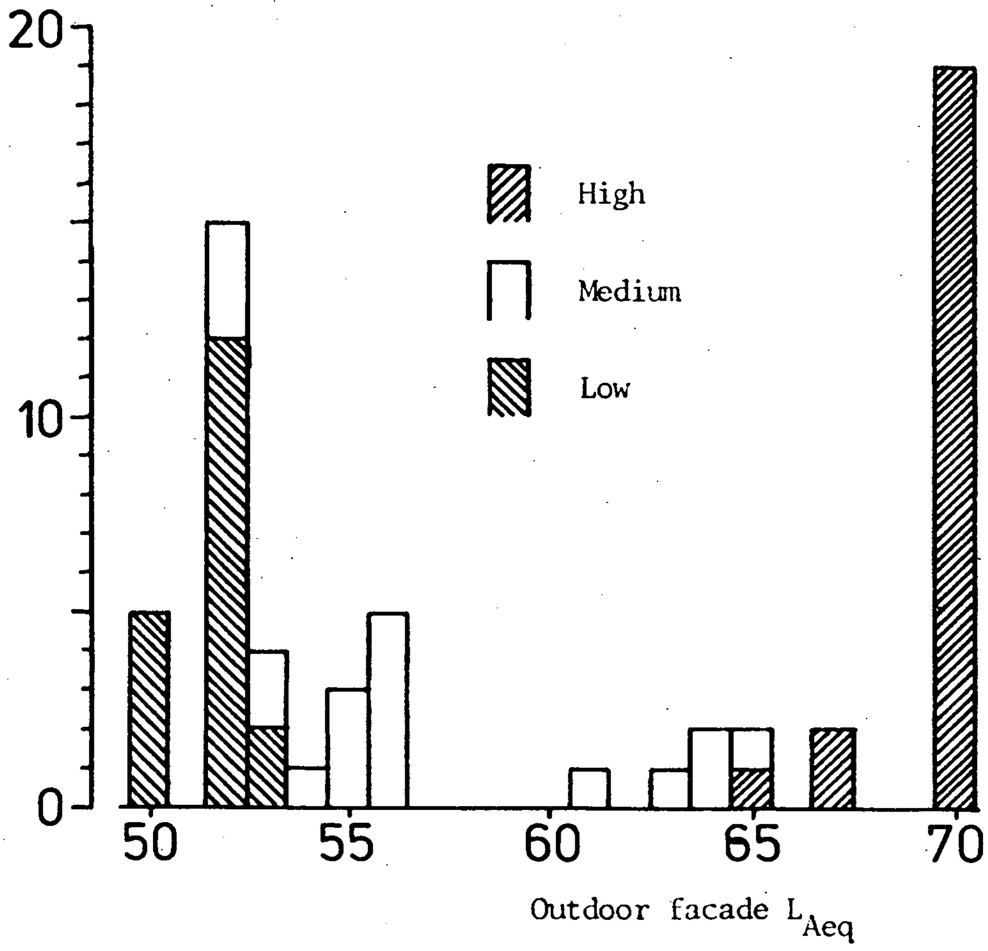


Figure 5.3

Sample distribution



Noise measurements

Ten minute sampling was adopted in order to characterise hourly noise levels throughout the district. The 24 hour variation in noise levels at three representative locations is shown at Figure 5.4 All measurements were restricted to the period Monday mid-day to Friday mid-day under good weather conditions only. Spot measurements were made throughout the district during the 1000 to 1600 period which was found to have a low variation in hourly noise levels except at the quietest locations which had fluctuations in noise levels caused by random and infrequent local vehicles. 24 hour L_{Aeq}'s were then derived at each spot measurement location by assuming that the 24 hour variation at those locations would be the same as at the most representative of the three 24 hour measurement locations. Subsequently, 24 hour L_{Aeq}'s were extrapolated outside every dwelling of interest. It would have been completely out of the question to measure for 24 hours outside of each and every dwelling of interest, as this would have involved violation of vagrancy laws.

Outdoor facade L_{Aeq}'s of 70, 63 and 54 were taken as representative of the three noise level areas in order to construct the tape recordings, in advance of subject recruitment. The sample mean L_{Aeq}'s were in fact 69.5, 56.7 and 51.6.

Tape recordings

The recordings had to be made on waste ground, after dusk, in analogous positions to the sample district in order to avoid extraneous noise. They were made at the appropriate distances from a busy urban road in order to obtain 10 minute L_{Aeq}'s of 70, 63 and 54. A separate sequence of local vehicles, recorded at 10 m from a quiet side street, was mixed in to the copy tapes from the master recordings. This was in order to simulate typical local traffic. Time histories of the three tapes are shown at Figure 5.5.

Figure 5.4

Hourly variation in L_{Aeq}s

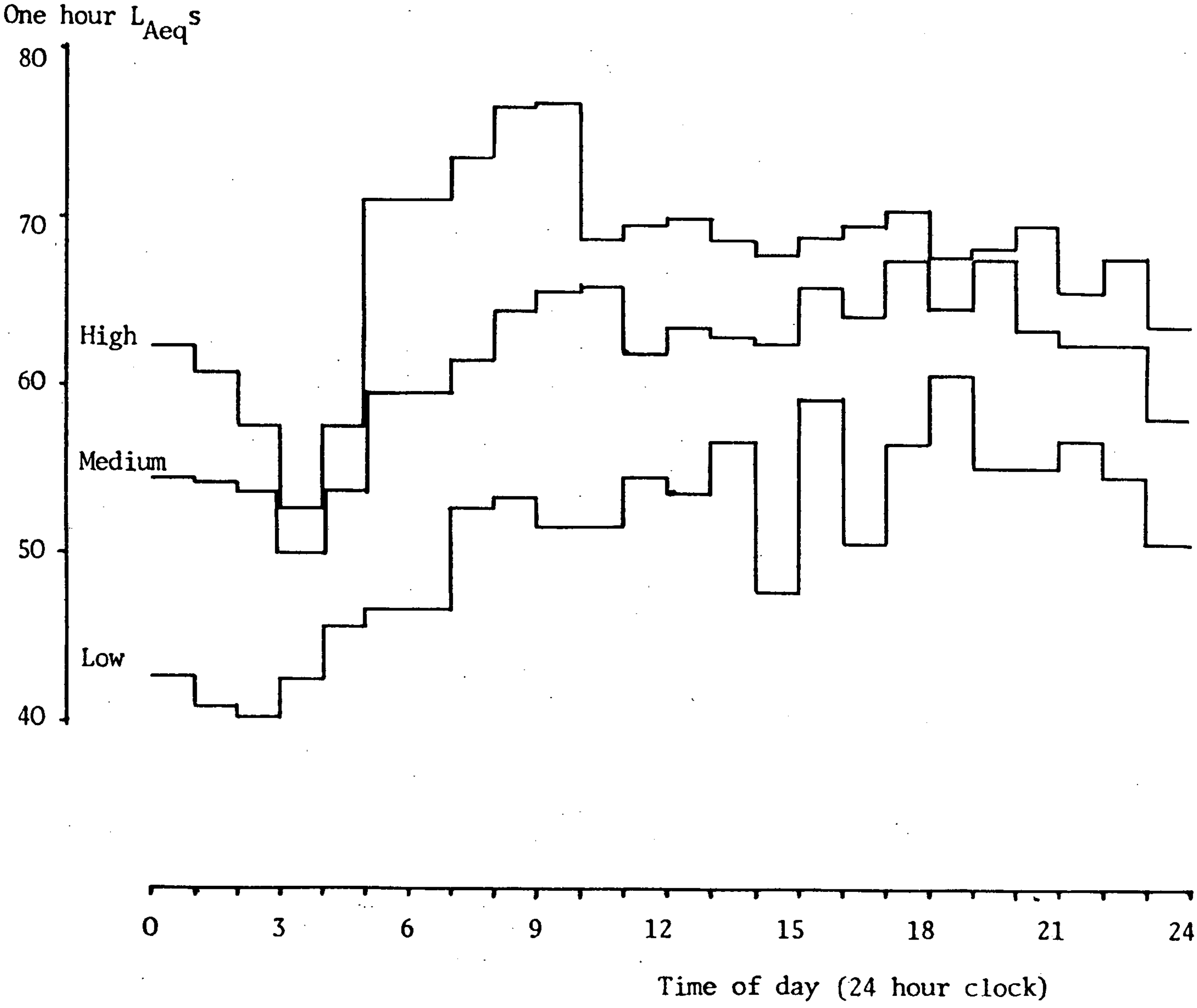


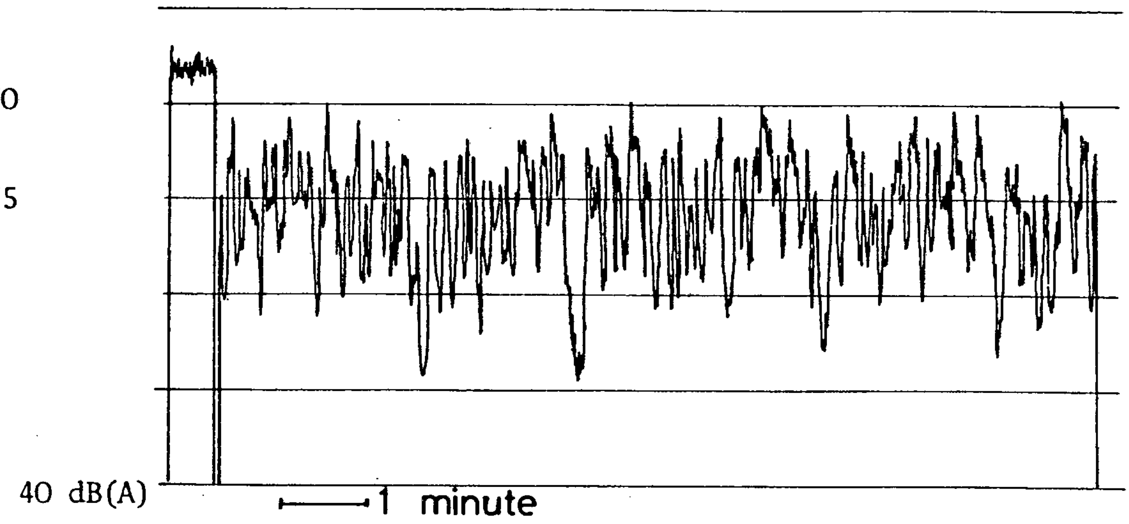
Figure 5.5

Tape recordings

High

L_{Aeq} = 70

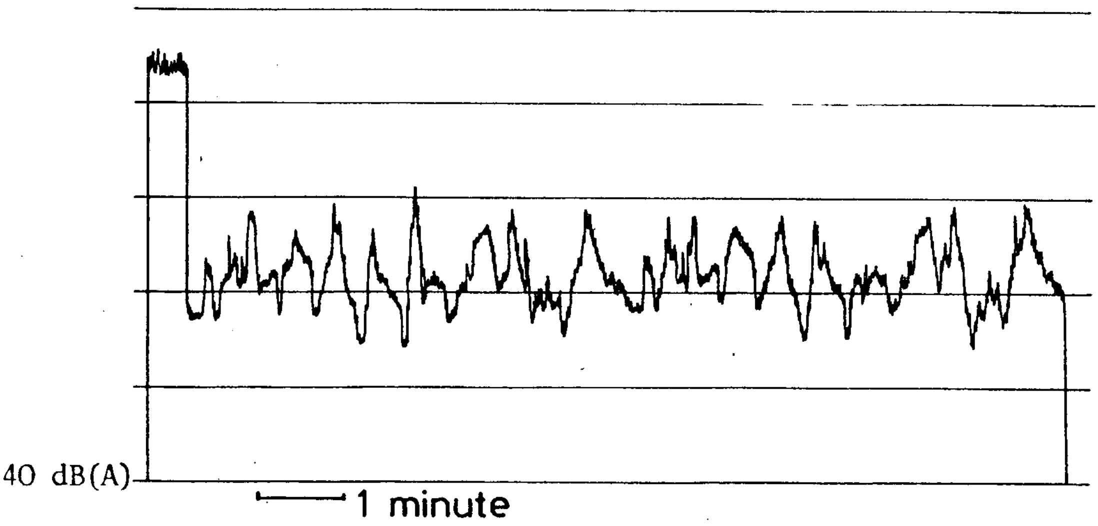
L_{10} = 75



Medium

L_{Aeq} = 63

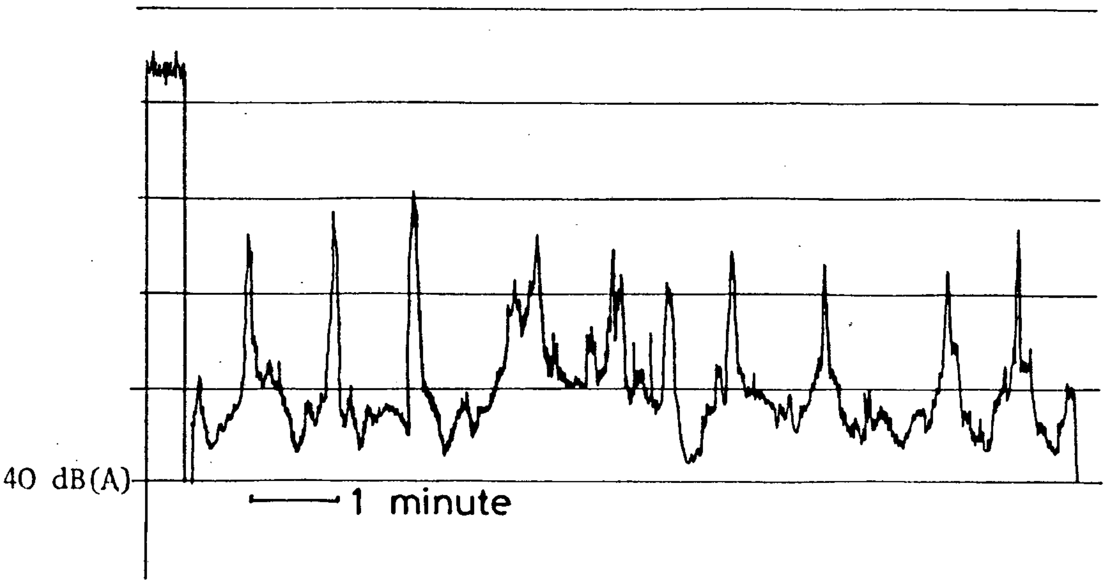
L_{10} = 65



Low

L_{Aeq} = 54

L_{10} = 56



Field questionnaire

The questionnaire is shown at Appendix D. It was not possible to use a concealed purpose format because it was necessary to explain the nature and purpose of the study in order to recruit subjects who were willing to take part in the laboratory phase. There would have been no point in interviewing subjects who then refused to take part in the laboratory phase.

Social and Community Planning Research (SCPR) were given a list of addresses in the sample district, broken down into high, medium and low road traffic noise exposure groups. The SCPR interviewers recruited subjects for the laboratory phase and then immediately interviewed them. The interviewers were given sample profiles to work to in terms of age and sex and were instructed to avoid persons with obvious hearing difficulties, and to avoid recruiting more than one person from each household, if at all possible. The interviewer's instructions are shown at Appendix F.

Laboratory questionnaire

The laboratory questionnaires are shown at Appendix G, together with the standard consent form which was completed by all subjects. The most important laboratory/field comparison was between the ratings to Q3(a) in the field questionnaire and Q6 in the laboratory questionnaire.

Laboratory procedure

On arrival at the laboratory (in groups of two, three or four) subjects had a hearing test and were then ushered into the simulated domestic living room in order to relax and acclimatise. The procedure was explained verbally, subjects having had previous experience with the rating scales in the field phase. During each exposure, subjects were free to converse, read, do private work or just relax. Refreshments were provided half-way through the evening and in all cases the experiment took place between 7 p.m. and 9 p.m.

The level matching task was carried out individually by means of a remote signalling system. Subjects were asked to match the reproduction level of a tape recording in the laboratory against the level of road traffic noise audible at precisely specified locations in their own homes. Having set an appropriate level, subjects then made a further annoyance rating (see Appendix G).

The remote signalling system carried the messages "too loud", "just about right", or "not loud enough". The experimenter adjusted the level from outside the laboratory until a consistent "just about right" was obtained. This level was then noted as the subject's best estimate. The task was difficult for some subjects but nevertheless, they all attempted it regardless of their personal confidence in the veracity of their estimates.

Laboratory/field comparisons

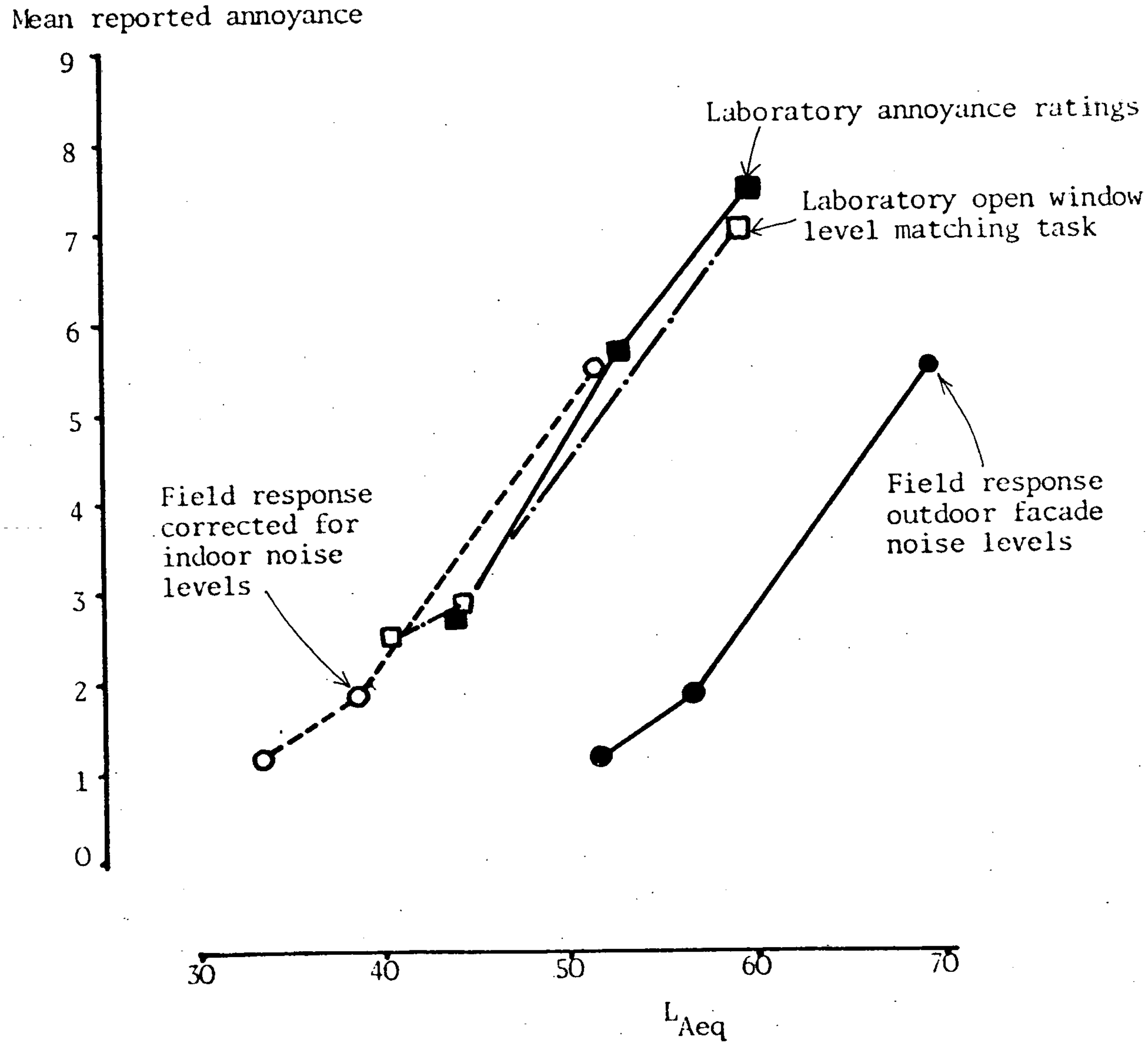
Figure 5.6 shows mean responses to Q3(a) in the field questionnaire and to Q6 in the laboratory questionnaire, against 24 hour L_{Aeq} outdoor facade noise levels, and 10 minute L_{Aeq} indoor laboratory noise levels. The level matching task estimated open window indoor noise levels and mean annoyance ratings are shown. The field responses have also been shown shifted 18 dB to the left, in order to take account of the typical outdoor/indoor open window attenuation discussed in Chapter 5.3 above.

The data points for the laboratory responses, for the open window level matching task, and for the field response corrected for indoor levels do not coincide. This is because the road traffic noise recordings were reproduced in the laboratory at levels that were 8 dB higher than typical open window indoor levels, as discussed above. It is therefore not meaningful to compare laboratory and field responses by means of correlation analysis.

However, the data points for the laboratory responses, for the open window level matching task, and for the field response corrected for indoor levels, all lie on the same curve of annoyance against noise level. Thus there is a close correspondence between the three sets of points.

Figure 5.6

Laboratory-field calibration results



This implies that any errors in reproducing the tape recordings at levels that were too high were fully compensated for by the subjects who responded with appropriately higher annoyance ratings. Subjects selected open window indoor levels in the level matching task that were too high but the same compensation in terms of annoyance ratings took place.

Figure 5.7 shows regressions of the same data shown at Figure 5.6. It is possible to see the close correspondence between laboratory and indoor corrected field responses in terms of the negligible differences between the field (corrected for indoor levels), laboratory and level matching task regressions.

Field survey results

Figure 5.8 shows a comparison between responses on the 7 point dissatisfaction scale Q2 in the field questionnaire and responses on the same questionnaire item in previous major road traffic noise social surveys [52, 53, 54]. It is reasonable to assume that the sample population in the laboratory/field calibration study were not responding differently to road traffic noise than the sample populations in those surveys.

Other results

There was a considerable amount of data collected in this study which was not directly relevant to the points discussed above. This data is presented in Appendix H. However, mean reported annoyance ratings in the laboratory were stable and without systematic order effects. Mean group responses were not significantly affected by home road traffic noise exposure levels.

Figure 5.7

Regressions of individual scores

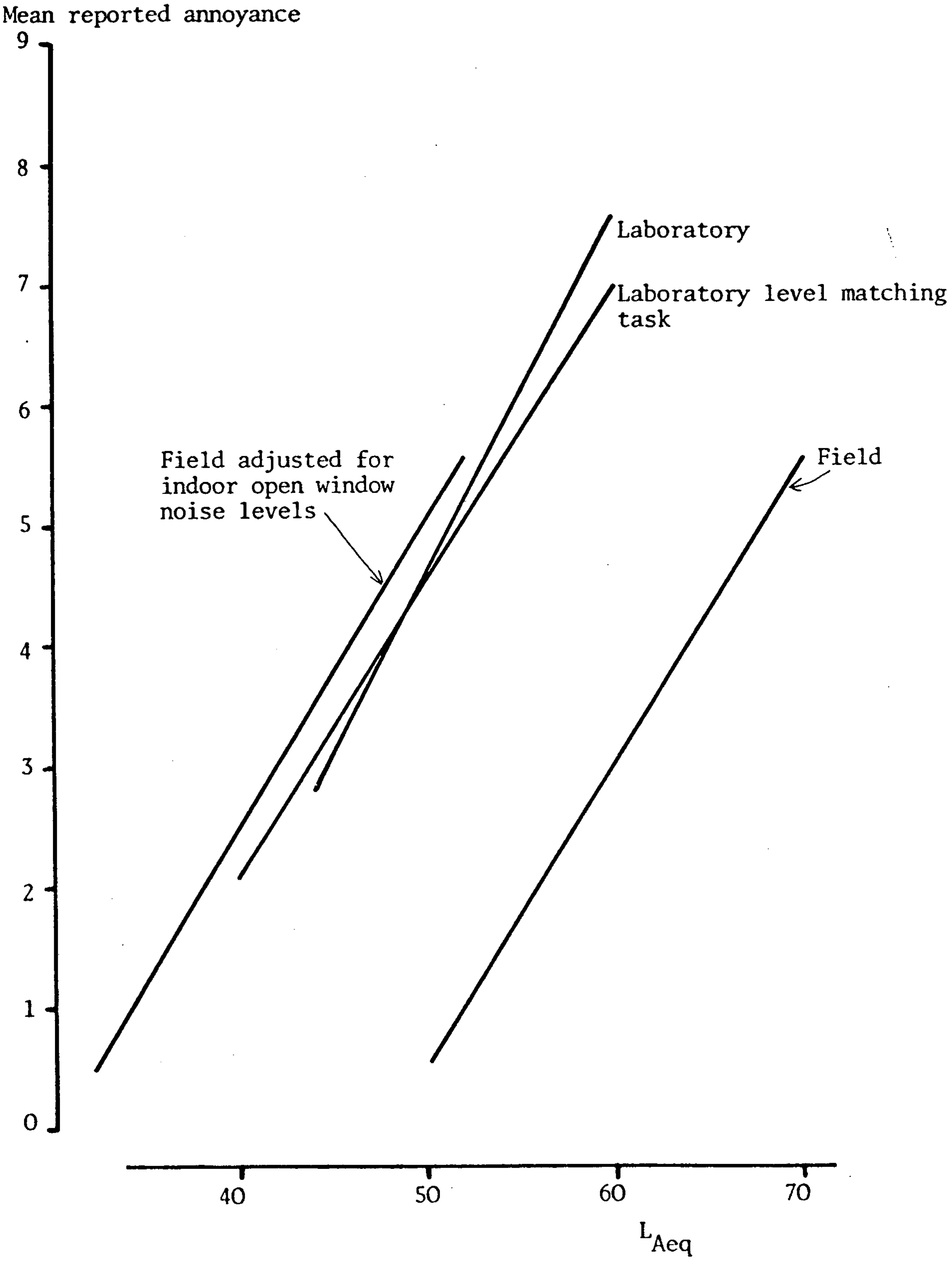
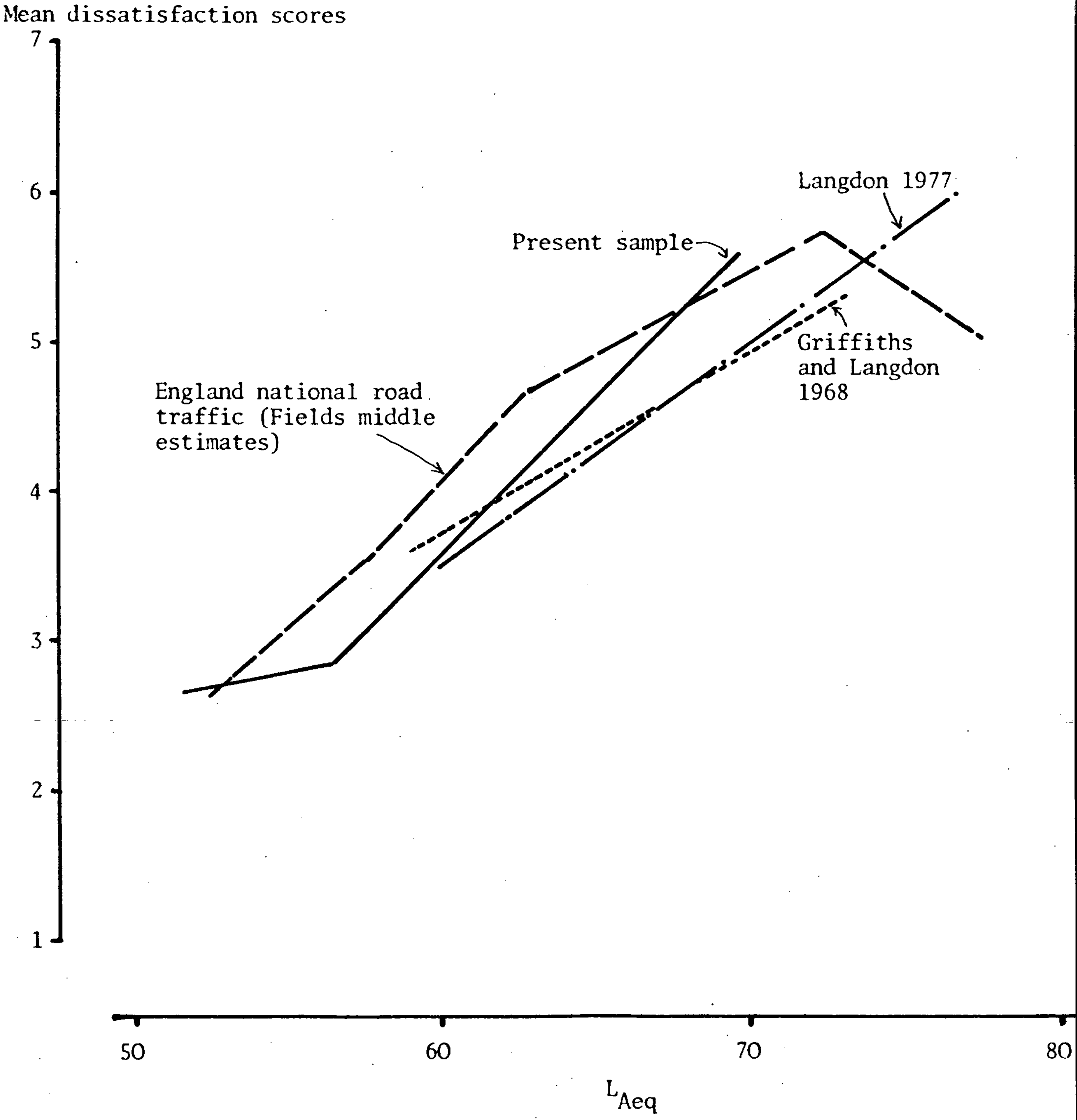


Figure 5.8

Comparisons with previous surveys



5.6 Discussion

The 18 dB attenuation factor is in good agreement with field measurements of the typical sound reduction obtained with an open window. Furthermore, the level matching task indoor noise levels and annoyance ratings are in good agreement for the open window indoor level estimation. This implies that differential constancy and concentrated attention effects do not apply to the specific techniques used in this study, in particular the laboratory projections to *at home in the evenings*.

However, typical closed window outdoor-indoor attenuations would be about 23 dB. Free field measurements would give outdoor 24 hour L_{Aeq}'s some 3 dB lower than facade levels, and the peak one hour L_{Aeq}'s are typically 5-6 dB higher than 24 hour L_{Aeq}'s. Thus projections to different parts of the day, and closed window simulations might lead to different results. Differential constancy and concentrated attention effects could be operating, in conjunction with different outdoor-indoor attenuations, such as for closed windows. It is not possible to separate out these possible effects, as noted in Chapter 5.1.

Accordingly, it must be concluded that the 18 dB attenuation factor is of value as a laboratory-field calibration in operational terms, but that the agreement with typical open window outdoor-indoor attenuation may be no more than coincidental.

Further, the appropriate calibration factor for other noise sources, in particular aircraft noise, may not be the same as for road traffic noise. A repeat of this study using subjects exposed to aircraft noise was completely outside of the available resources, but it is not possible to come to any conclusion as regards the appropriate calibration factor for other noise sources without such repeat studies.

6. ROAD TRAFFIC AND RAILWAY NOISE STUDY

6.1 Introduction

This experiment was intended to investigate laboratory responses to noise environments composed of five recordings of road traffic noise and five recordings of railway noise, heard separately and in combination.

The objectives were:

(a) To compare laboratory responses to road traffic noise and railway noise exposures at similar conventional L_{Aeq}'s.

(b) To investigate the higher level of laboratory response to noise sources in combination than implied by overall conventional L_{Aeq}, as observed by Powell [3].

Powell [3] used road traffic noise and aircraft noise in his work. This study used road traffic noise and railway noise in order to determine whether Powell's results could be repeated with different noise sources. Railway noise has more in common with aircraft noise than with road traffic noise, and similar results might have been expected on that basis. However, Fields and Walker [2] have shown that field survey data ranks aircraft noise above road traffic noise, and road traffic noise above railway noise when noise source specific questionnaires are used and L_{Aeq} is used as the noise measure.

pL_{Aeq} implies that road traffic noise should have greater annoyance potential than aircraft noise and railway noise, at similar L_{Aeq}'s. The psum procedure allows for enhanced annoyance potential of multiple noise sources, in a similar fashion to Powell's model.

Accordingly, this study was felt to be addressed to several interesting apparent contradictions.

6.2 Procedure

Tape recordings

Each exposure session lasted five minutes.

Five recordings of each noise source were prepared, to generally cover the range of outdoor facade noise levels from 60 L_{Aeq} to 80 L_{Aeq} in 5 dB steps. They were reproduced in the laboratory at 18 dB lower levels, on the basis of the results of the laboratory-field calibration study described in Chapter 5. This involved an assumption that the appropriate outdoor-indoor attenuation factor was the same for railway noise as for road traffic noise.

Time histories of the ten recordings are shown at Figure 6.1 in respect of indoor (laboratory) noise levels. The recordings were identified A, B, C, D and E for the road traffic and 1, 2, 3, 4 and 5 for the trains. The reproduction levels are shown at table 6.1, adjusted to outdoor levels by applying the 18 dB outdoor-indoor attenuation factor.

The road traffic noise recordings were recorded at either 10 m or 100 m from a busy dual carriageway near Southampton. Recording D was produced by mixing two consecutive recordings together so as to subjectively increase the apparent traffic flow rate. The other recordings were produced by processing the signals through a pair of Neve compressor-limiters in order to reduce noise level fluctuations due to individual vehicles. This procedure partly confuses the psychological sensation of distance from the source in order that each recording could sound subjectively right, although only two recording distances were used.

The railway noise recordings were recorded at 20 m, 75 m or 250 m from the track in an otherwise very quiet valley north of Winchester. A reasonably representative mix of electric passenger, diesel hauled passenger, and goods trains was recorded. Each recording had two train pass-bys, corresponding to 24 trains per hour in either direction.

Noise levels for each of the ten recordings and twenty-five combinations are shown at Table 6.1.

Figure 6.1 Tape recordings

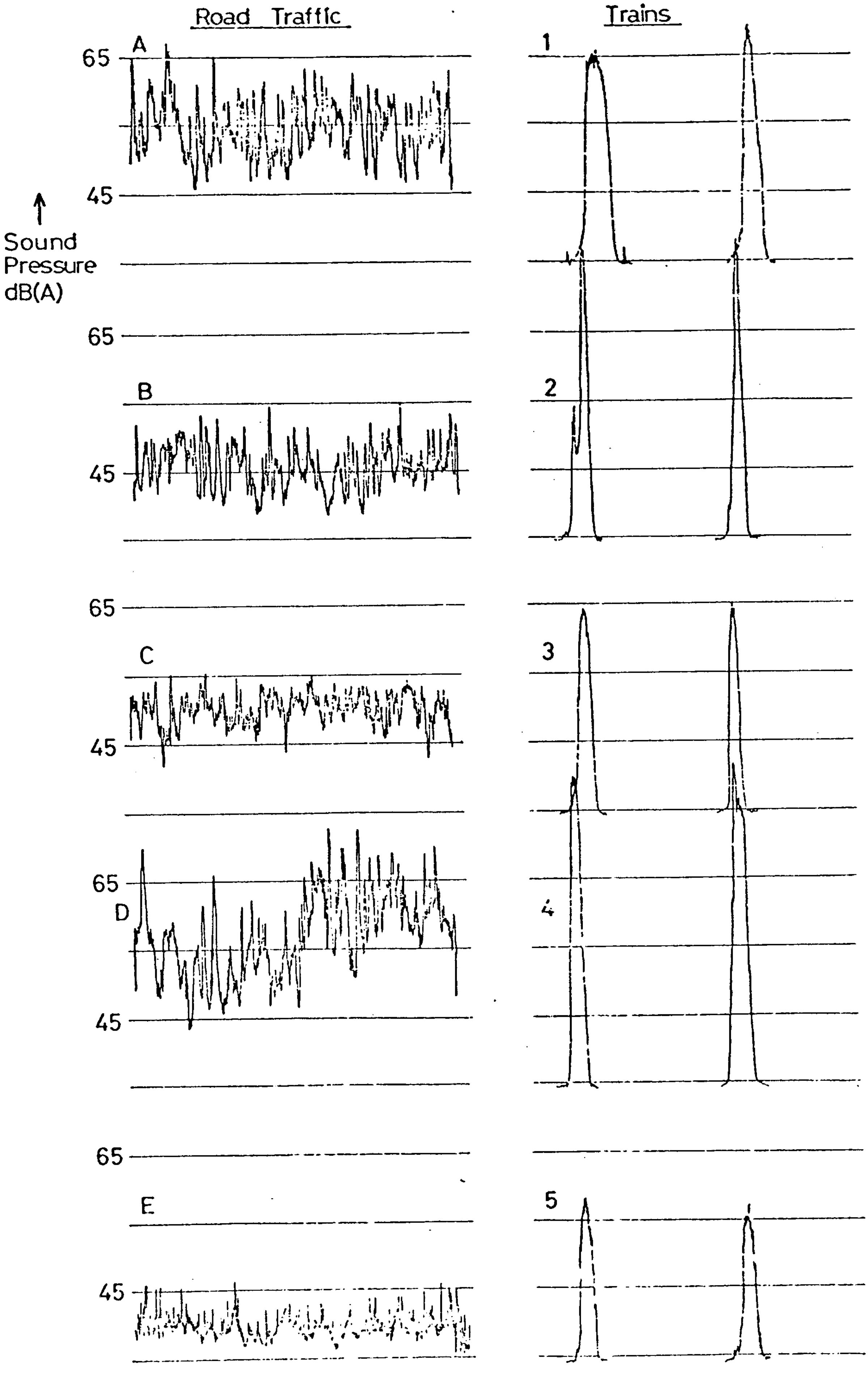


Table 6.1 Noise levels of recordings (outdoor facade)

Recording	L_{01}	L_{10}	L_{50}	L_{90}	L_{99}	L_{Aeq}	pL_{Aeq} (psum)
1	84.8	76.3	53.5	53.0	52.8	72.4	65.7
2	93.8	64.5	53.5	53.0	52.8	77.1	68.5
3	81.8	59.0	53.5	53.0	52.8	67.8	62.6
4	97.3	69.0	53.5	53.0	52.8	83.0	75.0
5	75.3	60.3	53.5	53.0	52.8	62.4	60.5
A	81.3	77.0	73.3	68.5	65.8	74.2	74.3
B	70.0	67.8	63.5	59.5	57.0	64.4	64.5
C	72.5	71.0	68.5	65.3	62.8	68.6	69.0
D	87.5	82.8	75.3	67.0	62.3	78.6	76.9
E	62.8	60.0	58.0	56.3	55.0	58.2	57.1
A1	86.5	80.8	74.3	69.3	66.5	76.9	77.0
A2	96.8	79.0	73.5	68.8	66.0	81.8	77.9
A3	85.8	79.3	73.3	67.8	65.0	76.1	76.3
A4	100.5	79.8	73.0	67.5	64.3	86.3	80.7
A5	82.3	78.5	73.0	67.8	65.0	74.8	75.9
B1	88.3	79.8	64.5	60.0	56.8	76.2	71.1
B2	97.8	70.8	63.5	59.3	56.8	81.2	72.7
B3	85.5	69.5	63.5	59.3	56.8	71.9	69.6
B4	100.5	72.8	63.8	59.5	56.8	86.2	77.3
B5	75.8	69.0	63.5	59.5	56.8	66.2	68.7
C1	84.8	77.3	68.8	65.5	62.5	73.8	73.5
C2	93.8	71.8	68.8	65.8	62.8	77.7	74.8
C3	82.0	71.8	68.8	65.5	62.5	71.1	72.4
C4	100.5	73.5	68.8	65.8	62.5	86.2	78.5
C5	79.0	72.0	68.8	65.8	62.5	70.4	71.8
D1	87.8	83.5	76.5	67.8	63.3	79.4	79.0
D2	96.3	83.8	75.8	67.3	63.3	82.5	79.7
D3	87.5	83.8	75.8	67.8	64.5	79.2	78.4
D4	100.5	85.3	76.0	67.3	64.5	86.8	82.0
D5	87.8	82.8	75.8	67.8	64.8	78.8	78.1
E1	84.5	76.5	58.3	56.3	55.0	72.5	68.4
E2	93.8	64.8	57.5	56.3	55.3	77.1	70.6
E3	81.8	62.8	57.5	56.0	55.3	68.0	66.3
E4	97.3	68.8	57.0	55.8	55.0	82.9	76.0
E5	75.3	60.5	57.0	55.8	50.0	63.0	65.0

Experimental design

Even at five minutes per session the thirty-five treatments (ten recordings heard separately and twenty-five combinations) take up four and a half hours of subject time. Each subject therefore made two visits to the laboratory, either on a morning and an afternoon, an afternoon and an evening, or on two consecutive days.

The ten separate recordings were rated at the first visit and the twenty-five combinations were rated at the second visit. The experimental design is shown at Appendix I. The designs for the two visits were separate.

The separate source treatments were presented according to 5 × 5 latin squares, all the road traffic recordings following all the train recordings for the first five subject groups and with a completely reversed order for the second five subject groups, in order to balance for noise source order and carry over effects. The combinations treatments were presented according to a cyclically repeated ten row by five column Graeco-latin rectangle. This design is perfectly balanced for order providing only that it is assumed that order is not important within each block of five columns. Each treatment occurs twice within each block of five columns. Letters and numbers are perfectly balanced separately for order and carry-over within each block of five columns. Overall carry-over balance is reasonable. Each row of five treatments within each block of five columns is a unique randomisation sequence. This design involved a considerable amount of trial and error in its development.

Letters were assigned randomly to the road traffic noise recordings and numbers were assigned randomly to the railway noise recordings. Forty subjects took part, there being four subjects in each of the ten subject groups. On several occasions only two or three subjects turned up or could be recruited. The experiment was re-run on these occasions in order to complete the design.

Questionnaires

Copies of the recruitment publicity hand-out, and questionnaires used in the study are shown at Appendix J. The major purpose of the preliminary questionnaire was not to gather useful data, but to set the subject's mood and encourage them to start thinking about their own home noise environment. In the laboratory-field calibration study (Chapter 5.5) each subject had very recently been interviewed in their own homes before visiting the laboratory. The preliminary questionnaire was intended to partially replicate for these subjects a similar degree of concentrated attention to their reactions to noise. No written instructions were used, reliance being placed on a verbal exposition of the procedure to be followed. It is perhaps worthwhile to point out that the meaning of the projection questions Q3 and Q4 was reinforced verbally. Subjects were asked to relate their projections to how they would feel if noise were to continue at home at the same level as sampled for only five minutes in each laboratory session.

Q3 in the laboratory questionnaire was of major interest. This question corresponds to Q6 in the laboratory-field calibration study (Chapter 5.5). Each subject was paid £5.

6.3 Results

The sample of forty subjects was composed of 17 females, mean age 33.5 years, and 23 males, mean age 25.3 years. Some subjects were students and staff of the University and the remainder were friends, neighbours and relatives of University staff and students.

The mean reported annoyance ratings at Q1 and Q3 and the percentages "highly annoyed" at Q2 and Q4 are shown at Table 6.2. A selection of correlation coefficients between mean reported annoyance and noise levels is given at Table 6.3. Considering the noise sources separately, the peak level correlates best with mean reported annoyance for trains, followed by L_{Aeq} and then pL_{Aeq}, which has a barely significant correlation. For road traffic, mean reported annoyance ratings correlate best with L_{10} and pL_{Aeq}.

Table 6.2 **Results** (mean ratings and percentages)

Recording	Q1	Q2	Q3	Q4
1	4.0	17	4.8	27
2	5.25	30	6.025	70
3	2.9	2	3.325	15
4	4.775	22	5.6	37
5	2.1	0	2.3	2
A	5.35	20	6.25	45
B	3.7	7	4.4	25
C	4.35	7	5.2	37
D	6.625	55	7.475	75
E	1.05	0	1.425	0
A1	4.725	20	5.725	35
A2	5.475	25	6.5	47
A3	4.55	17	5.6	35
A4	5.3	15	6.45	47
A5	4.425	17	5.475	32
B1	4.25	7	5.075	27
B2	4.325	12	5.175	25
B3	3.25	5	3.675	15
B4	4.675	15	5.9	37
B5	3.1	7	3.625	12
C1	4.9	12	5.2	22
C2	4.825	12	5.675	30
C3	3.925	5	4.875	15
C4	4.95	25	5.9	42
C5	3.625	5	4.525	12
D1	5.7	35	6.525	57
D2	5.75	37	6.85	57
D3	5.5	30	6.55	55
D4	6.05	37	7.05	70
D5	5.5	27	6.575	45
E1	2.7	0	3.425	7
E2	3.7	7	4.45	15
E3	2.5	2	2.975	7
E4	3.925	10	4.9	25
E5	1.475	0	1.8	5

Table 6.3 Correlation coefficients

Treatments	Question	Noise measure	r	Significance level (%)
Trains alone	1	L_{01}	0.944	5
1 2 3 4 5	1	L_{10}	0.512	ns
	1	L_{50}	-	ns
n = 5	1	L_{90}	-	ns
	1	L_{99}	-	ns
	1	L_{Aeq}	0.919	5
	1	pL_{Aeq}	0.839	10
	3	L_{01}	0.941	5
	3	L_{10}	0.592	ns
	3	L_{50}	-	ns
	3	L_{90}	-	ns
	3	L_{99}	-	ns
	3	L_{Aeq}	0.925	5
	3	pL_{Aeq}	0.844	10
Road Traffic alone	1	L_{01}	0.966	1
A B C D E	1	L_{10}	0.986	1
	1	L_{50}	0.974	1
n = 5	1	L_{90}	0.904	5
	1	L_{99}	0.805	10
	1	L_{Aeq}	0.980	1
	1	pL_{Aeq}	0.986	1
	3	L_{01}	0.954	5
	3	L_{10}	0.981	1
	3	L_{50}	0.975	1
	3	L_{90}	0.913	5
	3	L_{99}	0.820	10
	3	L_{Aeq}	0.977	1
	3	pL_{Aeq}	0.986	1

cont...

Table 6.3 (cont.)

Treatments	Question	Noise measure	r	Significance level (%)
Trains alone *and* Road	1	L_{01}	0.687	5
Traffic alone	1	L_{10}	0.802	1
1 2 3 4 5 *and*	1	L_{50}	0.547	ns
A B C D E	1	L_{90}	0.519	ns
n = 10	1	L_{99}	0.503	ns
	1	L_{Aeq}	0.861	1
	1	pL_{Aeq}	0.939	0.1
	3	L_{01}	0.672	5
	3	L_{10}	0.815	1
	3	L_{50}	0.553	ns
	3	L_{90}	0.529	ns
	3	L_{99}	0.515	ns
	3	L_{Aeq}	0.860	1
	3	pL_{Aeq}	0.941	0.1
Combinations	1	L_{01}	0.631	0.1
A1 to E5	1	L_{10}	0.838	0.1
	1	L_{50}	0.845	0.1
n = 25	1	L_{90}	0.790	0.1
	1	L_{99}	0.809	0.1
	1	L_{Aeq}	0.796	0.1
	1	pL_{Aeq}, psum	0.941	0.1
	3	L_{01}	0.656	0.1
	3	L_{10}	0.835	0.1
	3	L_{50}	0.834	0.1
	3	L_{90}	0.785	0.1
	3	L_{99}	0.754	0.1
	3	L_{Aeq}	0.828	0.1
	3	pL_{Aeq}, psum	0.960	0.1

Of the measures examined, pL_{Aeq} is by far the best predictor of mean reported annoyance for the ten separate noise source treatments considered together. The pL_{Aeq}, psum procedure also gives the best correlation with mean reported annoyance for the combinations treatments, although all noise measures give good correlations with mean reported annoyance.

These results imply that, for the range of noise levels and sources used in this study, pL_{Aeq} is a superior unified noise scale to conventional L_{Aeq} when used separately for road traffic or railway noise single noise source environments. Further, these results imply that the pL_{Aeq}, psum procedure is a superior unified noise scale to conventional L_{Aeq} for multiple noise source environments.

Figures 6.2 and 6.3 illustrate the different relationships between outdoor facade L_{Aeq} and pL_{Aeq} and mean reported annoyance at Q1 and Q3 for the noise sources considered separately. pL_{Aeq} reduces the differences between the separate noise source dose-response relationships. Figures 6.6 and 6.7 illustrate the reduction in scatter of mean reported annoyance at Q1 and Q3 obtained by using pL_{Aeq}, psum instead of L_{Aeq} for the combinations treatments. It is not possible to eliminate the scatter entirely, because of random variability and possible other factors which are not taken into account by pL_{Aeq}, psum.

Figures 6.4 and 6.5 illustrate the different relationships between outdoor facade L_{Aeq} and pL_{Aeq} and per cent highly annoyed at Q2 and Q4 for the noise sources considered separately. The improvement obtained by using pL_{Aeq} is not so convincing in this case. This may be because direct "highly annoyed" questions tend to give considerable scatter, if only because no information is collected with respect to moderate or low annoyance. Rice's [40] technique of re-interpreting individual annoyance ratings in terms of highly annoyed or not may be superior to direct highly annoyed questions. Rice asked subjects at the end of the experiment to indicate at what point on the 0-9 scale they would become highly annoyed, and used this information to re-interpret the individual annoyance ratings. He was able to show reasonably good agreement between his laboratory results and the USA Environmental Protection Agency (EPA) [62] levels document.

Figure 6.2

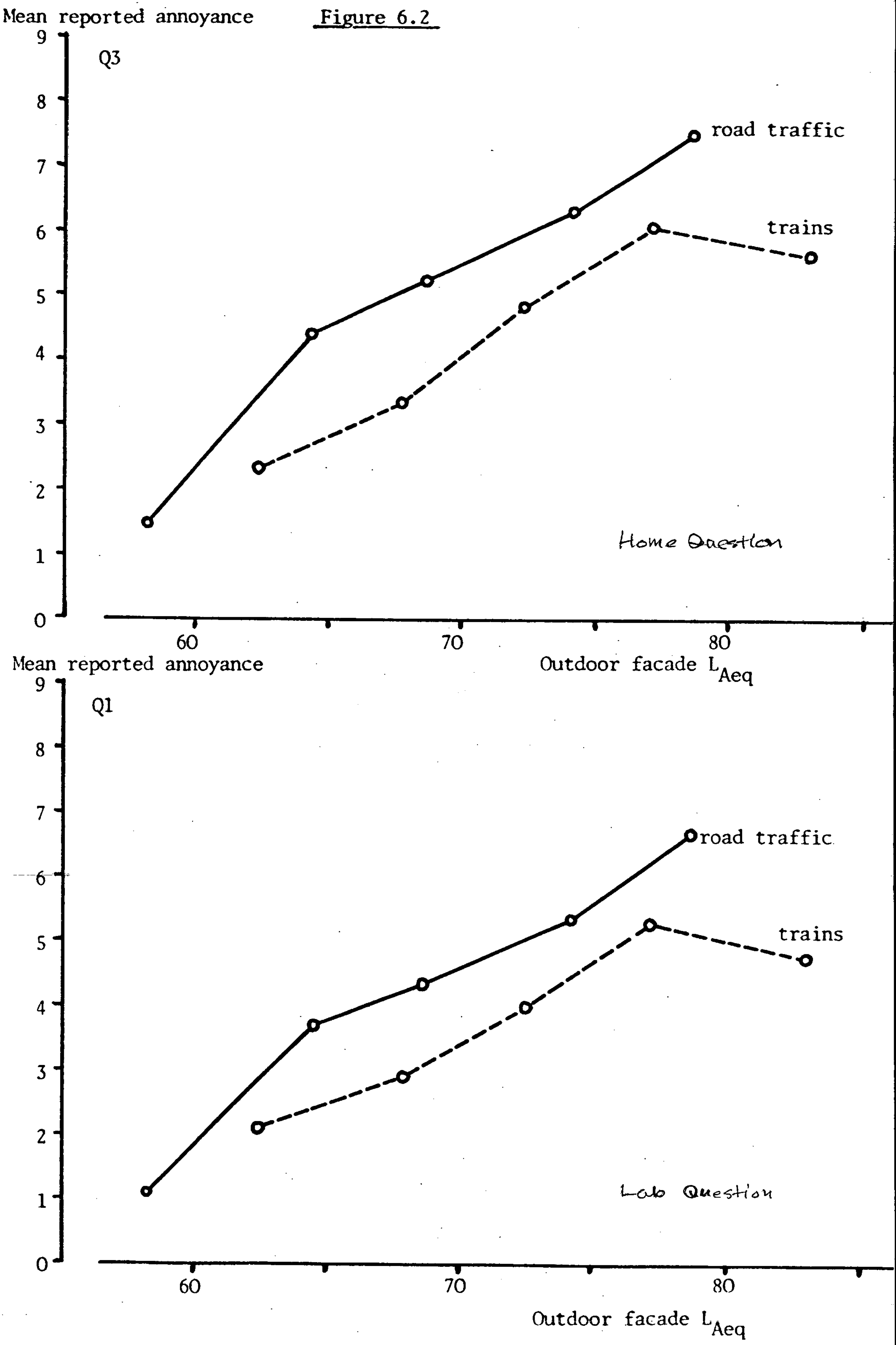

Mean reported annoyance
9
8
7
6
5
4
3
2
1
0
Q3
road traffic
trains
Home Question
60
70
80
Mean reported annoyance
Outdoor facade L_{Aeq}
9
8
7
6
5
4
3
2
1
0
Q1
road traffic
trains
Lab Question
60
70
80
Outdoor facade L_{Aeq}

Figure 6.3

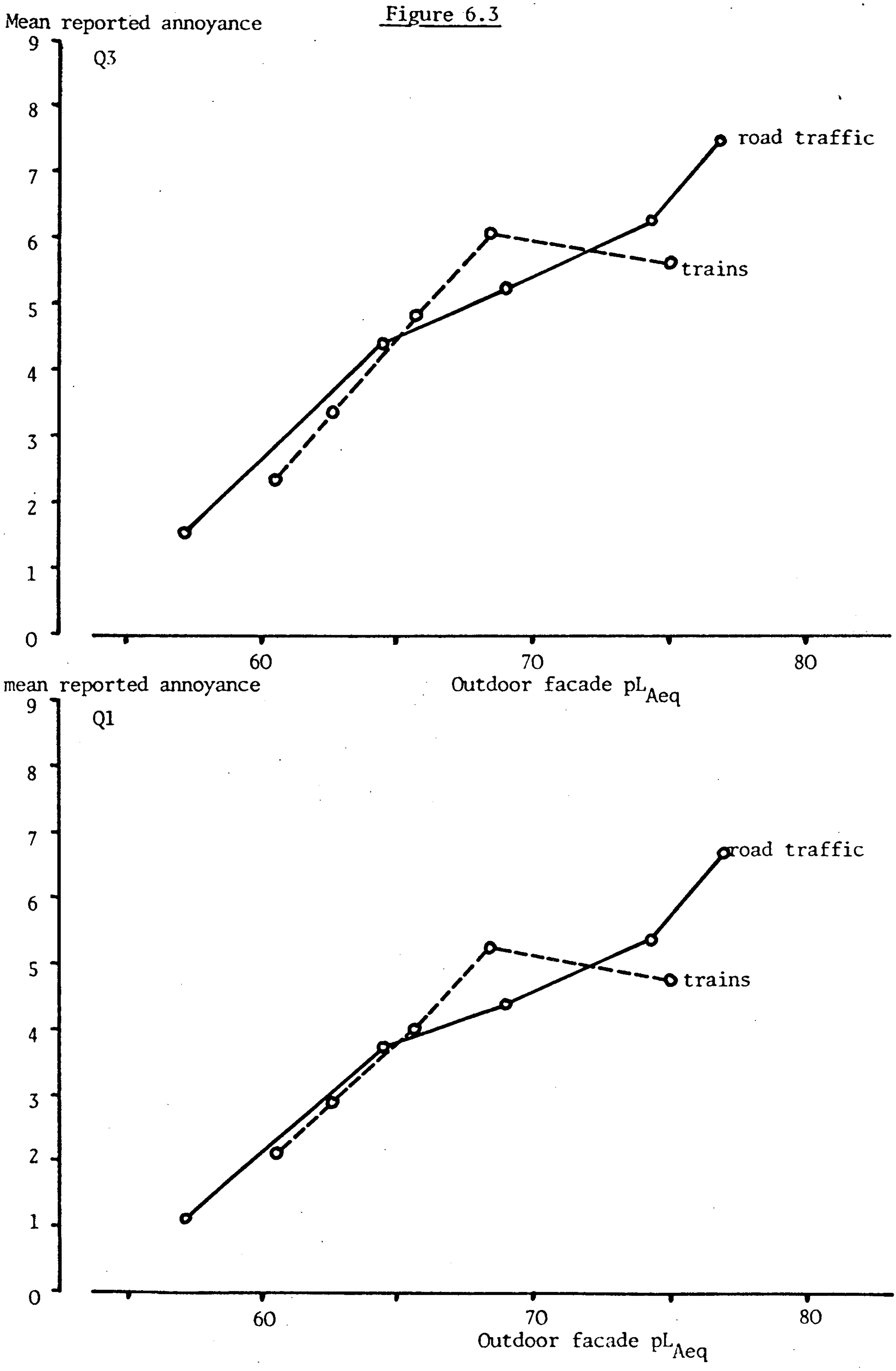
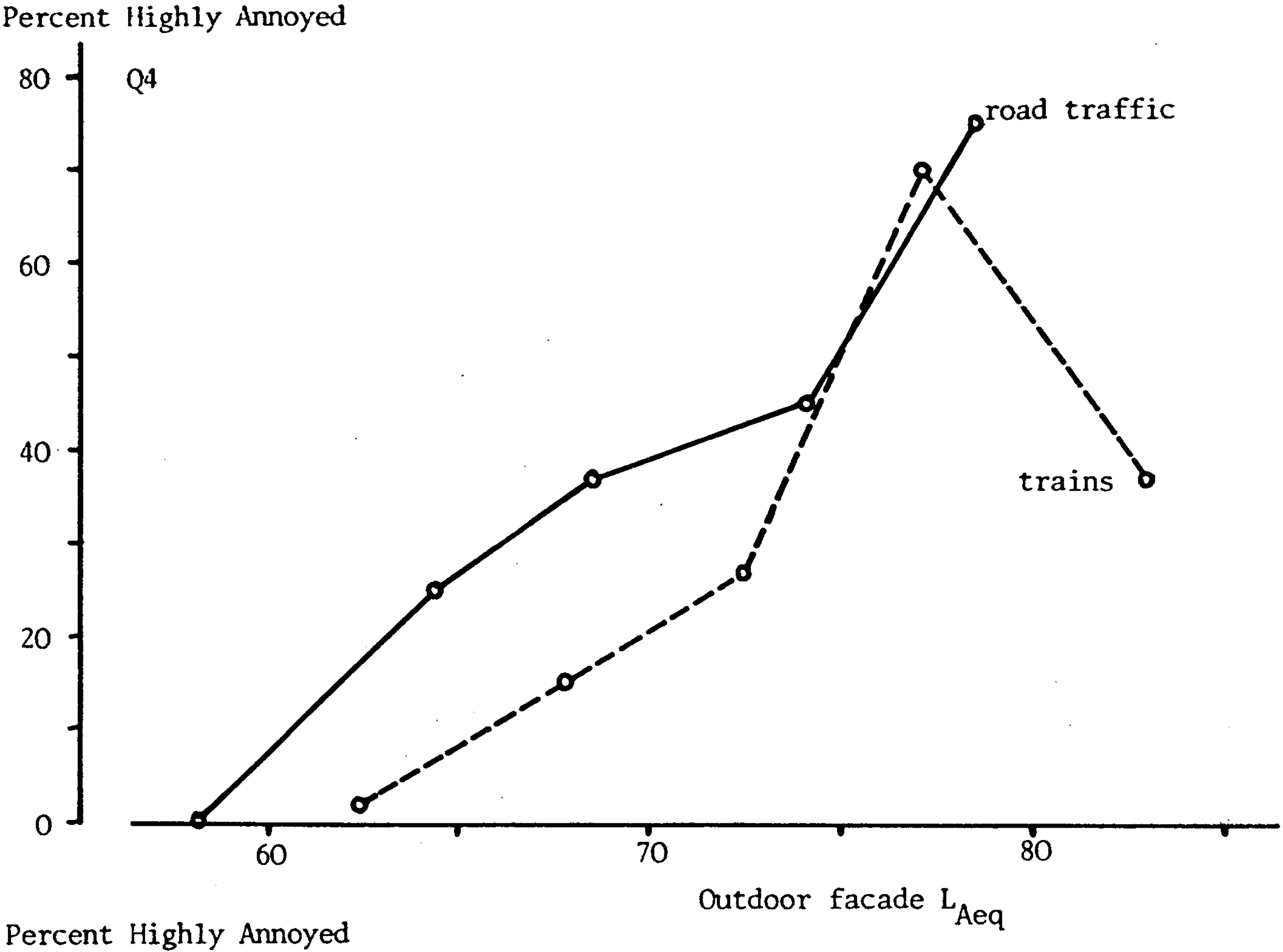

Mean reported annoyance
Q3
9
8
7
6
5
4
3
2
1
0
road traffic
trains
60
70
80
Outdoor facade pL$_{Aeq}$
mean reported annoyance
Q1
9
8
7
6
5
4
3
2
1
0
road traffic
trains
60
70
80
Outdoor facade pL$_{Aeq}$

Figure 6.4


Percent Highly Annoyed
Q4
80
60
40
20
0
60
70
80
Outdoor facade L_{Aeq}
road traffic
trains

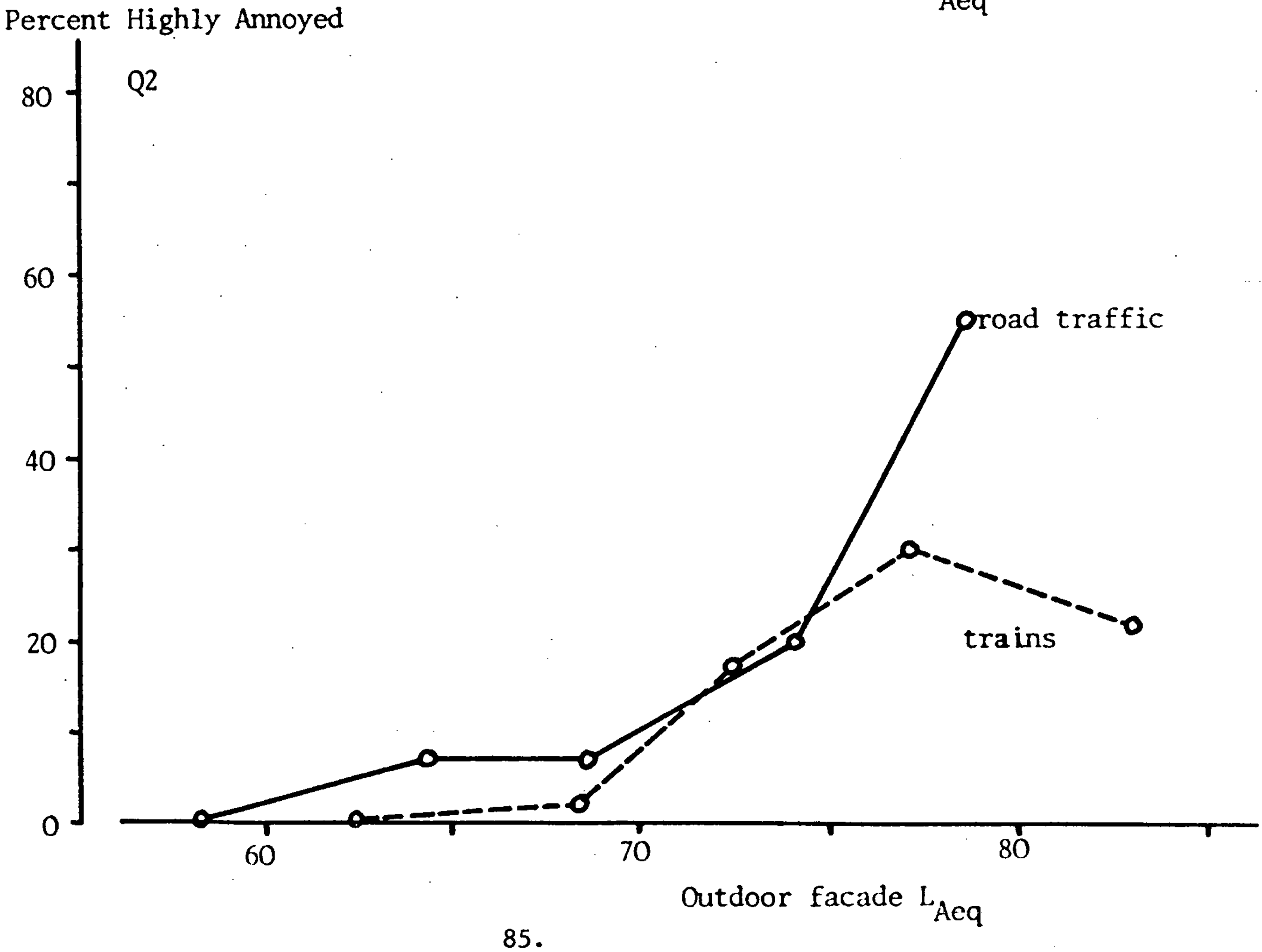
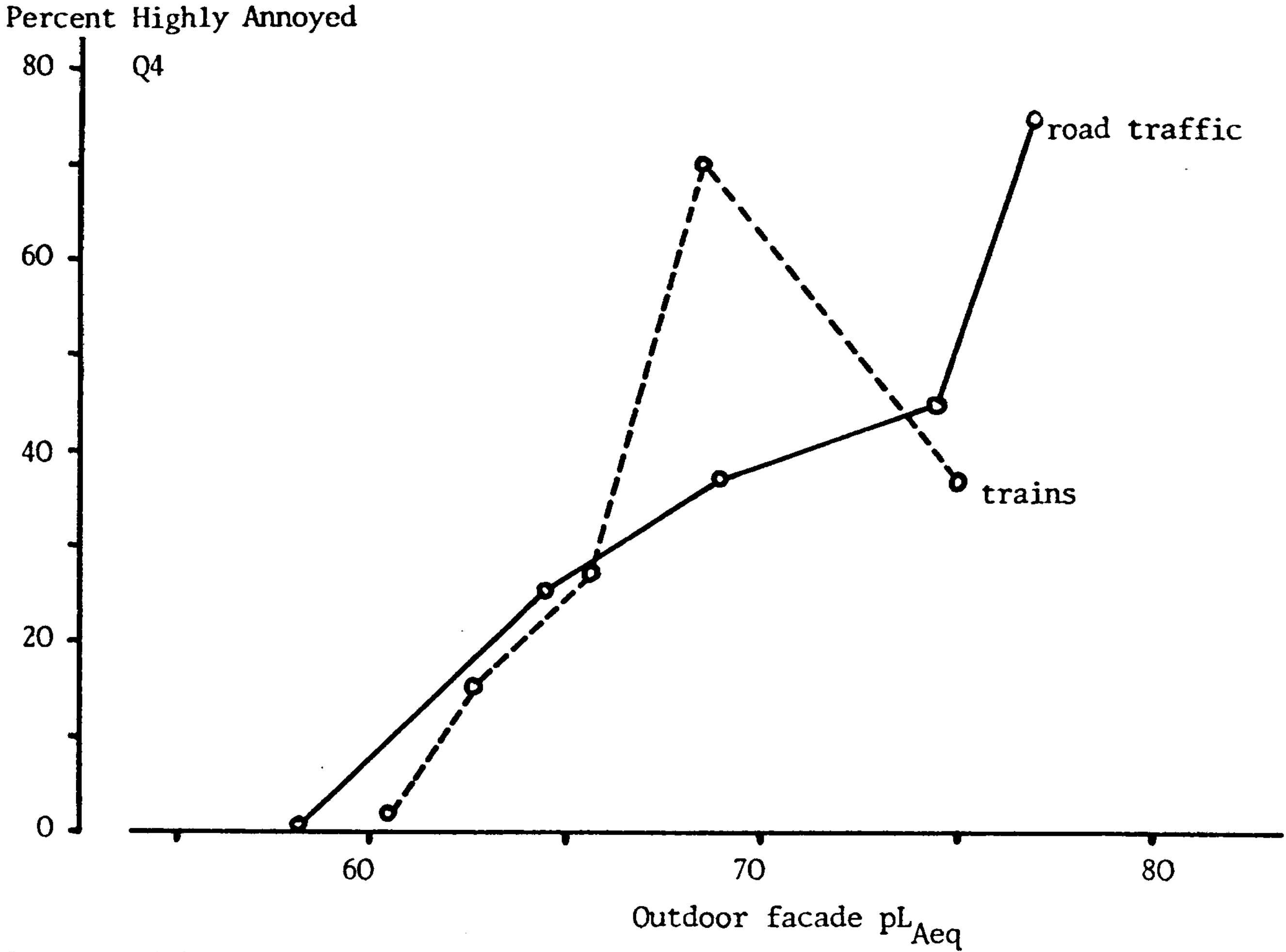

Percent Highly Annoyed
Q2
80
60
40
20
0
60
70
80
Outdoor facade L_{Aeq}
road traffic
trains

Figure 6,5


Percent Highly Annoyed
Q4
80
60
40
20
0
60
70
80
Outdoor facade pL_{Aeq}
road traffic
trains

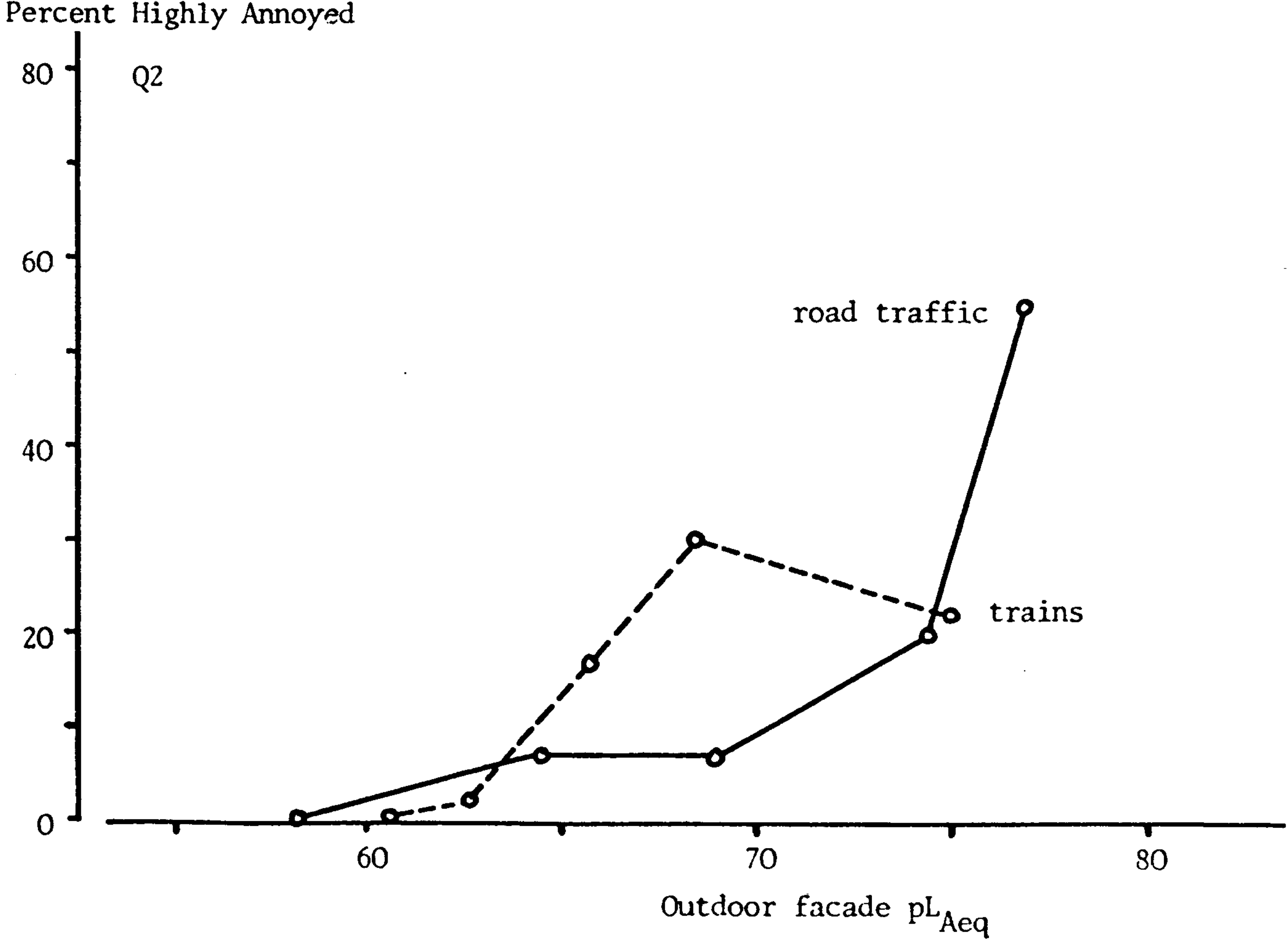

Percent Highly Annoyed
Q2
80
60
40
20
0
60
70
80
Outdoor facade pL_{Aeq}
road traffic
trains

Figure 6.6

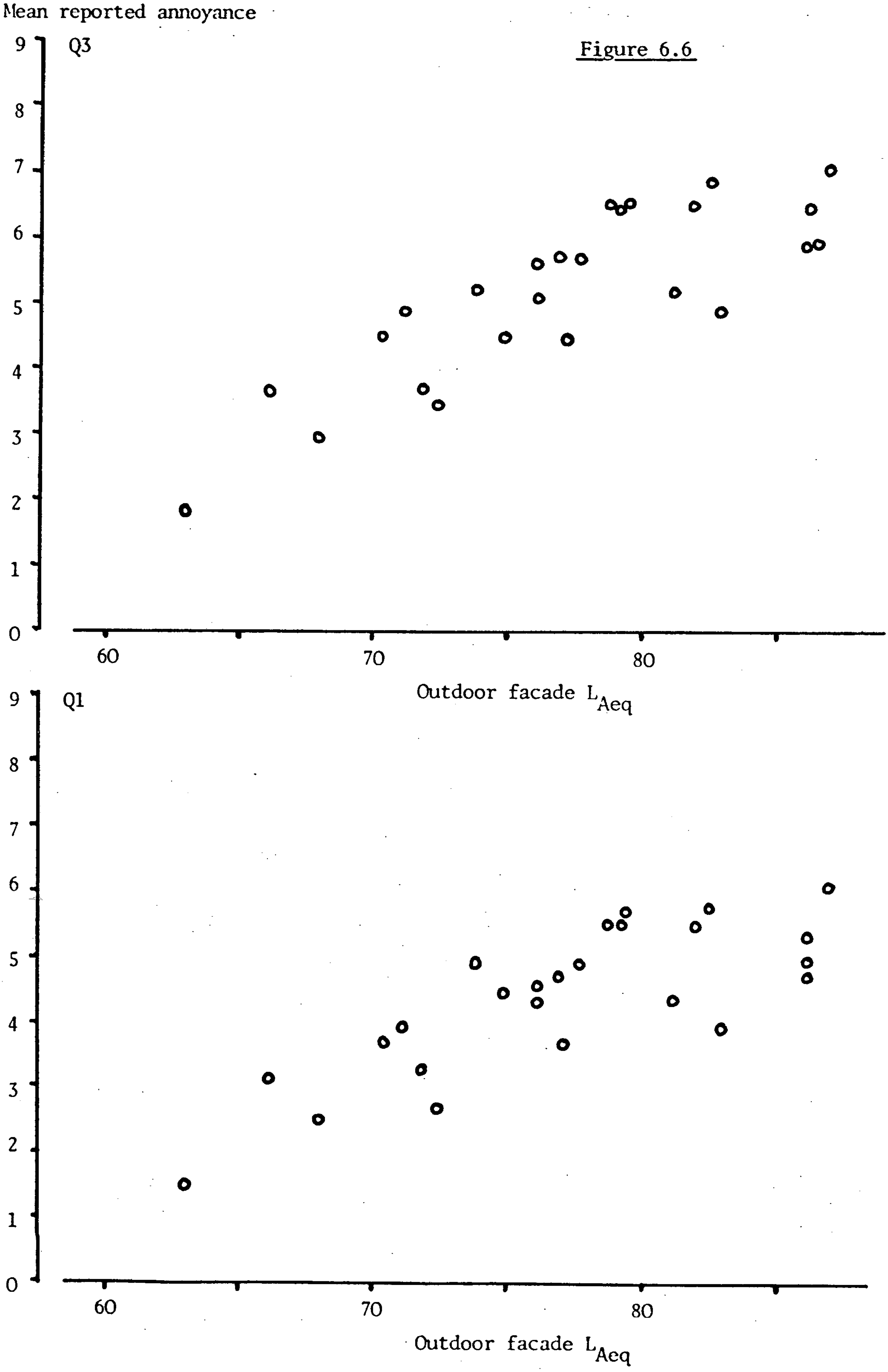
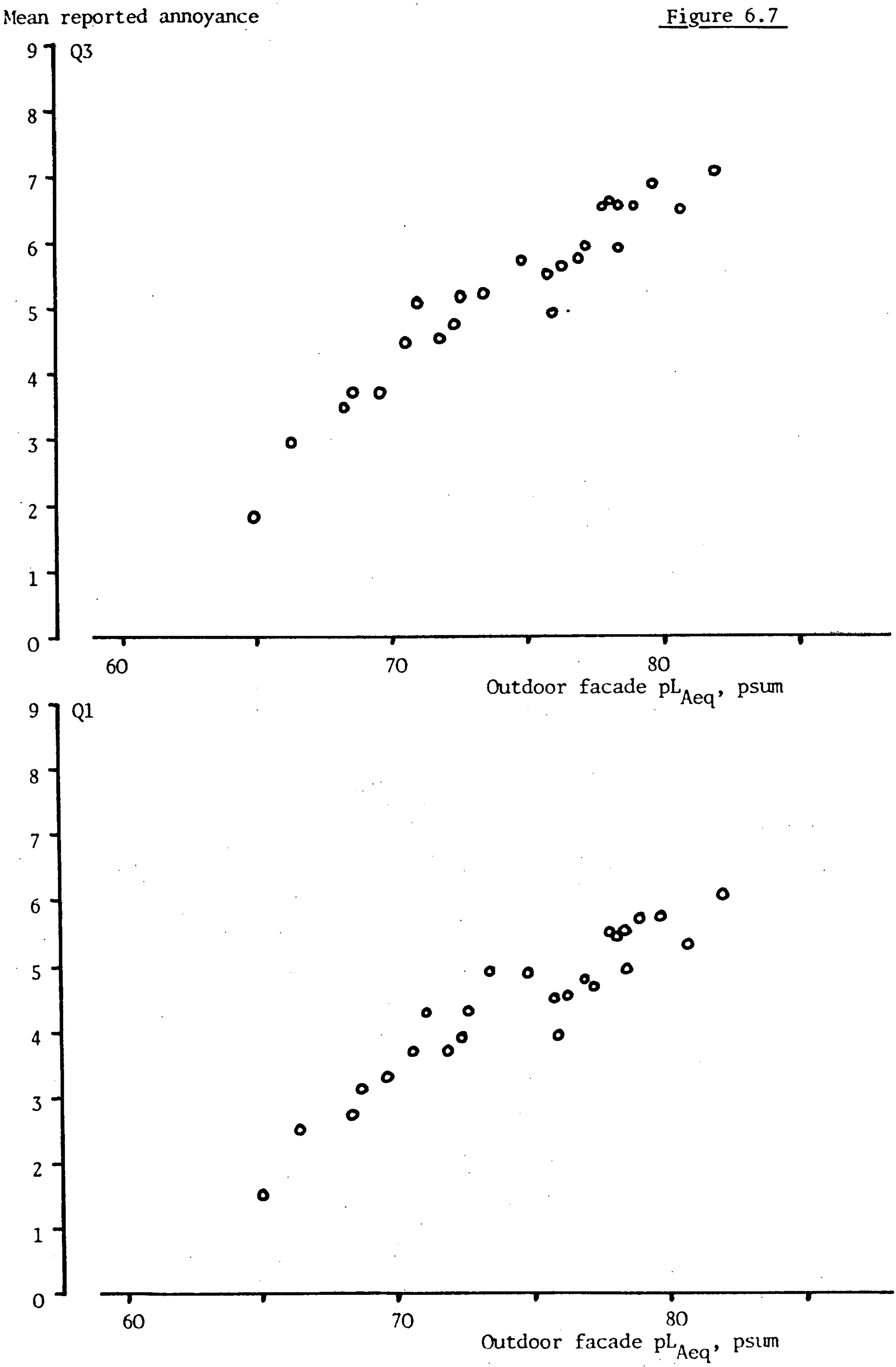

Mean reported annoyance
Q3
9
8
7
6
5
4
3
2
1
0
60
70
80
Outdoor facade L_{Aeq}
Q1
9
8
7
6
5
4
3
2
1
0
60
70
80
Outdoor facade L_{Aeq}

Figure 6.7


Mean reported annoyance
Q3
9
8
7
6
5
4
3
2
1
0
60
70
80
Outdoor facade pL_{Aeq}, psum
Q1
9
8
7
6
5
4
3
2
1
0
60
70
80
Outdoor facade pL_{Aeq}, psum

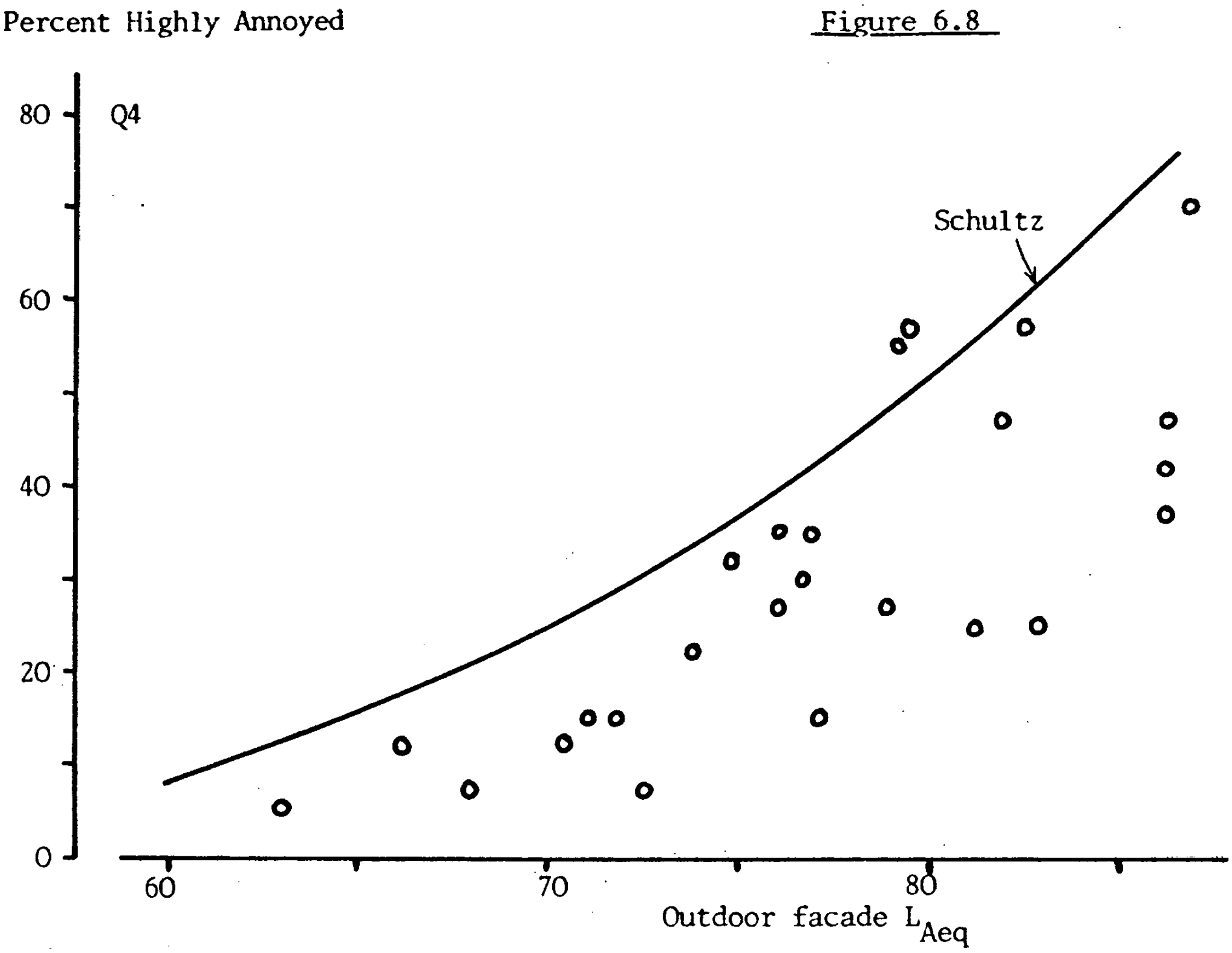
Figures 6.8 and 6.9 illustrate the reduction in scatter of per cent highly annoyed at Q2 and Q4 obtained by using pL_{Aeq}, psum instead of L_{Aeq} for the combinations treatments. There is an obvious improvement, although again, it is not possible to eliminate scatter entirely.

The Schultz curve [1] of per cent highly annoyed against noise level measured in L_{DN}, is plotted on Figure 6.8 (Q4). The Schultz curve was derived by averaging the results of eleven "clustering" surveys. As plotted, the Schultz curve generally predicts higher percentages highly annoyed than the percentages actually obtained. The discrepancy would be still greater if account had been taken of the difference between L_{DN} and 24 hour L_{Aeq}. This difference depends upon the amount of noise at night compared with the amount of noise during the day, and could be as much as 6 dB if noise continues at the same level through the night as during the day.

This discrepancy could be due to inaccurate projection to the home environment when directly asked about high annoyance in the laboratory or it could be due to the emphasis in the laboratory placed on response to the overall noise. The field surveys included in Schultz's synthesis were generally investigating source specific responses to environments which were not well specified with respect to other contributing noise sources. Aircraft noise, for example, is rarely heard in isolation from road traffic noise, yet Taylor *et al.*s [63] survey of response to aircraft noise around Toronto Airport is one of the few surveys that attempted to measure other contributing noise sources.

The emphasis in the laboratory placed on response to the overall noise can be traced back to Powell's work [41]. The effects of background noise can be different depending upon whether the subjects are asked to rate single intruding noises, or the overall noise for annoyance. In particular, where an experiment includes combinations of noise sources, it is not particularly useful to separate out the different sources in the subject instructions and questionnaires. With respect to the discrepancy between Schultz's curve and the road traffic and railway noise study per cent highly annoyed data, this might well be due to concentrated attention effects leading to an overestimation of high annoyance in the field, in relation to high annoyance in an overall context.

Figure 6.8


Percent Highly Annoyed
80
60
40
20
0
Q4
Schultz
60
70
80
Outdoor facade L_{Aeq}

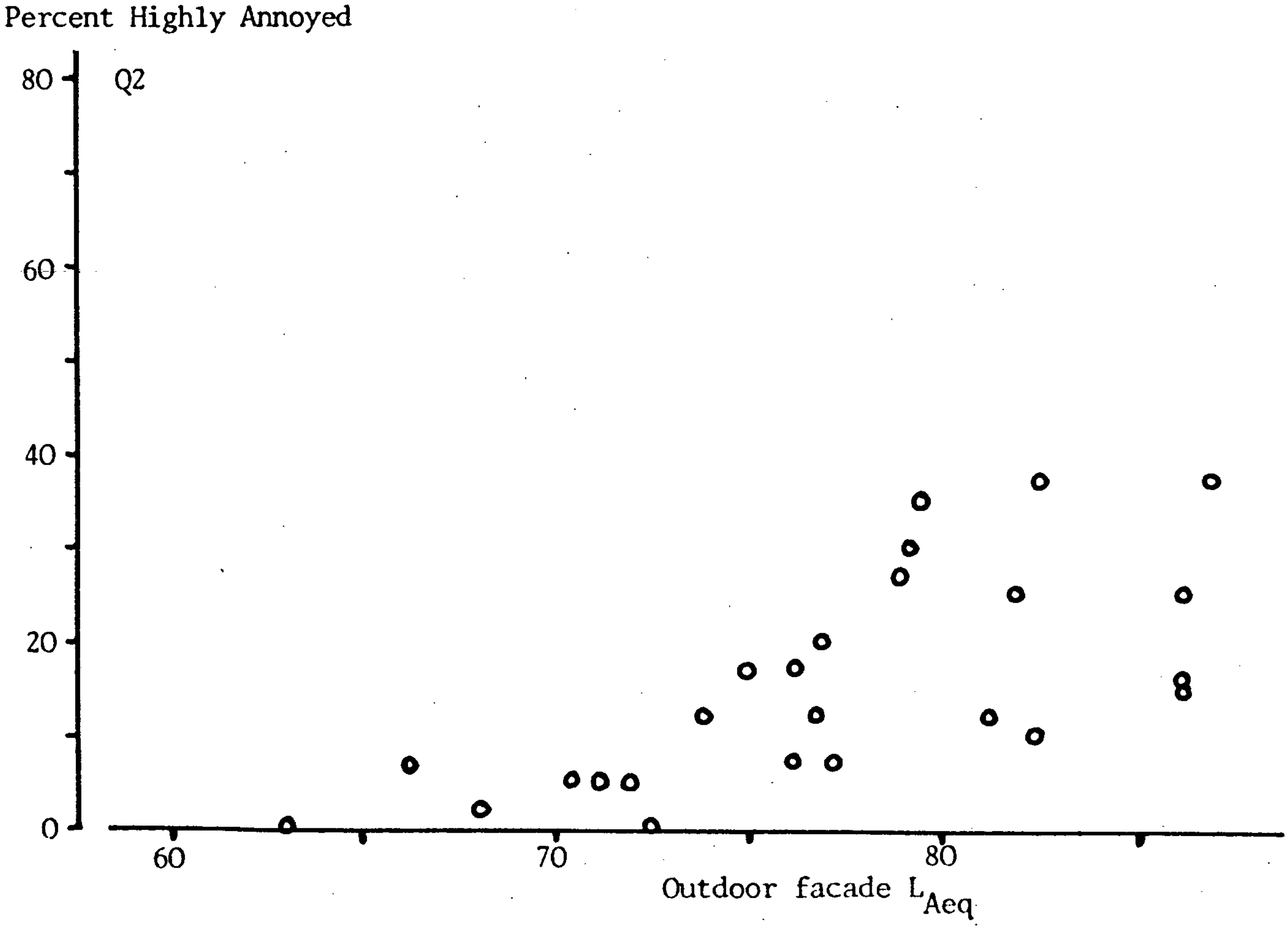
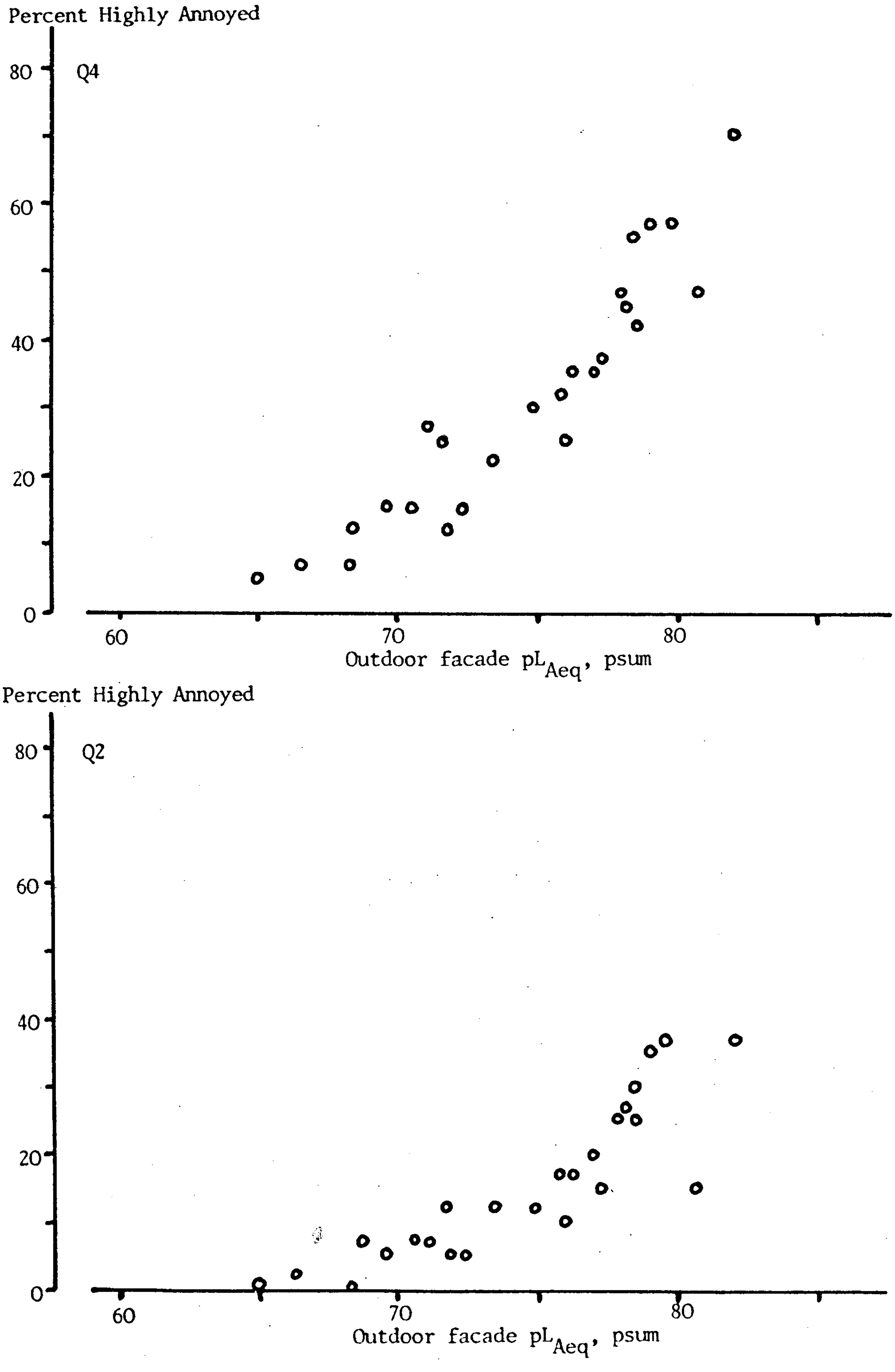

Percent Highly Annoyed
80
60
40
20
0
Q2
60
70
80
Outdoor facade L_{Aeq}

Figure 6.9


Percent Highly Annoyed
80
Q4
60
40
20
0
60
70
80
Outdoor facade pL_Aeq, psum
Percent Highly Annoyed
80
Q2
60
40
20
0
60
70
80
Outdoor facade pL_Aeq, psum

6.4 Other Models

There are other models requiring consideration (see Chapter 3.11). These are the corrected energy sum procedure and the Powell model. Both models require subjective weightings to be added to the separate noise source L_{Aeq}'s in order to take account of the differences in response at similar L_{Aeq}'s. These subjective weightings were derived by calculating corrected L_{Aeq}'s from the mean reported annoyance ratings for each separate noise source treatment, using the regression obtained for mean reported annoyance and road traffic noise L_{Aeq} (see table 6.3).

In theory, it would be possible to correct the measured road traffic noise levels in relation to the railway noise separate source regression. This was not done on the basis of an *a priori* decision that road traffic noise would be the reference against which to correct other noise sources. Road traffic is the most universal source of community noise throughout Britain. The correction procedure is illustrated at Figure 6.10. This shows the separate noise source mean reported annoyance ratings at Q3 plotted against outdoor facade L_{Aeq}. The regression for road traffic noise alone is shown. Corrected L_{Aeq}'s were derived by calculating the L_{Aeq} at which the horizontal projections from each data point cross the regression line. The corrections for the road traffic noise L_{Aeq}'s are very small, but they are significant for the railway noise L_{Aeq}'s.

Table 6.4 gives correlation coefficients between mean reported annoyance projections at Q3 and the different noise measures examined. The correlation coefficients for L_{Aeq} and pL_{Aeq}, psum are taken from table 6.3. The corrected energy sum is the overall L_{Aeq} using corrected L_{Aeq}'s instead of actual L_{Aeq}'s for the contributing noise source levels (see Chapter 3.3). The psum of corrected L_{Aeq}'s is the pressure sum (instead of the energy sum) of the corrected L_{Aeq}'s for each contributing noise source (as described in Chapter 3.5). The Powell model was applied using corrected L_{Aeq}'s for each contributing noise source [3].

pL_{Aeq}, psum, the corrected energy sum, the psum of corrected L_{Aeq}'s and the Powell model all perform significantly better than conventional L_{Aeq}, but are not statistically significantly different. However, there is a trend for the corrected energy sum and the Powell model to perform better than pL_{Aeq}, psum, and for the psum of corrected L_{Aeq}'s to perform best of all.

Figure 6.10

Corrections to L_{Aeq}s

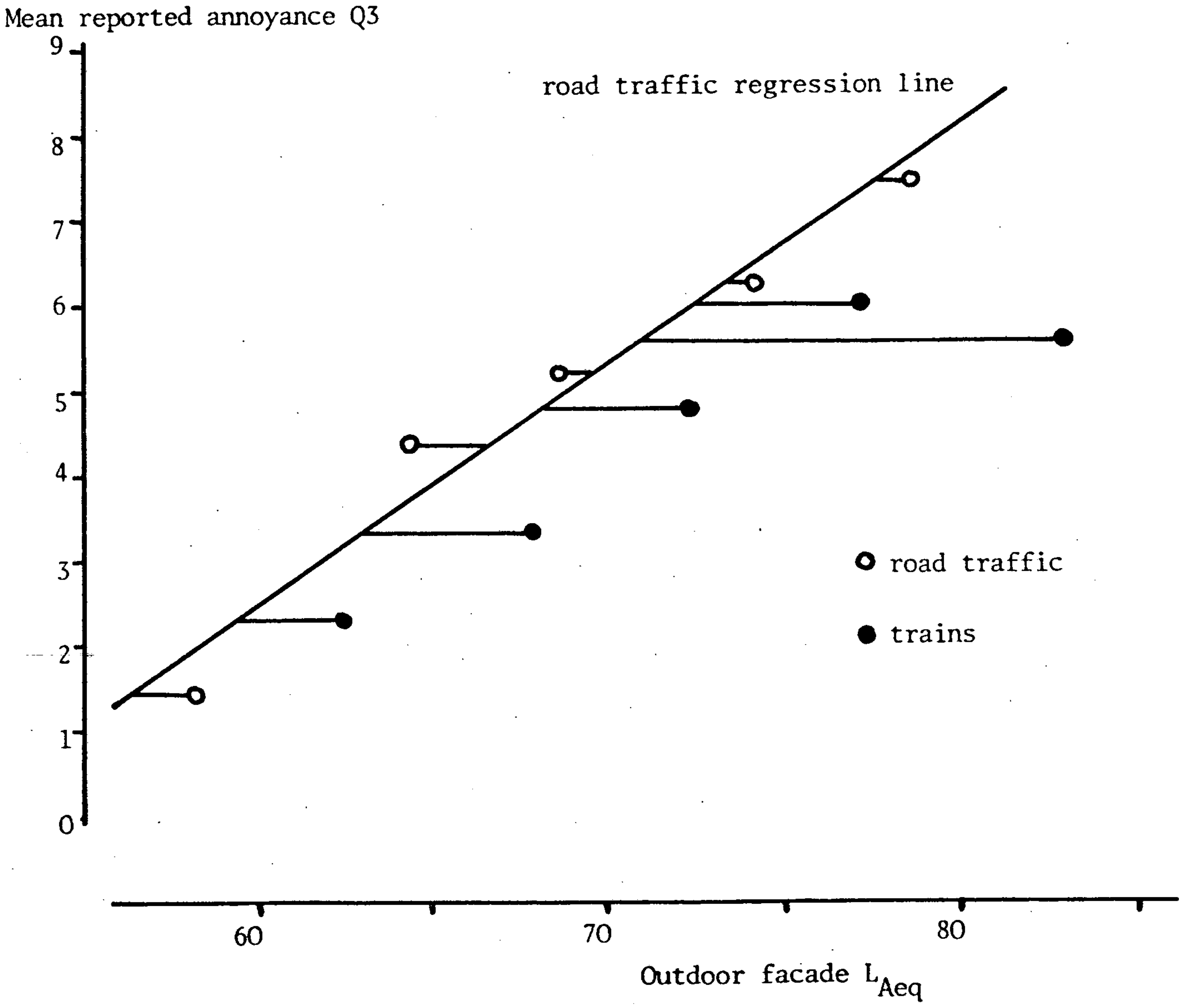


Table 6.4 Correlation coefficients

Mean reported annoyance projections and different measures. Combinations treatments.

Noise Measure	r
Conventional L_{Aeq}	0.828
pL_{Aeq}, psum	0.960
Corrected energy sum	0.969
psum of corrected L_{Aeq}'s	0.976
Powell model (corrected L_{Aeq}'s)	0.971

If this trend reflects the true state of affairs then the implication is that pL_{Aeq}, psum is not a universal solution to the assessment of multiple noise source environments. However, as stated in Chapter 1, the concept of taking the average rms pressure as opposed to the average intensity is proposed as an improvement without necessarily being a complete solution to the problems of predicting response to noise. The main argument in favour of pL_{Aeq}, psum is that it is superior to conventional L_{Aeq}, without necessarily being the last word on the problem. It may not be able to account for impulsive, tonal or other qualities of specific sounds that lead to increased annoyance potential in the same way that L_{Aeq} cannot necessarily account for these factors. For example, in the road traffic and railway noise study, condition 2 was found more annoying than condition 4 despite the fact that condition 4 had higher peak levels and longer signal durations (defined as the -10 dB down time) than condition 2. It is hard to conceptualise any objective measurement procedure that would account for such an odd result. Nevertheless, the fact that subjects found condition 2 more annoying is real. The reason may well have been because the train recordings reproduced at condition 4 had a more pleasant quality. However, one may as well attempt to devise an objective measurement scheme for music that correlates with subjective impression as attempt to explain the preference for condition 4 over condition 2 in purely acoustic terms.

Table 6.4 shows that the calculation procedures employing corrected L_{Aeq}'s performed better than pL_{Aeq}, psum. That is because corrected L_{Aeq} can take account of anomalies such as the subjective preference for condition 4 over condition 2 whereas pL_{Aeq} cannot. Nevertheless, there is no way that the appropriate correction (-12 dB) to the L_{Aeq} for condition 4 could have been predicted in advance. Thus pL_{Aeq} would be preferable to corrected L_{Aeq} as a unified noise scale for separate contributing noise sources except in the unlikely situation that all noise assessments could be carried out by a listening jury rather than by objective measurements.

The comparison between corrected energy sum, the psum of corrected L_{Aeq}'s and the Powell model with pL_{Aeq}, psum is thus unfairly biased against pL_{Aeq}, psum in the light of the comments above. However, it is useful to compare the three procedures for summing contributing noise source levels (energy sum, pressure sum and Powell model). There is a trend here for the pressure sum to perform best, followed by Powell and then by the energy sum. Now, the maximum difference between the psum and the energy sum is 3 dB, and the Powell model is very similar to the psum (see Chapter 3.11). Therefore the small differences in correlation coefficient obtained with the three summing procedures are not surprising. Nevertheless, the psum appears to have the advantage.

6.5 Conclusion

The major conclusion from this study is that the pL_{Aeq}, psum procedure was supported. However, it must be recognised that the psum of corrected L_{Aeq}'s can give slightly higher correlations with mean reported annoyance ratings. There is, however, a major disadvantage to the concept of corrected L_{Aeq}. This is that the appropriate corrections might have to be separately determined by a listening jury for every possible situation. If this is considered impractical, then pL_{Aeq}, psum offers a significant improvement over conventional L_{Aeq} *and is a completely objective procedure.*

CHAPTER 7

COMPARISONS WITH OTHER DATA

7.1 Introduction

The pL_{Aeq}, psum procedure was supported by the road traffic and railway noise study (Chapter 6). The mean reported annoyance to railway noise exposure as a separate noise source was similar to the mean reported annoyance to road traffic noise exposure as a separate noise source, at similar pL_{Aeq}'s. The mean reported annoyances to the two noise sources exposed as separate noise sources was not the same at similar L_{Aeq}'s. Further, the psum procedure for summing contributing noise source levels performed better than the energy sum or the Powell model, although the improvement was not statistically significant.

It is therefore essential to examine other sets of published data in order to establish whether any additional support for the pL_{Aeq}, psum procedure can be obtained. Unfortunately, very few sets of published data are suitable for a quantitative re-analysis to be undertaken. It is normally impossible to estimate noise exposure in terms of pL_{Aeq} due to an insufficiency of information. Furthermore, suitable studies must involve more than one noise source in order for comparisons to be possible.

A laboratory study of airborne aircraft, airport ground and road traffic noise [64] was carried out using very similar techniques to the road traffic and railway noise study (Chapter 6). This study supported both pL_{Aeq} as a unified scale for separate noise sources and the psum procedure for summing contributing noise source levels (Chapter 7.2). A similar laboratory study of response to road traffic and aircraft noise [3] supported the psum procedure, but not pL_{Aeq}, as a unified scale for separate noise sources (Chapter 7.3). However, the pL_{Aeq} concept was quantitatively supported by a study of relative responses to road traffic noise and aircraft noise [40].

The evidence from recent major field surveys of response to community noise is confusing. Some data support the pL_{Aeq}, psum procedure and other data do not support the procedure (Chapter 7.4). There are several possible reasons why certain field survey data do not support the pL_{Aeq}, psum procedure and these are discussed at their appropriate points in this chapter.

The pL_{Aeq}, psum procedure implies that a doubling of the number of noise events, such as aircraft flyovers, should be equivalent to an increase in peak level of those events of 6 dB. The current U.K. aircraft noise exposure measure, the Noise and Number Index (NNI) equates a doubling of number with an increase in peak levels of 4½ dB. A number of possible reasons for this discrepancy are discussed (Chapter 7.5) and a recent laboratory study by Powell [65] is quoted in qualitative support of the pL_{Aeq}, psum procedure.

7.2 Airborne Aircraft, Airport Ground and Road Traffic Noise Study

This study was carried out to provide evidence for the Stansted Airport Development Public Inquiry [64]. In their published form the results can only be used to support the pL_{Aeq} concept qualitatively, since airborne aircraft noise was found to make a smaller contribution to overall annoyance than airport ground or road traffic noise when present at similar separate source L_{Aeq}'s. However, the raw data was made available [66] by kind permission of the British Airports Authority who commissioned the study. This enabled a proper test of the pL_{Aeq}, psum procedure to be carried out, in comparison with overall L_{Aeq}, corrected energy sum, and the psum of corrected L_{Aeq}'s.

Twenty-four combinations of noises from the three noise sources were selected as being representative of the future noise environment in the area around a developed Stansted Airport. These were composed of airborne aircraft noise at outdoor facade L_{Aeq}'s of 45, 55, 65 and 75, airport ground noise at outdoor facade L_{Aeq}'s of 45, 55 and 65 and road traffic noise at outdoor facade L_{Aeq}'s of 45, 55 and 65. Tape recordings were reproduced in the simulated domestic living room using 10 minute sessions. The indoor laboratory L_{Aeq}'s were 15 dB below the outdoor facade L_{Aeq}'s. Only those combinations of levels of the three noise sources that might actually occur were used. Airport ground noise, for example, never occurs at higher L_{Aeq}'s than airborne aircraft noise.

The detailed techniques and questionnaires were very similar to those used in the road traffic and railway noise study described in Chapter 6, except that an incomplete block experimental design was used. This means that each of the forty-eight subjects only judged eight out of the twenty-four combinations treatments. Mean reported annoyance ratings were adjusted to take account of any bias that the use of incomplete blocks might have introduced. It was not possible to adjust the percentages highly annoyed at Q2 and Q4, and these percentages are not reported here.

The results are shown at Table 7.1. Overall L_{Aeq} and pL_{Aeq}, psum were obtained by direct measurement in the laboratory, allowing for the 15 dB outdoor/indoor attenuation. The corrected L_{Aeq}'s for use in calculating corrected energy sum (see Chapter 3.3) and the psum of corrected L_{Aeq}'s (see Chapter 3.5) were derived from an examination of Figure 7.1 which illustrates the effects of noise source and level as main effects in an analysis of variance. The corrected L_{Aeq}'s were derived by comparison against the curves of mean reported annoyance ratings with L_{Aeq} for road traffic noise. Because the patterns of response to Q1 (mean reported annoyance referred to the laboratory) and Q3 (mean reported annoyance projected to the home) were slightly different, the appropriate corrected L_{Aeq}'s for airport ground noise and for airborne aircraft noise are *different*, depending upon analysis of Q1 or Q3.

Table 7.2 gives correlation coefficients between mean reported annoyance ratings at Q1 and Q3 and the different noise measures examined. The correlation coefficients for pL_{Aeq}, psum and corrected energy sum are not statistically different. pL_{Aeq}, psum and corrected energy sum perform significantly better than overall L_{Aeq}. The psum of corrected L_{Aeq}'s performs significantly better than pL_{Aeq}, psum or corrected energy sum at Q3 but not at Q1, where there is only a trend to superior performance.

These results are very similar to the results obtained in the road traffic and railway noise study (see Chapter 6). They imply, first, that pL_{Aeq}, psum is a superior measure of the annoyance potential of multiple noise source environments than overall L_{Aeq}, and secondly, when corrected L_{Aeq}'s for the separate noise sources are taken into account, that the psum performs better than the energy sum. The same comments that were made in Chapter 6.4 apply here. Corrected L_{Aeq} can reflect

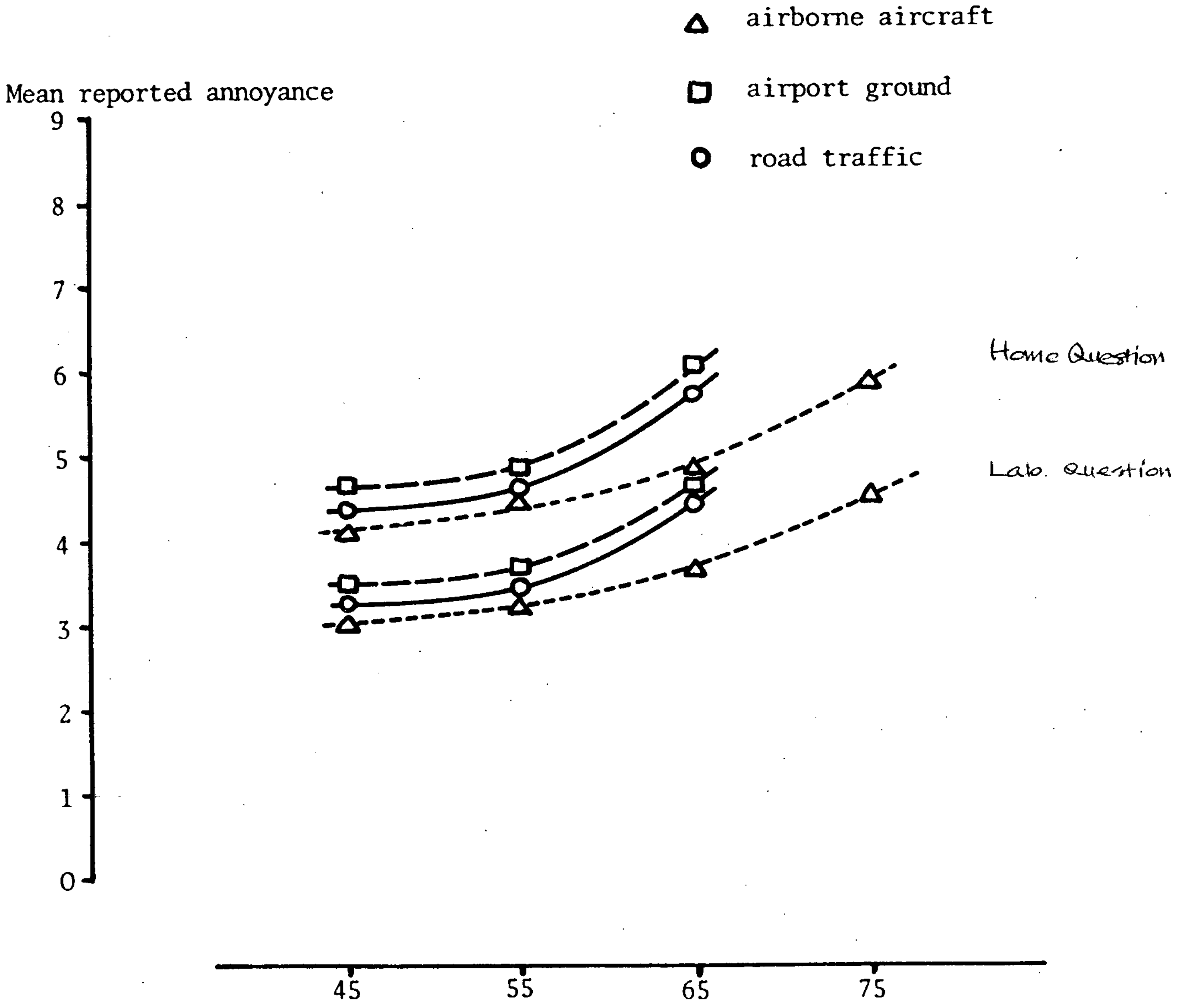
Table 7.1. Airborne aircraft, airport ground and road traffic noise study. Results.

Treatment	Aircraft L_{Aeq}	Ground L_{Aeq}	Road L_{Aeq}	Overall L_{Aeq}	pL_{Aeq}, psum	Q1 annoyance	Corrected (Q1) energy sum	(Q1) psum of corrected L_{Aeq}	Q3 annoyance	Corrected (Q3) energy sum	(Q3) pressure sum of corrected L_{Aeq}
1	75	45	45	75	64.6	3.92	66.5	68.9	5.16	66.3	68.7
2			55	75.1	66.3	4.09	66.7	70.0	5.41	66.6	69.8
3			65	75.4	69.3	5.10	68.8	72.8	6.54	68.7	72.7
4	75	55	45	75	65.7	4.13	66.8	69.6	5.30	66.5	69.2
5			55	75.1	67.2	4.30	67.0	70.6	5.55	66.8	70.3
6			65	75.5	70.0	5.31	69.0	73.3	6.68	68.8	73.0
7	65	45	45	65.1	58.9	2.96	59.4	63.5	4.03	58.8	62.8
8			55	65.5	61.9	3.10	60.8	65.5	4.28	60.1	64.9
9			65	68	66.4	4.14	66.1	69.8	5.41	65.9	69.5
10	65	55	45	65.5	60.9	3.17	60.9	64.8	4.17	59.8	63.7
11			55	65.8	63.5	3.34	61.8	66.5	4.42	60.9	65.6
12			65	68.2	67.3	4.35	66.4	70.5	5.55	66.1	69.9
13	65	65	45	68.0	67.5	4.12	67.5	70.0	5.40	67.6	70.0
14			55	68.2	68.7	4.29	67.7	71.0	5.65	67.9	71.0
15			65	69.8	71.1	5.30	69.4	73.6	6.78	69.5	73.6
16	55	45	45	55.8	54.9	2.60	56.3	60.2	3.70	56.5	60.6
17			55	58.2	59.4	2.77	58.5	63.0	3.95	58.6	63.2
18			65	65.4	65.0	3.78	65.5	68.4	5.08	65.5	68.5
19	55	55	45	58.2	58.0	2.81	58.7	62.0	3.84	58.1	61.8
20			55	59.8	61.3	2.98	60.1	64.3	4.09	59.7	64.1
21			65	65.8	66.1	3.99	65.9	69.1	5.22	65.8	69.0
22	45	45	45	49.8	53.2	2.33	55.4	57.4	3.28	55.2	57.2
23			55	55.8	58.4	2.50	58.0	61.0	3.53	57.9	60.9
24			65	65.1	64.5	3.51	65.4	67.4	4.66	65.4	67.3

Figure 7.1

Airborne aircraft, airport ground and road traffic noise study

Main effects



the annoyance potential of separate contributing noise sources better than pL_{Aeq}. However, when the corrections differ depending upon the question used to measure response, the correction procedure cannot be considered very satisfactory except in the unlikely situation that all noise assessments could be carried out by a listening jury rather than by objective measurements. It is important to note that pL_{Aeq}, psum performed as well as corrected energy sum which was the procedure recommended in the published report [64]. The pL_{Aeq}, psum procedure was not considered in that report.

The results are illustrated at figures 7.2, 7.3, 7.4 and 7.5.

Table 7.2 Airborne aircraft, airport ground and road traffic noise study. Correlation coefficients.

Question	Noise Measure	Correlation Coefficient
Q1	Overall L_{Aeq}	0.844
	pL_{Aeq}, psum	0.951
	Corrected energy sum	0.951
	psum of corrected L_{Aeq}'s	0.968
Q3	Overall L_{Aeq}	0.837
	pL_{Aeq}, psum	0.952
	Corrected energy sum	0.951
	psum of corrected L_{Aeq}'s	0.976

Figure 7.2

Airborne aircraft, airport ground and road traffic noise study

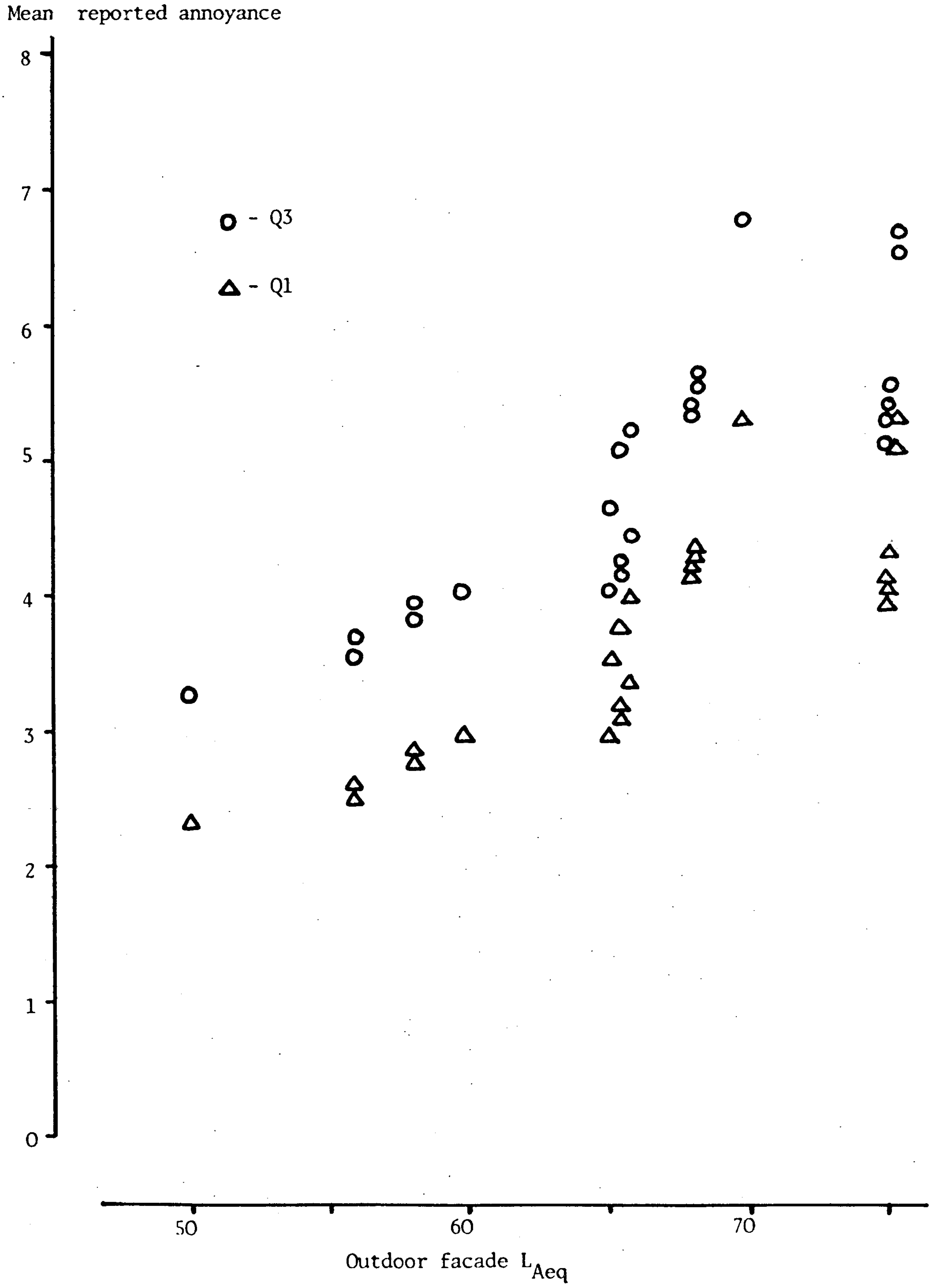


Figure 7.3

Airborne aircraft, airport ground and road traffic noise study

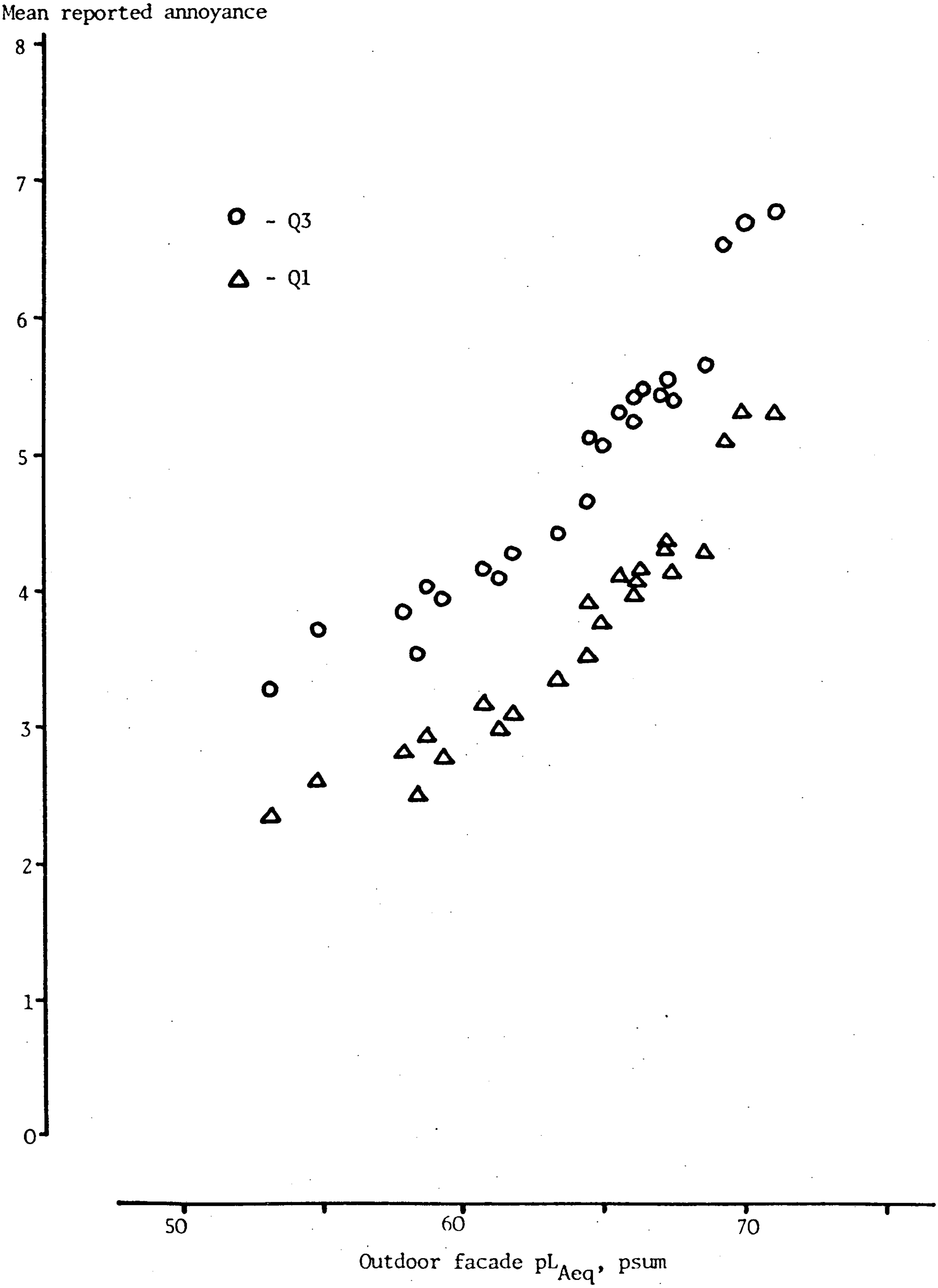


Figure 7.4

Airborne aircraft, airport ground and road traffic noise study

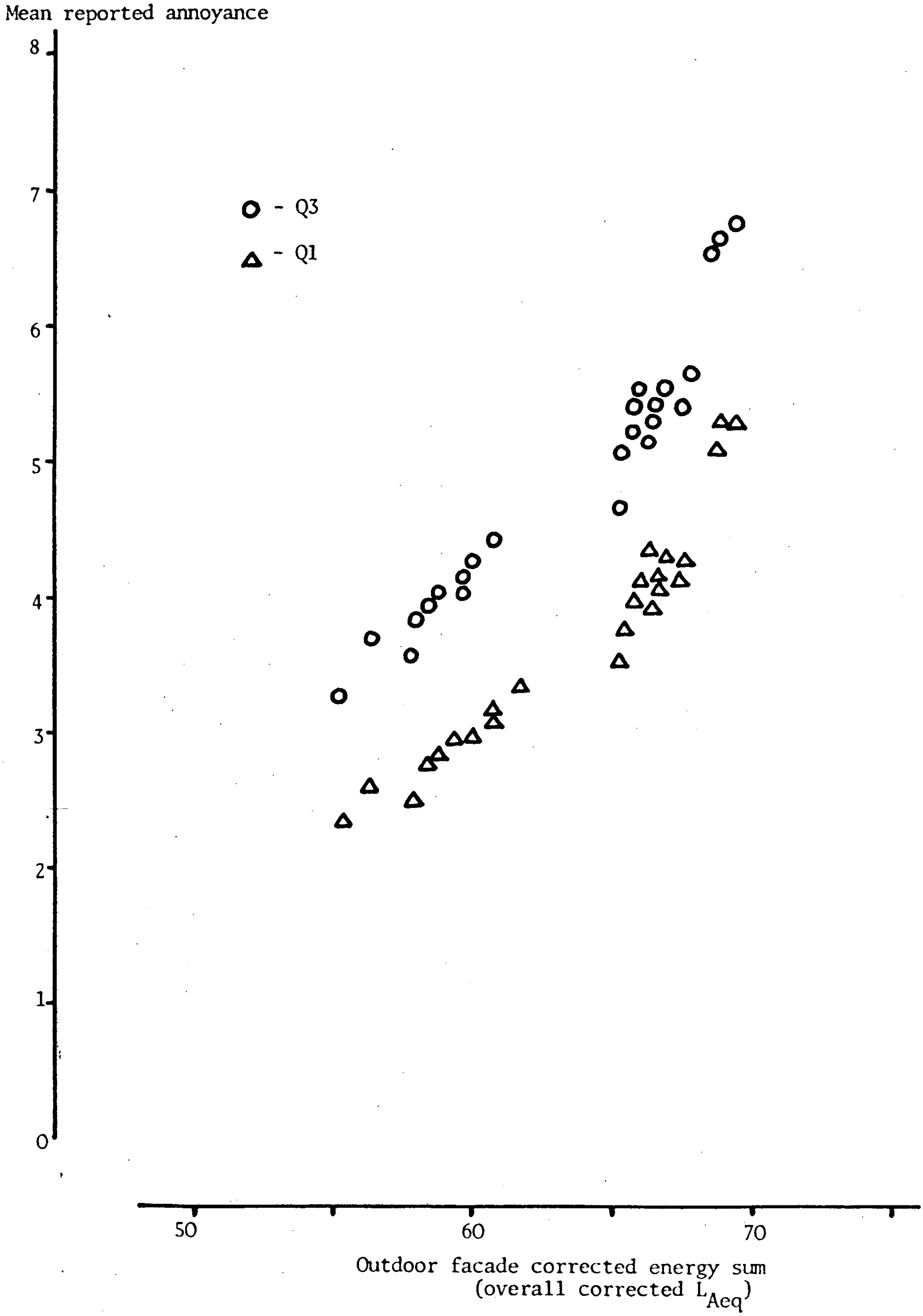
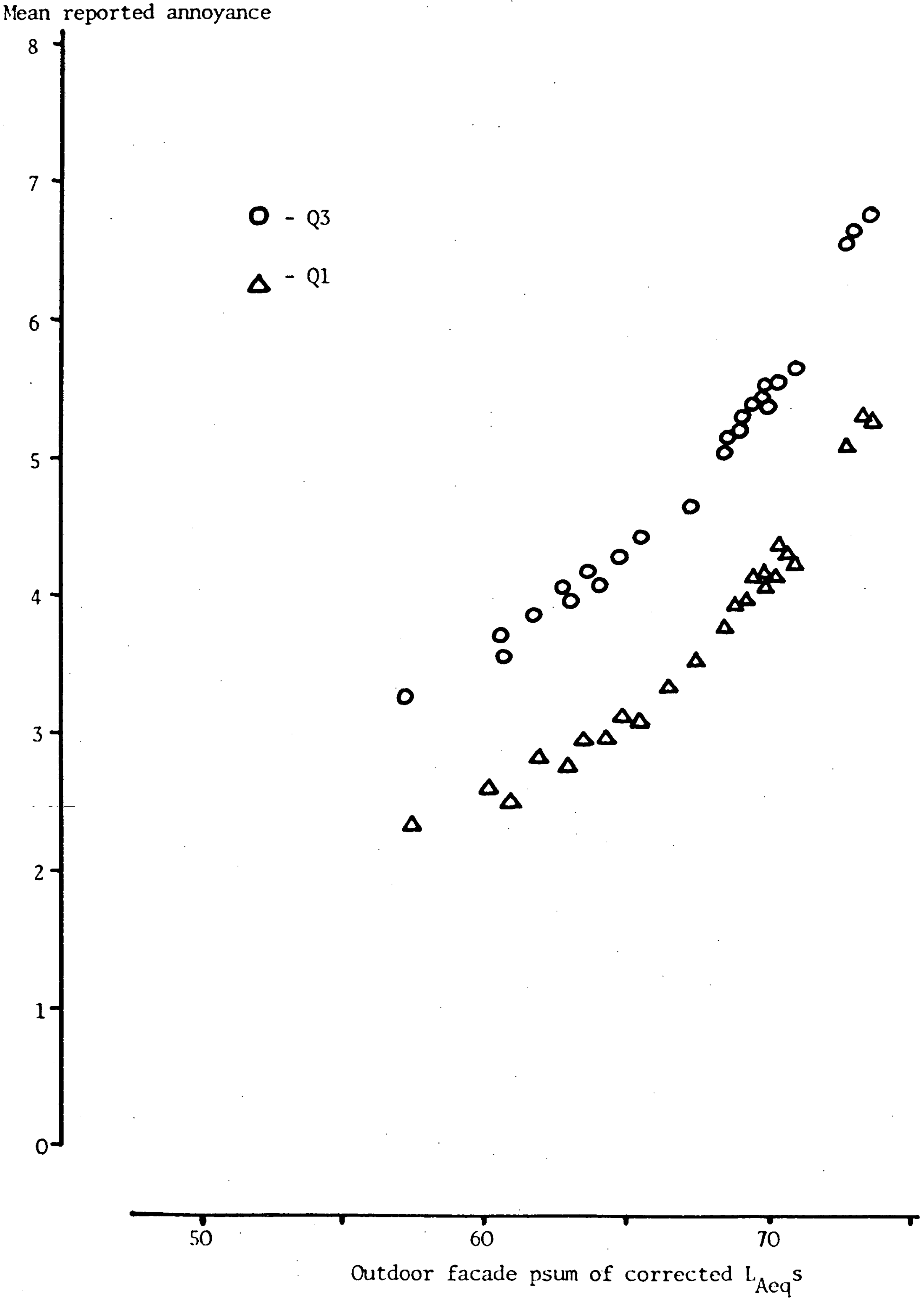


Figure 7.5

Airborne aircraft, airport ground and road traffic noise study



7.3 Powell's Laboratory Study of Road Traffic and Aircraft Noise

Powell [3] conducted a session type experiment in a simulated domestic living room in order to test his summation and inhibition model of annoyance responses to mixed noise sources. He used road traffic noise and aircraft noise tape recordings reproduced at indoor L_{Aeq}'s of 30, 40, 50 and 60, presented separately, and at all nine combinations of the 40, 50 and 60 L_{Aeq}'s of each noise source.

The mean reported annoyance ratings for the separate source aircraft noise treatments were marginally higher than for the separate source road traffic noise treatments at the same L_{Aeq}'s. In other words, corrections to the aircraft noise L_{Aeq}'s of the order of +2 or +3 dB were implied by the data. The combinations treatments gave higher mean reported annoyance ratings than would be implied by overall L_{Aeq}, where the two contributing noise sources were at similar L_{Aeq}'s. Powell considered that this enhanced annoyance potential of mixed noise sources was consistent with his summation and inhibition model.

It is not possible to calculate pL_{Aeq}'s for the noise recordings reproduced in Powell's study. Therefore no quantitative test of pL_{Aeq} is possible. However, Powell's finding that aircraft noise was more annoying than road traffic noise at the same L_{Aeq}'s is not consistent with the pL_{Aeq} concept. pL_{Aeq} implies that any intermittent noise, such as aircraft noise, should have less nuisance potential than any continuous noise, such as road traffic noise, at the same L_{Aeq}'s. Powell's data on the relative response to aircraft noise and road traffic noise is not consistent with Large's [64] and Rice's [40] data.

Table 7.3 gives correlation coefficients between mean reported annoyance projections and the different noise measures examined. The overall L_{Aeq} is given by Powell for each condition in his experiment. The corrected energy sum, the Powell model, and the psum of corrected L_{Aeq}'s were calculated on the basis of corrected L_{Aeq}'s for each contributing noise source. The corrected L_{Aeq}'s were calculated from the mean reported annoyance projections of each separate noise source condition using the regression between road traffic noise L_{Aeq} and mean reported annoyance projections for road traffic noise. The corrected energy sum is the overall L_{Aeq} using corrected L_{Aeq}'s instead of actual L_{Aeq}'s for the contributing noise sources. The Powell model was applied using the corrected L_{Aeq}'s for each contributing noise and the psum of corrected L_{Aeq}'s is the pressure sum (instead of the energy sum) of the corrected L_{Aeq}'s for each contributing noise source (as described in Chapter 3.5).

The correlation coefficients at Table 7.3 are not statistically significantly different. Nevertheless there are trends, first for the use of corrected L_{Aeq} to give an improvement in correlation coefficients and, secondly, for the psum or the Powell model to give even greater improvements in correlation coefficient. In fact, even higher correlation coefficients can be achieved using the generalised expression given at Chapter 3.4, equation (7) with a k factor of 33 (corresponding to a doubling of noise sources being equivalent to an increase in noise level of one of the sources by 10 dB).

These results imply that the psum or the Powell model reflect the annoyance potential of a combined noise source environment better than the energy sum. For this data, the Powell model "cusps" (see Chapter 3.11) actually give it a slight advantage over the psum. The point of the "cusp" of the Powell model corresponds to a doubling of noise sources being equivalent to an increase in noise level of one of the sources by 7.5 dB. This is at the point of subjective equality of the two contributing noise sources. At this point the psum corresponds to a doubling of noise sources being equivalent to an increase in noise level of one of the sources by 6 dB. Powell's data appears to fit the generalised expression (Chapter 3.4, equation (7)) with a k factor of about 33 (see above). This is within the range of k factors that might be expected on the basis of the physical correlate theory (see Chapter 3.12).

Nevertheless, the psum performs better than the energy sum, which is the result of greatest interest. The incompatibility of the data with the pL_{Aeq} concept for the separate noise sources is unexplained.

Figure 7.6 shows that the improvement gained by using the psum of corrected L_{Aeq}'s is marginal compared with conventional L_{Aeq}. This merely reflects the non-significant differences between correlation coefficients. There is considerable residual variance which would not be explained by any noise scale.

Figure 7.6

Powell Aircraft and road traffic noise

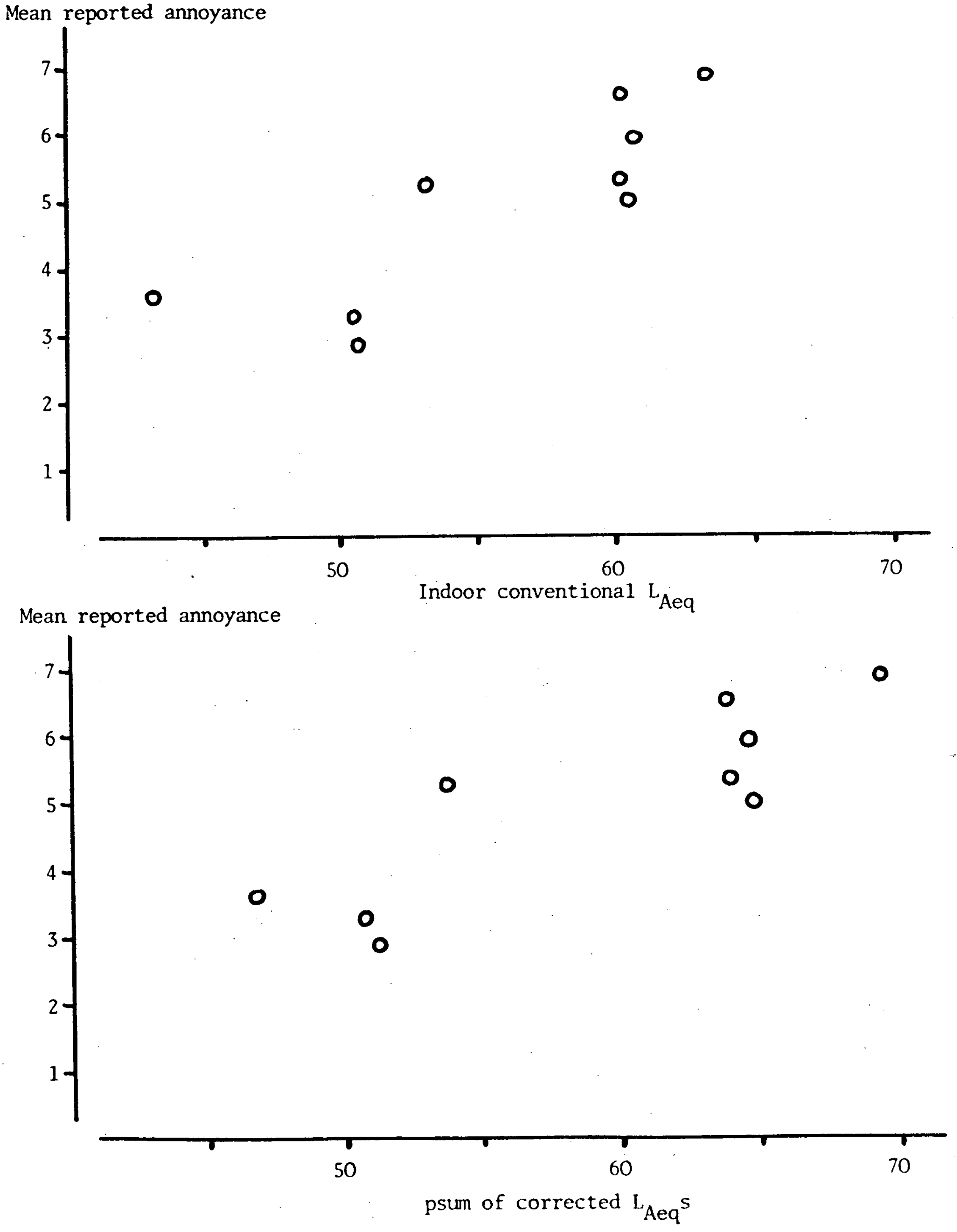


Table 7.3 Powell's road traffic and aircraft noise study. Correlation coefficients.

Noise Measure	Correlation Coefficient
Overall L_{Aeq}	r = 0.83
Corrected energy sum	r = 0.84
Powell model	r = 0.88
psum of corrected L_{Aeq}'s	r = 0.87

7.3 Rice's Comparison of Responses to Road Traffic and Aircraft Noise

Rice [40] conducted a session type experiment in a simulated domestic living room in order to investigate the concept of using a unified noise scale for the prediction of annoyance from aircraft and traffic noise heard over periods of time. The road traffic and aircraft noise conditions were only rated separately, and not in combination. Therefore the data is not suitable as a basis for comparing the psum with the Powell model and the energy sum. Further, there is no way of calculating pL_{Aeq}'s from the published data. Nevertheless, the data is in qualitative agreement with the pL_{Aeq} concept. This is because at equal L_{Aeq}'s traffic noise was found to be more annoying than aircraft noise. This finding is at variance with Powell's [3] data, discussed above although it is in qualitative agreement with Large's [64] data, discussed in Chapter 7.2, above.

7.4 Field Surveys

Field surveys by Bottom [67] and Hall, Birnie and Taylor [63] have investigated community reactions to noise environments having both aircraft noise and road traffic noise as contributing noise sources. Fields and Walker [2] carried out a detailed comparison of community reactions to railway noise, aircraft noise, and road traffic noise. They compared data from six surveys of community reactions to railway noise, aircraft noise and road traffic noise.

Bottom's survey [67]

Bottom conducted a field survey at nine sites combining three levels of aircraft noise (60 NNI, 45 NNI and 25 NNI) with three levels of road traffic flow (over 32,000 vehicles/day, 19,000 vehicles/day, and access traffic only). Bottom supported a Noise Pollution Level (L_{NP}) type of scale as the best predictor of general noise dissatisfaction. There was an interaction between aircraft noise and road traffic noise levels. General noise dissatisfaction at low aircraft noise levels increased with increasing road traffic noise but at high aircraft noise levels general noise dissatisfaction decreased with increasing road traffic noise.

Powell [41] criticised Bottom's survey on the grounds of inadequate noise exposure measures. Powell estimated L_{Aeq}'s due to the two contributing noise sources at the nine sites. These noise levels are shown at Table 7.4, together with mean general noise dissatisfaction. It is difficult to detect from these data which, if any, of the noise sources was making the greater contribution to general noise dissatisfaction at the difference exposure levels. However, the psum of Powell's estimated L_{Aeq}'s gives a slightly higher correlation with general noise dissatisfaction ($r = 0.923$) than the energy sum ($r = 0.910$), or in other words, the overall L_{Aeq}. Neither procedure can account for the interaction between the two noise source levels. Nevertheless, the data tends to support the psum procedure over the energy sum procedure although not with any worthwhile degree of statistical significance.

Table 7.4 Bottom's survey of road traffic and aircraft noise.

L_{Aeq}'s as estimated by Powell [41] and mean general noise dissatisfaction.

	Aircraft Noise	Road Traffic Noise	Mean Dissatisfaction
1	51	62	2.2
2		67	2.9
3		72	3.5
4	67	62	4.3
5		67	4.1
6		72	4.2
7	79	62	5.9
8		67	5.5
9		72	5.0

Taylor, Hall and Birnie's survey [63]

Taylor et al conducted a field survey at fifty-six sites combining different levels of aircraft noise and road traffic noise at each site. They concluded that the effect of road traffic noise (background) level on aircraft noise specific community reaction was generally not significant. Taylor kindly provided the aggregated data shown at table 7.5 for use in this analysis [68]. This data has very recently appeared in a paper by Taylor [75] which compares various models to predict annoyance reactions to noise from mixed sources.

Taylor investigated five models. These were: the simple energy summation model, overall L_{Aeq}; an independent effects model, in which the contributions of separate sources to total annoyance are assumed to be independent and additive; an energy difference model, in which annoyance is assumed to depend upon both the overall L_{Aeq} and the absolute difference between the separate source L_{Aeq}'s; Ollerhead's response summation model (see Chapter 3.8); and Powell's summation and inhibition of annoyance model (see Chapter 3.9).

Taylor concluded that firstly, the simple energy summation model was the weakest predictor of mean overall annoyance and secondly, that overall annoyance is the product of a mental combination of the annoyances induced by the separate sources. Taylor's energy difference model had a negative regression coefficient for the energy difference term, implying that for the same overall L_{Aeq} annoyance increases as the source L_{Aeq}'s approach equality.

It is not possible to derive separate source pL_{Aeq}'s from Taylor's data. Therefore, the hypothesis that pL_{Aeq} better represents the separate source contributions to overall annoyance than conventional L_{Aeq} cannot be tested quantitatively. Taylor's data, however, offers considerable support for the psum procedure as being superior to the energy sum procedure. This support is outlined below.

The correlation coefficients between overall disturbance ratings and the various models investigated by Taylor are shown at Table 7.6. Taylor's best fitting models, independent effects and energy difference give qualitative support for the psum procedure. The psum procedure is intended to account for a psychological rather than a physical phenomenon

Table 7.5. Taylor, Hall and Birnie's survey of road traffic and aircraft noise

	Aircraft L_{Aeq}	Road Traffic L_{Aeq}	Overall L_{Aeq}	Aircraft disturbance	Road traffic disturbance	Overall disturbance
1	55.6	55.0	58.3	3.65	0.31	2.18
2	55.8	69.9	70.1	2.17	4.33	3.53
3	56.9	52.2	58.2	2.80	0.46	2.09
4	58.6	56.1	60.5	4.26	1.00	2.76
5	58.6	62.1	63.7	3.68	4.23	4.33
6	59.0	58.0	61.5	3.05	0.17	1.90
7	59.7	54.0	60.7	3.90	0.28	2.75
8	60.0	57.4	61.9	6.46	0.83	4.35
9	61.6	60.7	64.2	5.06	2.94	4.32
10	62.0	57.5	63.3	4.66	1.65	2.63
11	62.7	55.6	63.5	5.91	0.13	2.99
12	63.4	54.1	63.9	4.76	0.98	3.65
13	63.8	52.7	64.1	4.52	0.42	2.54
14	64.5	58.5	65.5	4.87	1.46	2.46
15	65.6	56.0	66.1	5.90	0.07	3.25
16	67.1	67.9	70.5	6.23	3.78	5.15
17	71.1	59.5	71.4	5.00	0.52	3.95

(see Chapter 3.5), and is thus similar in concept to Taylor's independent effects model. The psum procedure also predicts greater annoyance than implied by the energy sum procedure, particularly where the contributing noise source levels are equal. It is thus consistent with the negative regression coefficient for the energy difference term found in Taylor's energy difference model.

Four further models were investigated for the purposes of this thesis. These were: the psum of separate source L_{Aeq}'s and the root pressure sum of separate source L_{Aeq}'s. (The root pressure sum uses k = 40 in the generalised expression given at Chapter 3.4, equation (7), and corresponds to a doubling of noise sources being equivalent to an increase in level of one of the noise sources of 12 dB); and the energy sum and psum of separate source corrected L_{Aeq}'s. The correlation coefficients between overall disturbance ratings and the various further models are shown at Table 7.6.

It is apparent that the psum and root psums of separate source L_{Aeq}'s perform as well as the response summation and Powell models. Bearing in mind that the psum and root psums of separate source L_{Aeq}'s do not take account of source specific response differences then this result implies an underlying superiority for the psum and root psum procedures. There would be no purpose in calculating the optimum k factor to give the highest correlation coefficient as the statistical confidence limits would be relatively wide. However, it is plausible that the psum procedure does not reflect the most appropriate k factor which may be greater than 20. None of the data reviewed in this thesis is capable of resolving this question with any degree of statistical confidence.

The highest correlation coefficients were obtained by taking the energy sum and psums of corrected L_{Aeq}'s. In these cases, the separate source corrected L_{Aeq}'s were obtained by subjectively weighting the aircraft noise specific L_{Aeq}'s against the regression for road traffic noise specific disturbance ratings and road traffic noise specific L_{Aeq}'s. However, these corrections, or subjective weightings, were obtained on the basis of source specific disturbance ratings so their applicability to overall disturbance ratings cannot be taken for granted. In fact, despite the high correlation coefficients obtained between overall disturbance ratings and the energy and psums of corrected L_{Aeq}'s, there is a discrepancy between the subjective weightings obtained on this basis and by Taylor's [75] procedures. The source specific disturbance ratings show aircraft noise to be more disturbing than road traffic noise at similar L_{Aeq}'s. Taylor's procedures, using overall disturbance ratings, show aircraft noise to be less disturbing than road traffic noise at similar L_{Aeq}'s. In fact, Taylor makes the suggestion that "overall annoyance is a weighted averaging of source specific annoyance where the weighting reflects the duration of the annoyance caused by the separate sources". This suggestion is entirely consistent with the concept of pL_{Aeq} in that intermittent noises are predicted to make smaller contributions to overall annoyance than continuous noises when present at similar L_{Aeq}'s.

The most reasonable explanation for the highest correlation coefficients being obtained with the "wrong" subjective weightings or corrected L_{Aeq}'s is that the overall disturbance ratings in Taylor et al's questionnaire were somehow partially confounded by the source specific disturbance ratings. This could easily have happened as the source specific and overall disturbance ratings were obtained consecutively as part of the same question in Taylor et al's questionnaire [69]. In such cases it is likely that respondents have a *tendency* towards making an arithmetic average of their source specific disturbance ratings to derive an overall disturbance rating rather than making a genuine overall disturbance rating. This hypothesis, and it is only a hypothesis, would imply that the higher correlations obtained with the energy and psums of corrected L_{Aeq}'s could have been an artefact of the questionnaire design. This hypothesis can only be tested by new field research which would obtain overall annoyance ratings *before* attempting to break down overall annoyance into its component parts.

These discrepancies between the patterns of response to source specific and overall disturbance ratings should be borne in mind when considering Fields and Walker's comparison of source specific annoyance ratings to different noise sources [2] (below and see Chapter 7.6). The implication of Taylor's data is that the pL_{Aeq} concept is qualitatively supported by the overall disturbance ratings data but not by the source specific disturbance ratings data, with the proviso that Taylor et al's overall disturbance ratings may have been partially confounded by the source specific disturbance ratings.

Table 7.6. Taylor et al's survey of road traffic and aircraft noise

Correlation coefficients for various mixed source models.

Model	Correlation coefficient
Energy sum (L_{Aeq})	0.608
Independent effects	0.714
Energy difference	0.721
Response summation	0.640
Powell	0.678
psum of L_{Aeq}'s	0.651
root psum of L_{Aeq}'s	0.679
energy sum of corrected L_{Aeq}'s	0.743
psum of corrected L_{Aeq}'s	0.808

Fields and Walker's comparison [2]

Fields and Walker conducted a field survey of community reactions to railway noise and designed their survey in such a way as to facilitate comparisons with the results of previous surveys of community reactions to road traffic noise and aircraft noise. They estimated that at the higher railway noise levels (74 L_{Aeq} or 55 NNI) railway noise is less annoying by the equivalent of 6 to 19 L_{Aeq} for road traffic and 13 to 30 NNI for aircraft. In some cases reactions to railway noise and other noises converged below 63 L_{Aeq} or 35 NNI. They were not able to explain these differences in response. Regularity of noise events, length of residence near a long standing noise source, sentimental attitudes to railways, confidence in the railway's inherent safety and even vested interest in so far as use of the railway were all considered and rejected as explanations.

The possibility that the response differences could result from a combination of many factors was mentioned but could not be tested.

A few respondents cited that the periodic nature of the noise with quiet periods between noisy pass-bys was a reason for railway noise being less annoying than road traffic noise. This was in response to an open question in the interview. This aspect would be allowed for by measuring railway noise and road traffic noise in terms of pL_{Aeq} instead of L_{Aeq}. There is some evidence, on the basis of substituting estimated pL_{Aeq}'s for L_{Aeq}'s in the comparison data, that the use of pL_{Aeq} does in fact eliminate or reduce the community reaction to railway noise and road traffic noise differences [70].

However, the use of pL_{Aeq} cannot account for the response differences between railway noise and aircraft noise. Substituting pL_{Aeq}'s for L_{Aeq}'s in the comparison data might even increase the apparent response difference not reduce it. This discrepancy is discussed in Chapter 7.6.

Fields and Walker's comparison data cannot be used to differentiate between the psum and energy sum procedures as multiple noise source environments were not considered.

7.5 The Decibel Equivalent Number Effect [73]

There has been disagreement in the literature concerning the extent to which numbers of events need to be taken into account by any measure of noise exposure. Rylander et al [72] concluded that "at a certain event frequency a threshold for the reaction is reached and a further increase will not augment the annoyance". Rice [74] concluded that "it is not unreasonable to suppose that there is no single dose-response relation that can suit all real-life situations". In a laboratory study of the noise and number trade-off, Rice [30] observed that the trading relationship between number and level was dependent on the annoyance judgement experience of the test subjects.

Nevertheless, there is a strong intuitive basis for assuming that some form of noise level and number trade-off would be reasonable. Consider a hypothetical noise environment exposed to railway noise or aircraft noise. Now, it is likely that the average peak noise level of the individual railway pass-bys or aircraft flyovers could be changed by up to 3 dB, or even more, without anyone noticing. However, if the number of events is halved or doubled then it is likely that this change would be noticed, providing that the number of events is sufficient to cause a problem in the first place. The current U.K. aircraft noise exposure measure, the Noise and Number Index (NNI) equates a doubling of number with a 4½ dB increase in peak levels, in terms of the effect on annoyance. Conventional L_{Aeq} equates a doubling of number with a 3 dB increase in peak levels and pL_{Aeq} equates a doubling of number with a 6 dB increase in peak levels.

That a doubling of number should generally be the equivalent of a 6 dB increase in peak levels seems reasonable on the assumption that both changes would be about equally noticeable. A recent laboratory study by Powell [65] supported a 4 to 6 dB decibel equivalent number effect with the proviso that subjects' sensitivity to change in exposure increased with experience (in the laboratory).

Fields [73] re-analysed existing field survey data in order to investigate the decibel equivalent number effect. He concluded that the form of the trading relationship between noise level and number was not sufficiently consistent across data sets to either reject or support any form. The effect of number was relatively weak, in any event. Fields felt that even a ten-fold change in number was probably equivalent to less than the 10 dB change in peak levels implied by conventional L_{Aeq}, although large sampling variances made estimates of the effect of number imprecise.

There are a number of difficulties inherent in the interpretation of both field and laboratory studies of the decibel equivalent number effect. In the field, respondents generally make one judgement only of a fixed noise environment. (Although of course, the noise environment around an airport may vary dramatically from day to day, nevertheless there is generally a fixed long-term-pattern.) Quite apart from the high correlations which are usually present between noise level and number, the different cells may be partially confounded with other attitudinal and situational variables. Further, source specific annoyance ratings might be more sensitive to the disturbance caused *when events occur* than to the contribution made to overall annoyance by the specific noise source (see Chapter 7.6). Thus the relative sensitivity to number found by comparing the responses of persons exposed in different number cells might be less than the true sensitivity of those same individuals to hypothetical changes in their individual numbers of events experienced.

In the laboratory, the relative effects of different noise event frequencies within sessions depends upon perception of time duration. Now, imprecise time duration perception is well known. Time goes slowly in the dentist's waiting room, and quickly when enjoying oneself. Time duration has to be measured against some reference. It is very difficult to judge the absolute frequency of events without using a clock, or some form of counting. For example, what is the number of lorries per hour on the nearest main road to where one lives? Thus it may be very difficult for subjects to compare any first-time laboratory session event rate against their own experience, or even against any other defined reference.

It is plausible that first-time ratings of noise level in the laboratory may be a far easier task than first-time ratings of number. People carry their own reference with them, in that they tend to be aware of how loud a noise has to be before it will interfere with speech, for example.

Once a subject has experience of several laboratory sessions, however, he can then form a reference against which to judge changes in noise level and number relatively. Because it might be easier for people to make first-time absolute judgements of noise level than number, it is possible that laboratory results pertaining to the number effect might be more sensitive to stimulus range and context than the results pertaining to noise level. Thus, Rice's [74] suggestion that experiments could be designed to support almost any trading relationship is very reasonable. One of the most difficult questions in designing any laboratory experiment is to what extent hourly and daily noise exposure variability in the field could or should be taken into account.

It is unlikely that any conventional field study could be carried out that would resolve these problems. Perhaps the most useful type of study would be the before and after type, investigating the relative importance of change in noise level and/or number. However, before and after type field surveys are fraught with methodological and ethical difficulties.

The laboratory studies by Powell [65] and Rice [74] can be taken as giving good indications of the relative effects of changes in noise level and/or number. Subjects experienced no changes in either parameter when making first session judgements and thus the aggregated responses over the complete experimental designs should be considered. Rice noted that as subjects' experience increased, they began to place a greater importance on the number of events, particularly at the higher numbers. Of his two NASA experiments, which each exposed subjects to nine treatments or sessions, one supported an L_{Aeq} (10 log N) type trade-off and the other supported a pL_{Aeq} (> 20 log N) type trade-off. As stated above, Powell's study supported a pL_{Aeq} (6 dB decibel equivalent number effect) type trade-off over an L_{Aeq} (3 dB decibel equivalent number effect) type trade-off.

To sum up, the greater proportion of the recent laboratory evidence supports the intuitive hypothesis that a doubling of number is equivalent to greater than a 3 dB increase in peak levels. The available field studies do not support this hypothesis but there are many difficulties of interpretation in this area.

7.6 Source Specific Ratings and the Overall Context

With the exception of Powell's [3] study of aircraft noise and road traffic noise, all the laboratory data supports the hypothesis that pL_{Aeq} is superior to conventional L_{Aeq} in accounting for the relative differences in response to different noise sources at similar exposure levels. However, field survey data obtained by using source specific ratings does not support the pL_{Aeq} hypothesis in respect of the differences in response between aircraft noise and road traffic noise.

This discrepancy is most likely due to either or both of the following reasons. First, field survey data is necessarily affected by attitudinal or situational factors that may not affect laboratory responses to the same extent (see Chapter 2). No purely acoustic noise measure can reflect positive or negative attitudes towards different noise sources. It is perfectly plausible that people may rate aircraft noise higher than road traffic noise on source specific response scales purely because of negative attitudes towards aircraft, or aircraft noise. However, a question which has not been fully explored in the past is to what extent do different noise sources contribute to overall annoyance in the field? It may be that a negative attitude to aircraft noise could enhance source specific responses to aircraft noise without enhancing overall responses, even when aircraft noise is present. The concept of annoyance potential, as defined in Chapter 2, is intended to reflect the relative contributions to overall annoyance of different sources in a way that is as free from attitudinal and situational influences as is possible. In particular, attitudes are peculiar to the individual and situation. There might be no simple rules for aggregating the effect of attitudes to separate noise sources to derive an attitude to the overall environment. Nevertheless, it is valid to aggregate the acoustical contributions to the overall environment purely to enable comparisons to be made against criteria and against other noise environments with known community response parameters.

Secondly, the response scales used in field surveys to measure source specific subjective responses might themselves have distorted the observed differences. Aircraft noise, in particular, has characteristically high peak levels, which may interfere with speech and/or other activities. However, there may also be relatively long periods when no aircraft activity is audible. The Guttman Annoyance Scale (GAS) type questions that are often used to measure aircraft noise activity interference may not be sensitive to the number and duration of events [71]. This implies that aircraft noise specific GAS ratings may be reflecting reactions to specific events and not properly reflecting the contribution to overall annoyance made by aircraft noise as only one of many community noise sources. In the 1967 Heathrow survey the GAS ratings were found to match up well with the ANAS ratings over ranges of aircraft flyover event numbers at constant average peak levels [71]. The ANAS ratings are not open to the criticism that they might not be sensitive to event numbers and durations. Nevertheless, the correlation between GAS and ANAS ratings would have to be very high in order to refute the hypothesis that GAS ratings are not sensitive to event numbers and durations, since the number effect is relatively weak (see Chapter 7.5).

In relation to the observed response difference between railway noise and aircraft noise source specific annoyances, it is interesting to consider the regular nature of train pass-bys as opposed to the "bunching" of aircraft flyovers that normally occurs. Airports vary runway use according to weather conditions and this can dramatically affect the short term noise exposure of nearby residents. A reasonable hypothesis is that GAS type ratings for aircraft noise might be particularly sensitive to worst-mode operations whereas in the case of similar ratings for railway noise, there is no worst-mode. In particular, this hypothesis relates to short term "bunching" of flyover events at peak travel demand times as well as to daily runway use variations. The airborne aircraft, airport ground and road traffic noise laboratory study [64] could not take account of flyover event bunching because of the necessarily restricted session lengths employed.

The emphasis that consideration of annoyance potential (as defined in Chapter 2) places on overall response to the total noise environment demands a fundamental re-appraisal of conventional field survey techniques. Questions pertaining to the relative merits of alternative subjective response scales and noise exposure measures are not of great importance when making assessments of source specific annoyance. In many cases the different noise exposure measures are so highly intercorrelated that few conclusions can be drawn relating to the relative merits of alternatives. However, new techniques are necessary in order to resolve the particular questions arising from a study of the relative contributions to overall noise annoyance from different contributing noise sources. The objective here is to measure the importance of any particular degree of source specific adverse reaction in an overall context.

For example, it may be that the interferences or disturbances to activities caused by aircraft noise or railway noise are similar at similar peak levels. Nevertheless source specific annoyance responses are quite different. Why is it that the same amount of activity interference can be found annoying to a different extent dependent upon the nature of the noise source? Surely it is worth examining the hypothesis that the different annoyance responses may be, at least in part, due to an artefact of the research techniques.

The simplest technique for measuring overall annoyance to the total noise environment is the use of direct annoyance scales administered as the first question in field questionnaires. Detailed noise measurements should also be undertaken, not from the point of view of characterising background noise (see Chapter 7.7) but in order to precisely define the contributions from each noise source. There is considerable evidence, presented elsewhere in this thesis, that overall annoyance to multiple noise source environments is greater than the physical sum of the noise source contributions implies.

Other more complex techniques for evaluating the importance of source specific ratings in an overall context can be readily devised but each would require considerable care in validation, whereas the overall annoyance rating has implicit face validity.

The choice between pL_{Aeq} and corrected L_{Aeq} has already been discussed (Chapter 6.4) in relation to the best measure of separate noise source contributions in the context of laboratory studies. There it was concluded that pL_{Aeq} would have the advantage because of the avoidance of subjectivity, provided that it correlated with subjective response better than conventional L_{Aeq}. In the field, the evidence is conflicting. Although the differences in response to road traffic noise and railway noise are consistent with pL_{Aeq} as a separate contributing noise source measure, the source specific response to aircraft noise is not consistent with pL_{Aeq}. Therefore, given the present state of knowledge, corrected L_{Aeq} must be used for aircraft noise contributions. However, if new field research is undertaken to investigate overall annoyance to total noise environments which include aircraft noise contributions, then it may be that pL_{Aeq} will be found to correlate well, thus supporting the conclusions of the airborne aircraft, airport ground, and road traffic noise laboratory study [64].

If future research should support pL_{Aeq} as a measure for separate contributing noise sources then it should be borne in mind that the difference between pL_{Aeq} and L_{Aeq} is dependent on the time history of the noise. Corrected L_{Aeq}'s derived on the basis of the differences between pL_{Aeq} and L_{Aeq} would be similarly dependent. Thus the correction factors involved in defining corrected L_{Aeq}'s would be situation dependent - an unsatisfactory state of affairs.

7.7 Background Noise

There is currently some controversy over the role of background noise in community response to noise. There is even disagreement over the definition of background noise. This thesis takes the view that background noise is the aggregate of whatever noises are left when any particular noise source is removed. In the context of the assessment of any proposed new noise source, the background noise is the pre-existing overall noise environment into which the new noise will be introduced. The most appropriate measures of background noise are therefore conventional L_{Aeq}, pL_{Aeq}, corrected L_{Aeq} or even pL_{Aeq}, psum or the psum of corrected L_{Aeq}'s.

This definition of background noise is consistent with current thinking in several quarters. For example, Taylor et al's [63] survey of aircraft noise and road traffic noise took the L_{Aeq} of the road traffic noise as the background noise against which source specific aircraft noise disturbance was judged.

However, there is a long tradition in the U.K. for considering the background noise as being that level which is exceeded for 90% of the time, measured in dB(A), (see BS4142 [74]). This L_{90} background level is intended to represent the lowest steady noise level present at any particular location in the absence of intruding noise sources. BS4142 rates an industrial noise in terms of the amount by which it exceeds either the measured or predicted L_{90} background level. BS4142 attempts to predict the likelihood of complaints and quantitative assessment of general community annoyance is beyond the scope of the standard.

The method of noise assessment implicit in BS4142 does not consider the intruding noise source in the context of the overall noise environment. It merely attempts to measure the signal-to-noise ratio and thus the detectability of the intruding noise. However, there is no necessary relationship between detectability and annoyance apart from the fact that a noise must be detectable as a pre-condition of causing annoyance. Many noises can be clearly detectable without causing annoyance.

In the context of road traffic, aircraft, railway, industrial, and construction noise annoyance, it is difficult to see any relevance for the L_{90} background level except in the case of noises with impulsive or tonal components. In these cases the impulsive or tonal components presumably make the noises more easily detectable, thus they may make a difference to the distance from the source at which they can still be heard. However, it is not known whether noises with impulsive or tonal components are judged more annoying in field surveys. There is a general consensus that some form of weighting for impulsive or tonal components should be applied, of the order of 5 dB but this is not based on field measurements of relative annoyance responses.

Nevertheless, if the necessity for impulsive or tonal corrections is proven then there is no reason in principle why they could not be incorporated into the pL_{Aeq}, psum procedure. The psum of corrected L_{Aeq}'s procedure, of course, could automatically take them into account, as the corrected L_{Aeq}'s have to be subjectively determined.

8. CONCLUSIONS

8.1 Laboratory-field Calibration

A good correspondence was obtained between laboratory and field responses to road traffic noise by using:

(a) a simulated domestic living room listening laboratory;

(b) realistic tape recordings using stereo and tape noise reduction reproduced through high quality equipment and recorded at the appropriate distances from the noise sources for the simulated reproduction levels;

(c) indoor laboratory reproduction levels at 18 dB below outdoor facade 24 hour L_{Aeq} levels, to correspond to typical open window outdoor/indoor attenuations;

(d) numerical category scaling with ten point annoyance scales in the field and ten point annoyance home projection scales in the laboratory with instructions related specifically to the evening period.

8.2 Multiple Noise Sources

Both the pL_{Aeq}, psum procedure and the psum of corrected L_{Aeq}'s procedure were found to be superior to overall conventional L_{Aeq} in all the studies where comparison was possible. However, pL_{Aeq}'s for the separate contributing noise sources were only available for the road traffic and railway noise laboratory study (Chapter 6) and the airborne aircraft, airport ground and road traffic noise laboratory study [64].

In these cases corrected L_{Aeq} was superior to pL_{Aeq} as a measure for the separate contributing noise sources because it took account of idiosyncratic preferences that might not be accounted for by any objective procedure.

In the field the differences between source specific annoyance ratings to railway noise and road traffic noise were consistent with pL_{Aeq} as a measure for separate contributing noise sources, but aircraft noise specific annoyance ratings were not consistent with pL_{Aeq}. This implies that the psum of corrected L_{Aeq}'s would be appropriate for environments including contributions from aircraft noise and that pL_{Aeq}, psum would be inappropriate for those environments. However, new field research is recommended that, by concentrating on overall annoyance responses to the total noise environment might replicate the laboratory results in the field.

Thus, the psum of corrected L_{Aeq}'s procedure can be recommended as superior to overall conventional L_{Aeq} for the assessment of multiple noise source environments, with the proviso that pL_{Aeq} as a measure for separate contributing noise sources should be seriously considered in future work.

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APPENDIX A: ISVR Simulated Domestic Living Room

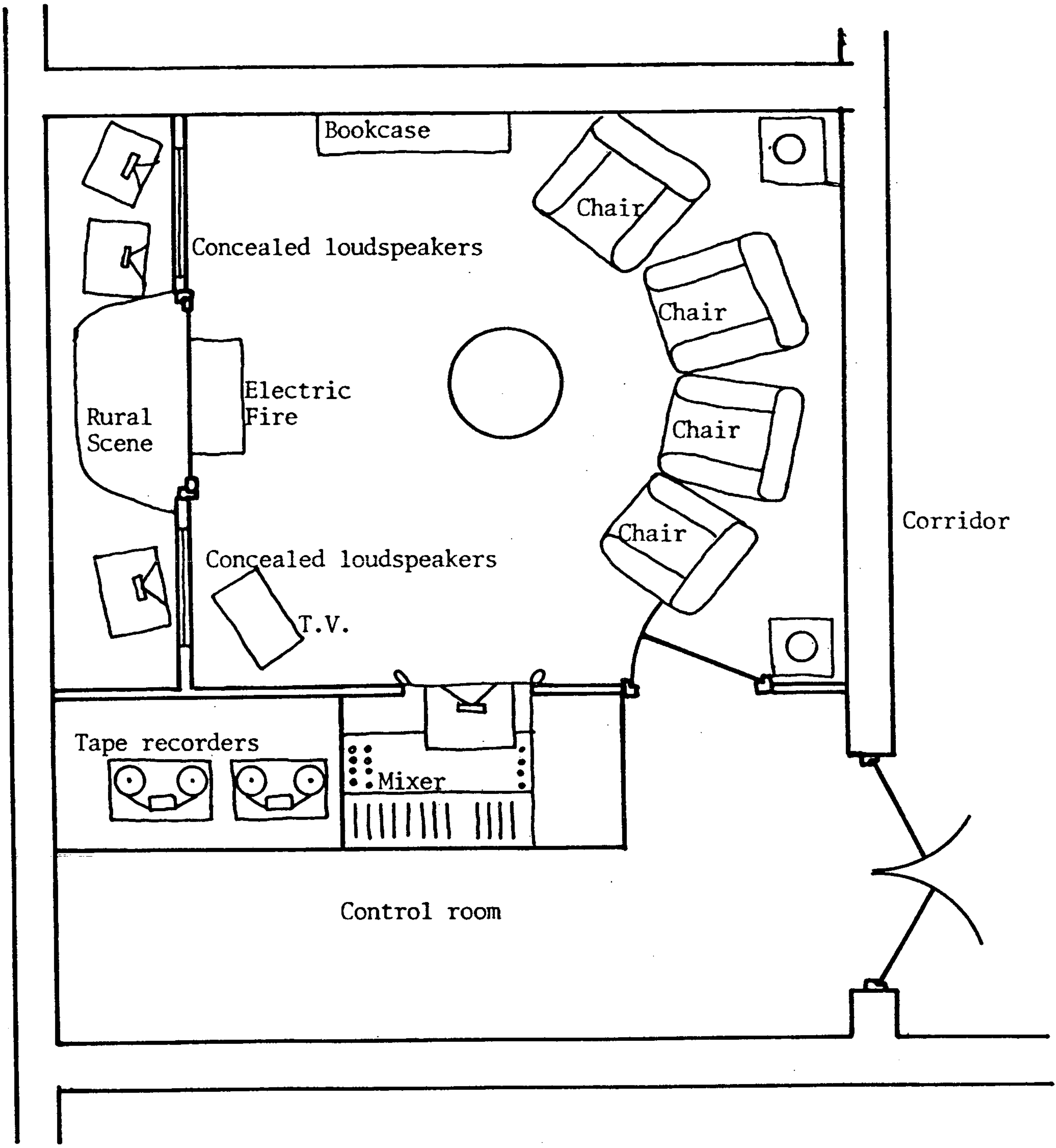
The simulated domestic living room allowed experimental subjects to make annoyance judgements of tape recorded sessions of noise in a similar way to that if they were in their own homes. Thus the room was furnished and subjects were allowed a free choice of relaxation, reading, conversation, private work or other activity. Three stereo sets of loudspeakers were provided. These were all concealed in order to make the simulation as unobtrusive as possible. Two stereo pairs of loudspeakers were mounted behind metal grilles in a false plasterboard wall, either side of an illuminated rural scene behind a glazed window which was normally left in an open position. One loudspeaker unit was mounted in a side wall in order to enable the apparent source directions of noises coming from each stereo pair to be differentiated. This side loudspeaker was concealed by a loudspeaker grille cloth mounted in a picture frame. Bowers and Wilkins type DM2 3-way loudspeaker units were used. Two interlaced arrays of wide range public address type loudspeaker units were mounted into flat baffle boards over the ceiling above a suspended aluminium mesh ceiling. These arrays were used for the simulation of aircraft flyovers overhead. Arrays were installed in order to give a more realistic simulation of the real-life indoor sound of aircraft flying overhead, where the sound is re-radiated by the ceiling in such a way as to give a confused impression of source movement.

The internal dimensions of the room were 3.7 x 3.8 x 2.3 m. A plan is shown at Figure A1. A control room adjacent to the simulated living room contained all the tape reproducing equipment and noise monitoring equipment. Revox and Nagra stereo tape recorders were used, replaying through dBx tape noise reduction compander systems into Quad audio amplifiers. Noise monitoring was carried out with Bruel and Kjaer microphones, pre-amplifiers, analysers and graphic level recorders. The room was calibrated with a microphone at the centre. Then the microphone was concealed at the level of the suspended ceiling in order to monitor the experiments.

An Audix MXT1000 four group mixing desk was used for signal re-recording and for various forms of signal processing, in the production of experimental tapes.

Figure A1

Simulated Domestic Living Room Plan



The frequency response to pink noise reproduced off the Revox tape recorders into the room via the Bowers and Wilkins loudspeakers was within ±5 dB from 70 Hz to 12 kHz. The frequency response of the field recording equipment was better, if the manufacturer's specification for the microphone responses can be believed. The frequency response of the ceiling loudspeakers was adequate in comparison with the Bowers and Wilkins loudspeakers.

The main criteria used when preparing tapes for playback in the simulated living room was the subjective realism. From that point of view quite gross distortions may not be important. Therefore, there would be no point in presenting data relating to the performance of the tape recorders, microphones, dBx systems, amplifiers and loudspeakers. Suffice it to say that only the best available professional quality equipment was used. In all cases, tapes were recorded in half-track stereo at 15 ips. 7½ ips would normally be adequate, but the higher tape speed was used to allow for the distortions inevitably introduced by the dBx compander system.

The background noise level of the ventilation system was approximately 33 dB(A). This effectively sets a limit to the lowest level of tape recorded noise that is audible within the room, although of course a tape recording with an L_{Aeq} of only 30 dB may still have clearly audible peak events.

APPENDIX B: Instructions. Open Day 1977

1. Welcome.
2. This is part of our continuing program of research into the effects of environmental noises, e.g., traffic, aircraft, etc.
3. In a moment, you will hear a recording of traffic noise as it is likely to sound in a typical home near to a main road.
4. Please take this response sheet which we will use to obtain a measure of how people respond to noises such as the noise we are using today.
5. Please enter the listening room.
6. Please listen to the noise and then choose the most appropriate number on your response sheet.
7. The question we are asking is: How annoying would you find this noise if you could hear it in your own home for most of the day?
8. Choose the number that best fits your annoyance.
   9 corresponds to extremely annoying
   0 corresponds to not annoying at all
9. Please take as much time as you like to make your choice.
10. Please make yourselves comfortable, talk, etc., as you might do in your own homes, but do not discuss your response until after you have left the room.
11. Please hand in your response sheet as soon as you have made your choice.

Response Sheet - Open Day 1977

Traffic Noise Experiment - May 7th, 1977

How annoying would you find this noise if you could hear it in your own home for most of the day?

Please circle one of the numbers below that best fits your annoyance.

Please take as much time as you like to make your choice.

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

Thank you for your co-operation.

APPENDIX C: Response Sheet Open Day 1978

Traffic Noise Experiment - May 6th, 1978

Version A:

How annoying would this traffic noise be in your own living room in the evening, with the windows open?

Version B:

How annoying would this traffic noise be in your own living room in the evening, with the windows closed?

Please circle one of the numbers below that best fits your annoyance.

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

Thank you for your co-operation.

APPENDIX C: Response Sheets. Open Day 1979

Traffic Noise Experiment 5th May 1979

Version A:

Imagine yourself at home, indoors, in the evenings.

1. How annoying would this traffic noise be in your own living room, in the evenings?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

2. Would you say you would be 'highly annoyed', or not?

Yes, high annoyed ...... ☐
No ...... ☐

3. Write the name of the road or street where you live.

____

Version B:

Imagine yourself outside your front door, at home.

1. How annoying would this traffic noise be just outside your own front door, in the evening?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

2. Would you say you would be 'highly annoyed', or not?

Yes, highly annoyed ...... ☐
No ...... ☐

3. Write the name of the road or street where you live.

____

APPENDIX D: Laboratory-field Calibration Study

Field Questionnaire

SOCIAL & COMMUNITY PLANNING RESEARCH
Main Office: 16 Duncan Terrace. London N1 8BZ Tel: 01-278 2061

P.514 June 1978

SOUTHAMPTON AREA NOISE STUDY

RECRUITMENT QUESTIONNAIRE

INTRODUCE SURVEY:

We are carrying out a study among people who live in Southampton, on the effects of noise on people's lives. We are looking for people to help us by coming along to the University one evening to take part in some research which will benefit people whose lives are affected by noise.

Those taking part in the sessions all come from around here. Each session will last from about 7 p.m. to about 9 p.m. and we can arrange for transport there, if you need it. We are paying £5 to each person helping us.

This research is sponsored by the Institute of Sound and Vibration Research at the University of Southampton.

First of all, before coming along to the University we will ask you a few questions about your reactions to the noises in this area.

The interview takes about twenty minutes only.

			Col./ Code	Skip to
1.	CHECK: IS RESPONDENT WEARING A VISIBLE HEARING AID?	Yes No	1 2	DO NO RECRU
2.	ASK: Do you have any difficulty at all with your hearing?	Yes No	1 2	DO NO RECRU
3.	RECORD SEX OF RESPONDENT	Male Female2	1 2	
4.	RECORD AGE	Under 40 40 years or over	1 2	
5.	NAME OF RESPONDENT: ______ ADDRESS: ______ TELEPHONE NO: ______			
6.	DOES RESPONDENT REQUIRE TRANSPORT TO UNIVERSITY?	Yes No	1 2	
7.	DATE OF SESSION FOR WHICH RESPONDENT IS BOOKED: ___/___/78			

RESPONDENT NO. ☐ ☐☐

DATE OF RECRUITMENT ___/___/78

NAME OF RECRUITMENT INTERVIEWER ______

SOCIAL & COMMUNITY PLANNING RESEARCH
Main Office. 16 Duncan Terraca, London N1 8BZ Tel: 01-278 2061

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SOUTHAMPTON AREA NOISE STUDY

June 1978

514 (1-
Record No (4-
Card 1 (7)

Col./ Code	Skip to
(8-11)	

Time interview started ____________

Sample group ☐ Serial No. ☐☐☐

1.a) We are interested in all the different sounds that you can hear indoors. Firstly, do you have in your home, READ OUT

		(a)		(b)		(c)			
		Yes	No	Bothers	Does not bother	Item	Traffic	Same	
i)	A washing machine	A	0	B	1	4	5	6	(12)
ii)	A vacuum cleaner	A	0	B	1	4	5	6	(13)
iii)	A particularly noisy plumbing system	A	0	B	1	4	5	6	(14)
iv)	Radio, TV or stereo	A	0	B	1	4	5	6	(15)
v)	An electric drill	A	0	B	1	4	5	6	(16)
vi)	Any other particularly noisy appliance or tool? (IF YES, SPECIFY MOST NOISY ONE) ____________	A	0	B	1	4	5	6	(17)
	And when you are indoors do you ever hear any of these noises; READ OUT								
vii)	Aircraft	A	0	B	1	4	5	6	(18)
viii)	Cars, lorries & other road traffic	A	0	2	1	▨	▨	▨	(19)
vi.	Factories or machinery	A	0	B	1	4	5	6	(20)
x)	Building works	A	0	B	1	4	5	6	(21)
xi)	Animals outside	A	0	B	1	4	5	6	(22)
xii)	Children outside	A	0	B	1	4	5	6	(23)
xiii)	Other people outside	A	0	B	1	4	5	6	(24)
xiv)	Neighbours	A	0	B	1	4	5	6	(25)
xi)	Or any other noises (IF YES SPECIFY) ____________	A	0	B	1	4	5	6	(26)

FOR EACH 'YES' AT a) ASK b) (27)

b) Do noises from ... bother or annoy you at all? RECORD ABOVE

FOR EACH 'BOTHER' EXCEPT (viii) ASK c) (28)

c) Which bothers you more; the sound from ... or the sound from road traffic here?

CARD 1

			Col./ Code	Skip to
	ASK ALL		(29)	
2.a)	Please look at this scale (SHOW CARD C) and tell me; how do you feel about the amount of noise round here?	Definitely satisfactory	1	
			2	
			3	
			4	
			5	
			6	
		Definitely unsatisfactory	7	
			(30)	
b)	In particular, how do you feel about the amount of noise here from cars or lorries or other road traffic?	Definitely satisfactory	1	
			2	
			3	
			4	
			5	
			6	
		Definitely unsatisfactory	7	
	EXPLAIN SCALE TO ALL: THEN ASK			
3.a)	Thinking about when you are indoors, in the evenings, and using this scale now (SHOW CARD A), how annoying is the traffic noise here?	0 1 2 3 4 5 6 7 8 9	(31)	
	SHOW CARD B			
b)	How disturbing is the traffic noise to general relaxation? CODE IN GRID	0 1 2 3 4 5 6 7 8 9	(32)	
c)	(STILL SHOWING CARD B). How disturbing is the traffic noise here to conversation? CODE IN GRID	0 1 2 3 4 5 6 7 8 9	(33)	
d)	How disturbing is the traffic noise here to reading? CODE IN GRID	0 1 2 3 4 5 6 7 8 9	(34)	
	SHOW CARD A			
e)	Now thinking about being indoors, when the windows are open, how annoying is the traffic noise here with the windows open? CODE IN GRID	0 1 2 3 4 5 6 7 8 9	(35)	
f)	(STILL SHOWING CARD A). How annoying is the traffic noise here with the windows shut? CODE IN GRID	0 1 2 3 4 5 6 7 8 9	(36)	

CARD 1

			Col./ Code	Skip to
	ASK ALL			
4.a)	Leaving the scales for a moment; just to confirm would you say you are "highly annoyed" by the traffic noise or not?		(37)	
		Yes, highly annoyed	1	
		No	2	
5.a)	Can you hear traffic noise from any other road apart from (NAME RESPONDENT'S ROAD) when you are indoors?		(38)	
		Yes	1	
		No	2	Q.6
	IF YES AT a)		(39-40)	
	b) What road is that? WRITE IN ______________________			
	c) Thinking now about the noise from (READ OUT ROAD NAME) as compared with the noise from (NAME RESPONDENT'S ROAD); when you are indoors, does the traffic noise from (READ OUT ROAD NAME) bother or disturb or annoy you more, less, or about the same as the traffic noise from (NAME RESPONDENT'S ROAD)?		(41)	
		More	1	
		Less	2	
		About the same	3	
	ASK ALL THOSE IN SAMPLE GROUPS 2 AND 3 OTHERS GO TO Q.7		(42)	
6.a)	Imagine you lived in one of the houses in Winchester Road, just near here. Think about the traffic noise in Winchester Road, by the petrol station, opposite the end of Thornhill Road. How annoying would you find the traffic noise if you lived in a house there; when you were indoors? (SHOW CARD A) For here you gave an answer of ___ (RESPONSE AT Q.3a)	Not annoying at all	0	
			1	
			2	
			3	
			4	
			5	
			6	
			7	
			8	
		Extremely annoying	9	
			(43)	
b)	And how disturbing would you find the traffic noise to conversation, if you lived in a house there; when you were indoors? (SHOW CARD B) For here you gave an answer of ___ (RESPONSE AT Q.3b)	Not disturbing at all	0	
			1	
			2	
			3	
			4	
			5	
			6	
			7	
			8	
		Extremely disturbing	9	

CARD 1

			Col./Code	Skip to
	ASK ALL THOSE IN SAMPLE GROUPS 1 AND 2 OTHERS GO TO Q.8		(44)	
7.a)	Imagine you lived in one of the houses down by the Sports Centre car park, say in Highclere Road, or Lordswood Gardens, away from all the main roads. How annoying would you find the traffic noise if you lived in a house there; when you were indoors? (SHOW CARD A) For here you gave an answer of ___ (RESPONSE AT Q.3a)	Not annoying at all	0	
			1	
			2	
			3	
			4	
			5	
			6	
			7	
			8	
		Extremely annoying	9	
			(45)	
b)	And how disturbing would you find the traffic noise to conversation, if you lived in a house there; when you were indoors? (SHOW CARD B) For here you gave an answer of ___ (RESPONSE AT Q.3c)	Not disturbing at all	0	
			1	
			2	
			3	
			4	
			5	
			6	
			7	
			8	
		Extremely disturbing	9	
	ASK ALL		(46)	
8.a)	How sensitive are you to noise in general? Would you say you are; READ OUT	very sensitive	1	
		moderately sensitive	2	
		a little sensitive	3	
		or not at all sensitive	4	
			(47)	
b)	And would you say you are more sensitive or less sensitive than other people to noise?	More sensitive	1	
		Less sensitive	2	
		(Same)	3	

CARD 1

ASK ALL

9.a) We are interested in finding out what kinds of traffic noise people can hear when they are indoors. Which of these do you ever hear when you are indoors? (READ OUT ONE BY ONE)

	(a)		(b)		c) Most bothered by			Col./ Code	Skip to
	Hears	Does not hear	Bothers	Does not bother	Item	Rumble of traffic	(Same)		
Car horns and hooters	A	0	B	1	4	5	6	(48)	
Car doors slamming	A	0	B	1	4	5	6	(49)	
Engines starting, gear changing or revving up	A	0	B	1	4	5	6	(50)	
Squeal of brakes or tyres	A	0	B	1	4	5	6	(51)	
Motorbikes	A	0	B	1	4	5	6	(52)	
Lorries	A	0	B	1	4	5	6	(53)	
Individual cars passing	A	0	B	1	4	5	6	(54)	
Buses	A	0	B	1	4	5	6	(55)	
Other (SPECIFY) ____________	A	0	B	1	4	5	6	(56)	

FOR EACH YES AT a) ASK b) (57)

b) Does the noise from ... bother or disturb or annoy you at all?

FOR EACH 'BOTHERS' AT b) ASK c) (58)

c) Thinking about the noise of ... compared with the general rumble of traffic; which bothers you more, the general rumble of traffic or the noise of ...?

CARD 1

			Col./Code	Skip to
	ASK ALL		(59)	
10.a)	Is there any double glazing or new windows in the house?	Yes - new windows	1	
		- double glazing	2	Q.11
	IF YES AT a)		(60)	
	b) Did you instal it, or have it installed? Or was it here when you moved in?	Yes, we installed it	1	
		No, already here	2	Q.11
	IF YES AT b)		(61)	
	c) What was your reason for installing it? Was it to reduce noise indoors, or for any other reason?	To reduce noise indoors	1	
		For another reason	2	
11.	Do you ever close windows to reduce the noise coming in?		(62)	
		Yes	1	
		No	2	
	ASK ALL		(63)	
12.a)	On which floor is your main living room?	Basement	0	
		Ground floor	1	
		First floor	2	
		Second floor	3	
	Higher (SPECIFY) ______________________		4	
b)	Is it in the front or the back of the house?		(64)	
		Front	1	Q.13
		Middle	2	Q.13
		Back	3	
		Through room	4	Q.13
	IF AT BACK OF HOUSE		(65)	
	c) Is there a room at the front of the house which you could use as a living room instead?	Yes	1	
		No	2	Q.13
	IF YES AT c)		(66)	
	d) Why do you use the room at the back of the house as a living room? Is it because it is too noisy at the front, or for any other reason?	Yes, too noisy at the front	1	
		Other reason	2	
	ASK ALL		(67)	
13a)	On which floor is the room in which you usually sleep?	Basement	0	
		Ground floor	1	
		First floor	2	
		Second floor	3	
	Higher (SPECIFY) ______________________		4	
b)	Is it in the front or the back of the house?		(68)	
		Front	1	Q.14
		Middle	2	Q.14
		Back	3	
	IF AT BACK OF HOUSE		(69)	
	c) Is there a room at the front of the house which you could use as a bedroom instead?	Yes	1	
		No	2	Q.14
	IF YES AT c)		(70)	
	d) Why do you use the bedroom at the back of the house? Is it because it is too noisy at the front, or for any other reason?	Yes, too noisy at the front	1	
		Other reason	2	

CARD 1

			Col./Code	Skip to
	ASK ALL			
14.a)	Have you yourself ever felt like doing anything about traffic noise in this area? For example, have you ever felt like writing or talking to an official, or signing a petition or getting someone to do something? IF YES: Have you ever actually done something?		(71)	
		Yes, have done something	1	
		Just felt like doing something	2	Q.15
		No, have not felt like doing anything	3	Q.15
	IF YES, HAVE DONE SOMETHING (CODE 1 AT a))		(72)	
	b) What was the problem you did something about? DO NOT PROMPT			
			(73)	
	c) What did you actually do about the problem? (PROBE FULLY) (IF MORE THAN ONE, DISCUSS MAIN PROBLEM)		(74)	
			(75)	
	ASK ALL		(76)	
15.a)	Have you any plans to move house in the near future?	Yes	1	
		No	2	c)
	IF YES AT a)		(77)	
	b) Is that because of traffic noise, or is it for any other reason?	Because of traffic noise	1	Q.16
		Other reason	2	
	IF NO AT a)		(78)	
	c) Have you ever felt like moving house because of traffic noise?	Yes	1	
		No	2	
	ASK ALL		(79)	
16.	Now just to check, does the noise of the traffic bother or annoy you: READ OUT	very much	1	
		moderately	2	
		A little	3	
		or not at all	4	Q.19
		SPARE	(80)	
		P.514	(1-3)	
		Record No.	(4-6)	
		CARD ②	(7)	

			Col./Code	Skip to
17.	At what times of the day are you most bothered by traffic noise? Using this card (SHOW CARD D) how bothered do you feel;			
	a) In the morning	0 1 2 3 4 5 6 7 8 9	(8)	
	b) In the afternoon	0 1 2 3 4 5 6 7 8 9	(9)	
	c) In the evening	0 1 2 3 4 5 6 7 8 9	(10)	
	d) At night after you have gone to bed	0 1 2 3 4 5 6 7 8 9	(11)	
	And what about weekdays in general, compared with weekends? e) Weekdays	0 1 2 3 4 5 6 7 8 9	(12)	
	f) Weekends	0 1 2 3 4 5 6 7 8 9	(13)	
	ASK ALL		(14)	
18.a)	Now thinking specifically over the last couple of days, has the traffic noise been more, less or about the same as usual?	More	1	
		Less	2	
		The same	3	Q.19
	IF 'MORE' OR 'LESS' AT a)		(15)	
	b) (SHOW CARD A) Using this scale, how annoying has the traffic noise been over the last couple of days?	Not annoying at all	0	
			1	
			2	
			3	
			4	
			5	
			6	
			7	
			8	
		Extremely annoying	9	
	ASK ALL		(16)	
19.a)	Did you know about these interviews before I came here?	Yes	1	
		No	2	Q.20
	IF YES AT a)		(17)	
	b) Did you know it was about traffic noise?	Yes	1	
		No	2	
	CLASSIFICATION		(18)	
20.	Sex.	Male	1	
		Female	2	
		EXACT AGE (Write in) ☐☐	(19)	
21.	Age last birthday.	18-29	1	
		30-49	2	
		50+	3	

CARD 2

			Col./ Code	Skip to
			(20)	
22.	Age finished full-time education.	14 or under	1	
		15	2	
		16	3	
		17	4	
		18	5	
		19 or over	6	
			(21)	
23.	Marital status.	Married	1	
		Single	2	
		Separated/Widowed/Divorced	3	
			(22)	
24.	Household status.	HoH	1	
		Housewife	2	
		Both	3	
		Other	4	
			(23)	
	Activity status.	Working full time (30+)	1	
		Shift worker full time	2	
		Working part time (10-30)	3	
		Seeking work	4	
		Retired/Sick	5	
		Housewife	6	
	Other (WRITE IN) ____________		7	
26.	Household composition.	No. in H/hld 0-4		(24)
		No. in H/Hld 5-15		(25)
		No. in H/Hld 16+		(26)
		Total		(27)
27.	OCCUPATION OF HEAD OF HOUSEHOLD (Present or last main paid job) (IF WIDOW AND NOT WORKING NOW RECORD OCCUPATION OF LATE HUSBAND.			
	Name/title of job ____________			
	Description of activity ____________		(28-29)	
	Skill/training/qualifications normally required for job ____________			
	____________			
	Supervision/management responsibilities ____________			
	Industry/business/profession (of employer) ____________			
	Number of people employed at place of work ____________			
	EMPLOYMENT STATUS	Employee	A	
		Self-employed	B	
	TIME INTERVIEW COMPLETED ____________	LENGTH OF INTERVIEW (IN MINS) ☐☐	(30-31)	
	DATE OF INTERVIEW ___/___/78 SIGNATURE OF INTERVIEWER ____________	INTERVIEWER NO. ☐☐☐☐	(32-35)	

CARD A

P.514

Please choose one of the numbers below that best fits how annoying the noise is.

Not annoying at all	0
	1
	2
	3
	4
	5
	6
	7
	8
Extremely annoying	9

CARD B

P.514

Please choose one of the numbers below that best fits how disturbing the noise is.

Not disturbing at all	0
	1
	2
	3
	4
	5
	6
	7
	8
Extremely disturbing	9

CARD C

P.514

Please choose one of these numbers that best fits the amount of noise round here.

Definitely satisfactory	1
	2
	3
	4
	5
	6
Definitely unsatisfactory	7

CARD D

P.514

Please choose one of the numbers below that best fits how bothered you feel.

Not bothered at all	0
	1
	2
	3
	4
	5
	6
	7
	8
Extremely bothered	9

APPENDIX E: Laboratory-field Calibration Study
Laboratory experimental design

Each group of subjects was exposed to four ten-minute sessions of road traffic noise. The first session corresponded to their home road traffic noise environment reproduced at a level 10 dB below the nominal outdoor facade level (see Chapter 5.5). The second and third sessions corresponded to the other two road traffic noise environments included in the study, and the last session was a retest of the first. Six presentation orders were required, as below:

Home road traffic noise exposure	Subject group	Laboratory presentation order 1	2	3	4
High	A1	H	M	L	H
	A2	H	L	M	H
Medium	B1	M	H	L	M
	B2	M	L	H	M
Low	C1	L	H	M	L
	C2	L	M	H	L

Key: laboratory treatment H = 60 L_{Aeq}

laboratory treatment M = 54 L_{Aeq}

laboratory treatment L = 43 L_{Aeq}

The design was confounded between subjects, noise level and order. This was necessary as it was important to be able to compare first session laboratory responses with the field responses. Unfortunately, the more powerful analysis techniques such as analysis of variance, were inappropriate to this design. Therefore, the fourth session retest was included. As there was no significant order effect, it was in order to average the results over the first three sessions.

APPENDIX F: Laboratory-field Calibration Study

Interviewer's Instructions

scpr
an institute for survey research

SOCIAL & COMMUNITY PLANNING RESEARCH
16 Duncan Terrace London N1 8BZ · Tel: 01-278 6943
01-278 2061

P.514 **SOUTHAMPTON NOISE STUDY** May/June 1978

SOUTHAMPTON NOISE STUDY

Project Instructions

1. GENERAL

The Institute of Sound and Vibration Research (ISVR) at the University of Southampton is carrying out a programme of experimental work in the effect of noise on people's lives. As part of this research, Social and Community Planning Research have been asked to recruit people living in Southampton to take part in some experimental work being undertaken at the University.

For this reason, we are asking interviewers to recruit a sample of residents to take part in about 15 sessions. As well as recruiting the people, you will be carrying out a 20 minute interview with each person at the time of recruitment. We need four people to attend each session which will last for about two hours. Respondents will be paid £5 for attending.

2. FIELD MATERIALS

Before you begin each day's recruiting check that you have these materials with you:

Your Identity Card
Recruitment Questionnaire)
Questionnaire)
Introductory Letters) one for each person recruited
Invitation Cards)
Maps of the area and the University)
List of sessions
Address listing sheet

At home you should have a supply of Weekly Return Sheets (for claiming pay and expenses); some Fees and Expenses Query forms; a few Supplies Request forms; some paper clips or pins; a supply of large brown envelopes for returning work.

As is normal practice, you should notify police stations before starting work.

3. TIME AND PLACE OF RECRUITMENT AND INTERVIEWING

Recruitment should take place between one and three days before each session. If you start recruiting earlier than this, it may lead to non-attendance. All recruitment should be carried out personally by you in respondents' homes, in the predefined area of Southampton.

4. INTRODUCING THE SURVEY

Always start off by showing your SCPR Identity Card. Introduce the survey in the way suggested at the top of the Recruitment Data Sheet, and show your introductory letter. Respondents should always be told:

- the subject of the study
- why the study is being carried out
- the name of the Sponsor (Institute of Sound and Vibration Research)
- how long the session will last
- how much they will be paid for attending

5. WHO TO RECRUIT AND NOT TO RECRUIT

It is very important that we recruit four people to come along to each session. There will not be any quota controls for each individual session. Instead, we are asking you to try to get a reasonable spread of recruits in terms of sex and age (between 18 and 70). If, after a number of sessions, we do not manage to get a representative cross-section of people, we may have to set down tighter quota controls.

Please do not recruit

- anyone wearing a hearing aid or anyone who has any difficulty with his hearing
- anyone you know personally
- people who seem doubtful about attending; only recruit those people who seem to take it seriously and are sure that they can come along) (If people fail to come we will have to replace them later with others)
- anyone who is unable to speak reasonable English
- anyone who may be an 'expert' on the subject, e.g., anyone in the medical profession, other researchers
- anyone who is a reporter or journalist
- anyone who is a full-time student at college or university

You should not recruit people who might know each other as neighbours to the same session. If you are recruiting for a particular session leave at least ten houses between successful calls, so that there is less chance of people at the session knowing each other. However, someone within this 10 house gap could be recruited for another session.

Never, of course, invite two people from the same family to the same session. If you find someone from the same family 'volunteering' you should put his or her name down on your 'Reserve List' (see Section 6 below).

6. THE 'RESERVE LIST'

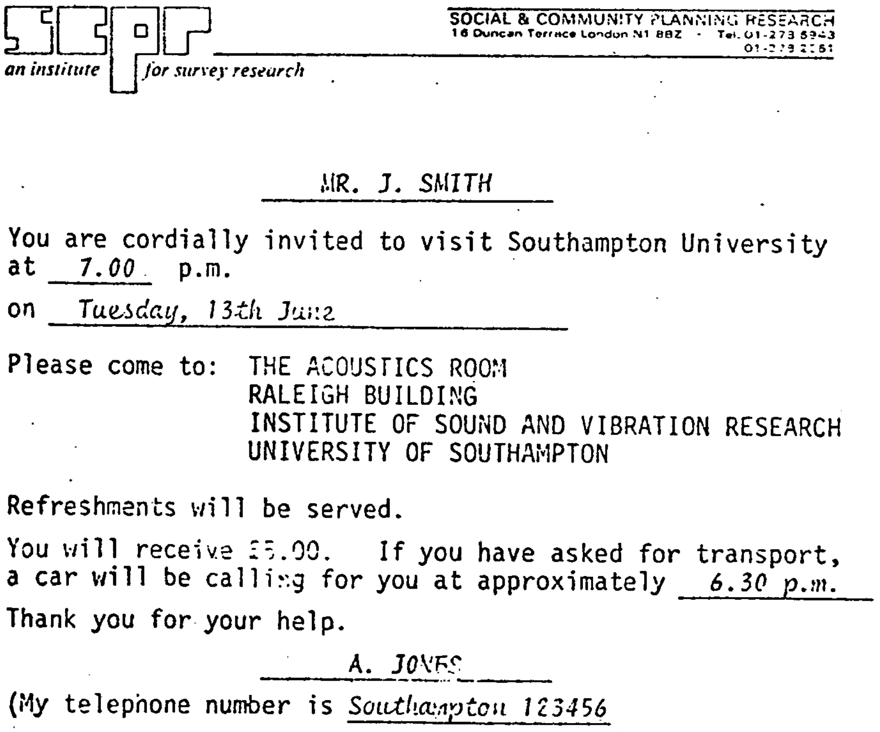
As mentioned above, you may come across people who are willing to take part in the Project but who cannot attend the session(s) you are recruiting for, either because they are members of the same household as someone attending, or because they are not free to come to that/either of those particular sessions.

It would be a good idea to have a 'reserve list' of such people, which you can draw on later if necessary. Preferably, we would rather not invite two or more people from the same household to take part in the project; but it may be necessary to get in touch with and invite them in an emergency, so you may add their names to your 'reserve list', indicating that someone from the same household has already been invited. Do not collect full classification details from people you put on your reference list: you should do this when you call again to give them a proper invitation.

If someone lets you know that they cannot attend a session, if you have time, try to get someone to replace them. You could then use someone suitable from your 'reserve list'. However, you will have to go first and interview them. 'Invitations' and interviews must never be done over the telephone.

7. GIVING AND CONFIRMING INVITATIONS

Complete an invitation card and leave it with the person you invite. An example of how to complete the invitation card is given below:



an institute for survey research

SOCIAL & COMMUNITY PLANNING RESEARCH
16 Duncan Terrace London N1 8BZ · Tel. 01-278 5943
01-278 2061

MR. J. SMITH

You are cordially invited to visit Southampton University
at *7.00* p.m.

on *Tuesday, 13th June*

Please come to: THE ACOUSTICS ROOM
RALEIGH BUILDING
INSTITUTE OF SOUND AND VIBRATION RESEARCH
UNIVERSITY OF SOUTHAMPTON

Refreshments will be served.

You will receive £5.00. If you have asked for transport, a car will be calling for you at approximately *6.30 p.m.*

Thank you for your help.

A. JONES

(My telephone number is *Southampton 123456*

1) Please put your name and telephone number at the bottom of each card, so that your respondent can contact you if anything prevents him or her attending. (You may then have time to recruit a substitute.)

2) Ask each respondent whether he needs transport to take him or her to the session; if he does, then write these details on the invitation card, and on the Recruitment Questionnaire.

3) Before you leave, stress these points to ensure a good attendance:

   - that someone will be there specially to take the session
   - that people like themselves will be attending
   - that the results of the study could benefit people whose lives are affected by noise.

4) As you are leaving, remind the respondent of the date, time and place of the session. A brief reminder note sent first class on the day before will help ensure his attendance. If he is on the telephone, you should take his telephone number and remind him by 'phone shortly before the session.

8. THE RECRUITMENT QUESTIONNAIRE

The Recruitment Questionnaire must first be completed fully for each person you recruit. The sheet should then be immediately posted to Mrs. J. Nunn whose address is given in section 9.

You should retain a note of the names, addresses and telephone numbers of the people recruited, so that you can remind them of the session.

9. THE QUESTIONNAIRE

Q.1 Ask all of part a) before asking all of part b) and then c). If an item is heard at all, it is heard; if it bothers at all, then it bothers. If you are not certain where to record a particular noise, enter it under 'Or any other noises' eg a builders yard next door, might be 'neighbours' or 'building works'. Therefore record it as other.

Q.2 Here we are using a seven point scale. When introducing the scale, the essential point is that the respondent expresses the degree of satisfaction by indicating whichever of the seven boxes best fits his opinion, given that maximum satisfaction is expressed by box 1 and dissatisfaction by box 7. Some people tend to think that only the extremes and the middle are supposed to mean anything (1, 4 or 7) and it needs to be explained that the scale represents all shades of opinion from unsatisfactory up to satisfactory. If they have a genuinely neutral opinion box 4 applies. If a little better than neutral, then box 3; if better still but not quite satisfied then box 2; if completely satisfied then box 1. The numbers are not scores as much as convenient aids to identifying a box and getting across the idea of a gradual progression up the scale.

The question refers to noise in general.

Q.3 You must first explain that we are now using a different 10 point scale from 0 to 9. If the respondent is not at all bothered or annoyed by the noise he/she would give a score of 0. If he/she was extremely annoyed the score would be 9. There is no mid-point, so that if the respondent was moderately annoyed he/she would have to choose between a score of 4 or 5.

If the respondent says annoyance varies depending on which room is being used, then ask the respondent to think of the room in which he/she spends most time.

Q.6 If you are working on a group 1 sample miss this question. Read out the question slowly and fully. Remind the respondent of the answers he gave for his present home.

Q.7 If you are working on a group 3 sample miss this question. See instructions for Q.6.

Q.10a Any type of double glazing or new windows are included at (a) since at (c) we will discover why they were installed.

c If it was installed to reduce noise <u>and</u> for some other reasons just ring code 1.

Q.11 If the respondent says they never open the windows ask "Why is that". If the answer is "because of noise" then ring code 1. If any other reason is given, ring code 2.

Q.15a If the respondent is only "just looking" still code the response as 'Yes'.

b & c If traffic noise is one of several reasons ring code 1 only.

Q.17 If the respondent says it varies according to weather, season etc., ask the respondent to assess the 'usual' situation.

Q.18 Should the respondent query why we are asking, say 'traffic noise does vary from day to day and we would like to hear how you have found it over the last couple of days'.

9. FIELD CONTROL

Field control on this project is being handled by our local supervisor, Mrs. Jenny Nunn. Her address is:

2, Tollgate Road,
Swanwick,
Southampton, SO3 7DD.

Tel: Locks Heath (04895) 4413

APPENDIX G: Laboratory-field Calibration Study

Laboratory Questionnaires and Consent Form

INSTITUTE OF SOUND AND VIBRATION RESEARCH
THE UNIVERSITY Southampton S09 5NH *Telephone* 559122

Ref. IF/JA

Dear Sir/Madam,

Community awareness of noise as a public nuisance has recently been increasing to such an extent that considerable effort, both at national and local government level, is now being devoted to its reduction and control. The Institute of Sound and Vibration Research at the University of Southampton has been studying noise problems for many years now, and is currently engaged on a new programme of research that will benefit people living nearby to busy roads. We have asked an independent social research organisation, Social and Community Planning Research, to help us with this study by talking to you at your home.

The next and most important stage in this study will take place at the University. You have been invited to come along to the University and give your reactions to different types of traffic noise. The sessions will take place between 7 pm and 9 pm in our simulated living room, where you can read, talk or just sit back and relax. If you wish, you may bring along your own reading or work material, knitting, or even a quiet game.

We will offer you refreshments, test your hearing, and pay you £5 for coming. If it would be helpful, the University minibus is available to transport you there and back. It will call at about 6.30 p.m.

I sincerely hope that you will be able to support this important research. Should you have any questions at all, please feel free to ask the interviewer, or to contact me at the University.

Yours sincerely,

Ian Flindell

IAN FLINDELL.

Research Fellow in Environmental Noise.

scpr
an institute for survey research

SOCIAL & COMMUNITY PLANNING RESEARCH
16 Duncan Terrace London N1 8BZ · Tel: 01-278 6943
01-278 2061

____

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UNIVERSITY OF SOUTHAMPTON

Refreshments will be served.

You will receive £5.00. If you have asked for transport, a car will be calling for you at approximately ________

Thank you for your help.

____

(My telephone number is ____________________

UNIVERSITY OF SOUTHAMPTON INSTITUTE OF SOUND & VIBRATION RESEARCH

Operational Acoustics & Audiology Groups

Consent form to be completed by a subject volunteering to undergo an experiment. for research purposes before the experiment commences.

I,______________________________of______________________________

consent to take part in____

to be conducted by____

during the period____________________to________________________19

The purpose and nature of this experiment have been explained to me. I understand that the investigation is to be carried out solely for the purpose of research and I am willing to act as a volunteer for that purpose on the understanding that I shall be entitled to withdraw this consent at any time, without giving any reasons for withdrawal. I further certify that I have seen the list of questions concerning medical fitness for this experiment and confirm that to the best of my knowledge I do not suffer from any of the conditions listed.

Date:________________________ Signed:___________________________

I confirm that I have explained to the subject the purpose and nature of the investigation which has been approved by the Safety & Ethics Committee.

Date:________________________ Signed:___________________________________

(Researcher in charge of Experiment)

dmh/
23.6.77

QUESTIONNAIRE

1. How annoying is this traffic noise?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

2. How disturbing is this traffic noise to general relaxation?

Not disturbing at all 0 1 2 3 4 5 6 7 8 9 Extremely disturbing

3. How disturbing is this traffic noise to conversation?

Not disturbing at all 0 1 2 3 4 5 6 7 8 9 Extremely disturbing

4. How disturbing is this traffic noise to reading?

Not disturbing at all 0 1 2 3 4 5 6 7 8 9 Extremely disturbing

5. Would you say you are 'highly annoyed' by this traffic noise or not?

Yes, highly annoyed........☐

No......................☐

6. Now, thinking about when you are at home, indoors, in the evenings:
How annoying would this traffic noise be in your own living room, in the evening?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

7. Would you say you would be 'highly annoyed' by this traffic noise,or not, in your own living room, in the evening?

Yes, highly annoyed........☐

No......................☐

8. Is this traffic noise louder, about the same, or quieter than the amount you normally experience at home? (In your own living room in the evening).

Louder....................☐

About the same............☐

Quieter...................☐

How loud is the traffic noise at your own home?

Firstly, when you are indoors, in the evening, in your own living room, with the windows closed

Secondly, in the street just outside your own front door.

INSTRUCTIONS

1. Listen to this traffic noise tape and compare it with the amount you normally experience at home, in your own living room, in the evening, with the windows closed.

After a short while, the 'Respond now please' light will come on.

Choose either 'Too loud'
'Just about right'
or 'Not loud enough'

The loudness of the traffic noise tape will be adjusted up or down. Wait until the 'Respond now please' light comes on again and make another choice of 'Too loud'
'Just about right'
or 'Not loud enough'

Repeat this procedure until asked to stop.

2. How annoying did you find the last loudness level of the traffic noise tape?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

3. Repeat the same procedure as above, but this time compare the traffic noise tape with the amount you normally experience in the street just outside your own front door. Continue to respond each time the 'Respond now please' light comes on.

4. How annoying did you find the last loudness level of the traffic noise tape?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

QUESTIONNAIRE

1. At what point on your scale would you start to become 'highly annoyed' ?
   Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

2. How realistic or lifelike did you find the traffic noise that you have just heard ?
   Not realistic at all 0 1 2 3 4 5 6 7 8 9 Extremely realistic

3. How difficult did you find it to score the traffic noise for annoyance ?
   Not difficult at all 0 1 2 3 4 5 6 7 8 9 Extremely difficult

4. How difficult did you find it to imagine how annoying the traffic noise would be in your own home ?
   Not difficult at all 0 1 2 3 4 5 6 7 8 9 Extremely difficult

5. Did you find the 0 to 9 scale questions, or the Yes/No questions easiest to answer ?
   0 to 9 questions easiest............ ☐
   Yes/No questions easiest............ ☐

Any further comments

We hope you have found this experiment interesting and would like to thank you for your co-operation

APPENDIX H: Laboratory-field Calibration Study Results not discussed in text

H.1 Field Survey

Table H.1 shows a breakdown of the sample in terms of age, sex, education, marital status, etc. The sample was 50% male and 50% female, and all adult age groups were reasonably well represented.

Table H.2 gives a summary of the field survey results broken down into the three road traffic noise exposure groups. Table H.3 gives a selection of correlation coefficients between various field questionnaire items and individual 24 hour L_{Aeq}. The responses to Q3(a) correlate with 24 hour L_{Aeq} as highly as any other questionnaire item responses.

Figure H1 shows the percentages bothered or annoyed by different noise sources at Q1 in the questionnaire. Figures H2 and H3 show an increase in dissatisfaction or annoyance with road traffic noise exposure. Figure H4 shows a similar increase in terms of per cent *highly annoyed*, or *a little, moderately* or *very much annoyed.*

Figure H5 shows the results of the field projection questionnaire items Q6 and Q7. There was a tendency for people from the low and medium road traffic noise exposure groups to overestimate projected annoyance to the high road traffic noise exposure group, compared with residents in that group. Figure H6 illustrates the relative importance of different road traffic noise components. Figures H7 and H8 show reported time-of-day and day-of-week effects on annoyance. Questions relating to evening and night-time annoyance gave higher mean ratings than questions relating to morning and afternoon annoyance.

Persons from the low and medium road traffic noise exposure groups were more likely to be annoyed by road traffic noise from a road other than that fronting their houses. Reported noise sensitivity did not follow any systematic pattern with respect to noise exposure groups. The percentages who ever closed windows to reduce noise varied from a majority in the high road traffic noise exposure group to a minority in the medium, and low road traffic noise exposure groups. Complaints or a tendency to complain followed a similar pattern, and high road traffic noise exposure may have been a factor in plans to move house.

SAMPLE CLASSIFICATION 60 Subjects

SEX	Male	30
	Female	30
AGE	18-29	11
	30-49	26
	50+	23
AGE FINISHED FULL TIME EDUCATION	14 or under	8
	15	12
	16	11
	17	8
	18	10
	19 or over	10
	Don't know	1
MARITAL STATUS	Married	42
	Single	11
	Separated/Widowed/Divorced	7
HOUSEHOLD STATUS	Head of Household	28
	Housewife	22
	Other	3
	Both	7
ACTIVITY STATUS	Working full time	32
	Working part time	6
	Seeking work	2
	Retired/Sick	9
	Housewife	11

HOUSEHOLD COMPOSITION	Age groups	Number of persons in Household					
		1	2	3	4	5	6
	0-4	3	4				
	5-15	9	12	3			
	16+	9	32	9	6	2	1
	All Ages	9	15	6	16	11	3

SOCIO-ECONOMIC GROUPING	Code Number	Number of Subjects
	1	2
	2	8
	3	-
	4	6
	5	11
	6	15
	7	2
	8	1
	9	6
	10	5
	11	2
	12	1
	13	-
	14	-
	15	-
	16	16
	17	-
	18	-

TABLE H.2 Summary of field survey responses by noise exposure group

Question	Remarks (Note overall percentages ignoring filters)	High n=22	Medium n=19	Low n=19
	Average outdoor 24 hour L_{Aeq}	69.5	56.7	51.6
1b.	Percentage bothered by:			
	A washing machine	9	16	21
	A vacuum cleaner	23	11	21
	A particularly noisy plumbing system	14	11	11
	Radio, TV or stereo	23	42	21
	An electric drill	9	21	16
	Other noisy appliance or tool	14	5	26
	Aircraft	14	11	11
	Cab, lorries and other road traffic	86	47	32
	Factories or machinery	0	0	0
	Building works	0	0	5
	Animals outside	14	16	5
	Children outside	14	11	26
	Other people outside	5	11	11
	Neighbours	9	11	5
	Other noises	23	16	32
	For example: Sports Centre	0	0	11
	Road works	14	11	0
2a.	General noise dissatisfaction, 7 pt. scale	5.091	2.579	2.263
b.	Road traffic dissatisfaction, 7 pt. scale	5.591	2.842	2.632
3.	10 point annoyance scales			
a.	Evening annoyance	5.455	1.842	1.158
b.	Relaxation disturbance	4.955	1.526	1.316
c.	Conversation disturbance	3.909	0.895	0.895
d.	Reading disturbance	3.273	0.789	0.789
e.	Open window indoor annoyance	6.682	2.579	2.263
f.	Closed window indoor annoyance	5.227	1.474	1.158
4.	Highly annoyed (or not) percentage	36	11	5
5a.	Noise from another road audible	36	84	84
b.	More annoying from that road	5	37	26
6.	Projection to Winchester Road			
a.	Indoor annoyance, 10 point scale	-	6.474	7.684
b.	Conversation disturbance, 10 point scale	-	5.211	7.579
7.	Projection to Lordswood Gardens			
a.	Indoor annoyance, 10 point scale	1.773	1.588	-
b.	Conversation disturbance, 10 point scale	0.762	1.235	-
8a.	Noise sensitivity, 4 points (reversed codes)	1.955	2.421	2.000
b.	Noise sensitivity, 3 points (reversed codes)	2.318	2.316	2.211

CONT.....

Table H.2 continued.

Question	Remarks	High n=22	Medium n=19	Low n=19
	Average outdoor 24 hour L_{Aeq}	69.5	56.7	51.6
9b.	Percentages bothered by:			
	Car horns and hooters	50	26	16
	Car doors slamming	55	42	37
	Engines starting, gears, revving up	64	47	21
	Squeal of brakes or tyres	68	47	32
	Motorbikes	82	58	42
	Lorries	77	47	21
	Individual cars passing	45	5	21
	Buses	45	16	11
	Other	27	5	5
	Ambulances	14	0	0
10a.	Percentage with new windows or d/glazing	32	32	47
b.	Percentage installed self	32	32	32
c.	Percentage installed to reduce noise	5	0	5
11a.	Percentages who ever close windows to reduce noise	91	21	32
12.	Percentage not using front room due to noise	5	0	5
13.	Percentage not using front bedroom due to noise	0	11	0
14.	Percentage complained or felt like complaining	55	16	0
15a.	Percentage planning to move because of traffic noise	5	11	0
b.	Percentage felt like moving because of traffic noise	23	0	0
16.	Annoyance, 4 point scale (reversed codes)	1.773	2.947	3.368
17.	10 point bothered scale - time of day			
a.	In the morning	3.952	1.526	1.944
b.	In the afternoon	4.571	1.579	0.625
c.	In the evening	5.286	2.579	2.368
d.	At night after gone to bed	4.952	2.579	3.421
e.	Weekdays	5.809	1.722	2.474
f.	Weekends	5.238	2.421	3.632
18a.	Percentage noticing more or less/last few days	14	11	11
19a.	Percentage knowing of interviews	14	21	0
b.	Percentage knowing of subject	5	16	0
20.	Percentage male (vs female)	50	53	47
21.	Percentage 18-29 years	36	16	0
	30-49	23	37	74
	50+	41	47	26

Table H.3. Field phase - correlation coefficients with 24 hour L_{Aeq} (individual ratings and noise levels)

Question		No. of points on scale	r
2 (a)	General dissatisfaction	7	0.671
(b)	Traffic dissatisfaction	7	0.653
3 (a)	Evening annoyance	10	0.653
(b)	Relaxation disturbance	10	0.615
(c)	Conversation disturbance	10	0.553
(d)	Reading disturbance	10	0.523
(e)	Open window annoyance	10	0.653
(f)	Closed window annoyance	10	0.676
17 (a)	Morning annoyance	10	0.494
(b)	Afternoon annoyance	10	0.681
(c)	Evening annoyance	10	0.442
(d)	Night-time annoyance	10	0.242
(e)	Weekday annoyance	10	0.579
(f)	Weekend annoyance	10	0.330

Notes

1. Value of r to be significantly different from zero at the 1% level is r = 0.329.
2. Assuming an r value of 0.6. Then r values outside the range 0.4 to 0.74 are significantly different at the 5% level.

Figure H1 Percentages bothered or annoyed by different noises

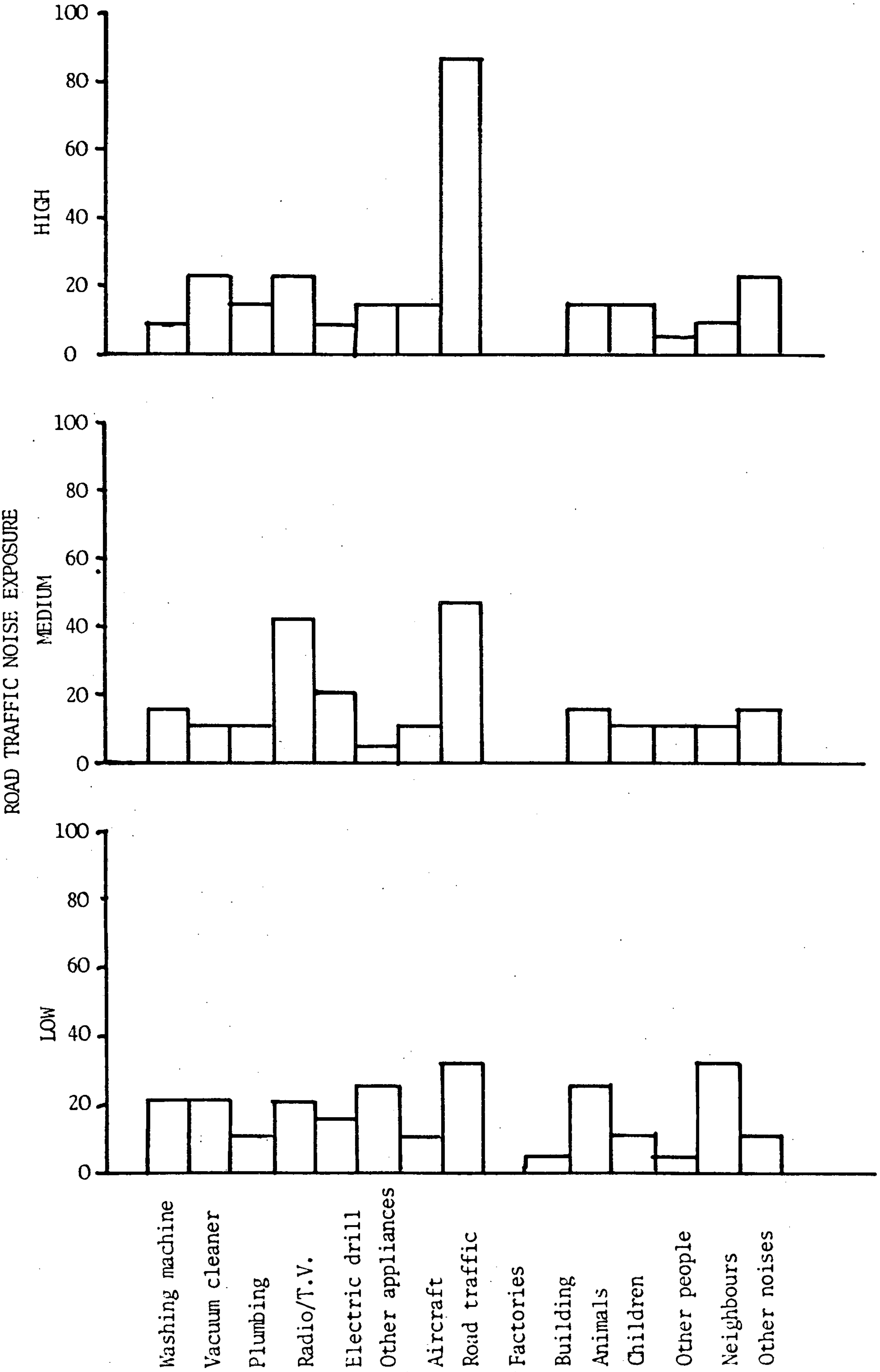


Figure H2

Seven point dissatisfaction scale

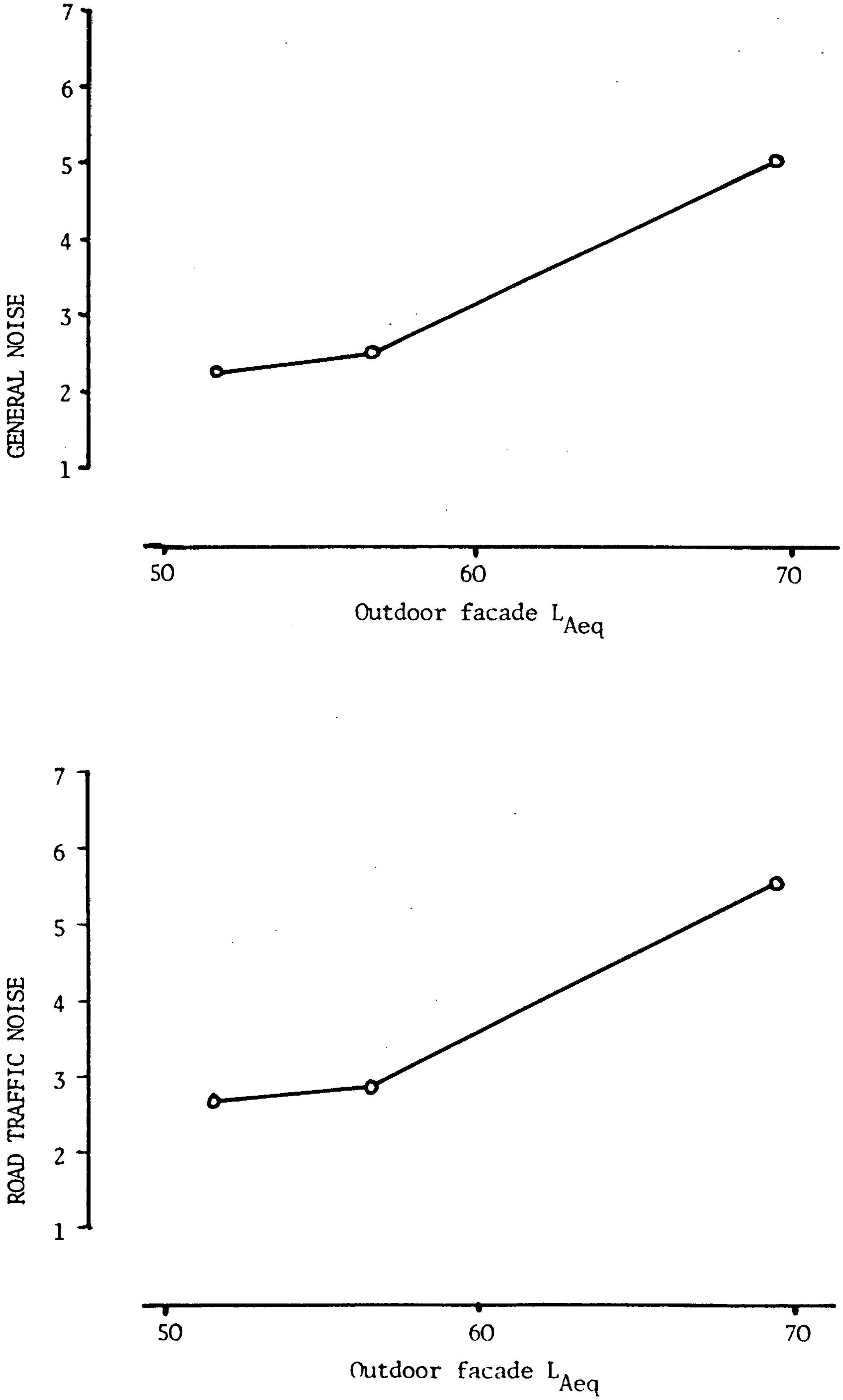


Figure H3

Ten point annoyance and disturbance scales

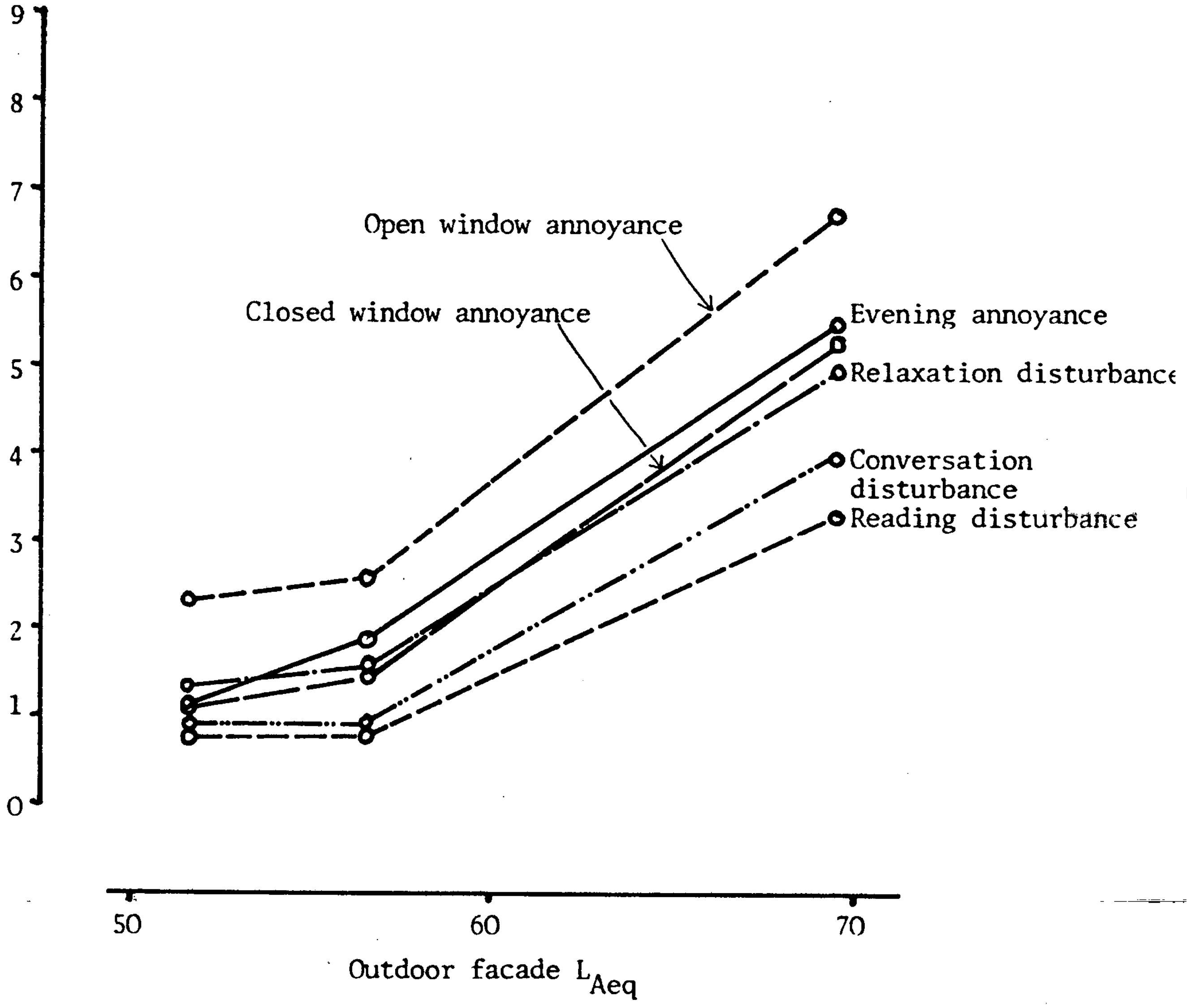


Figure H4

Percentages Highly annoyed

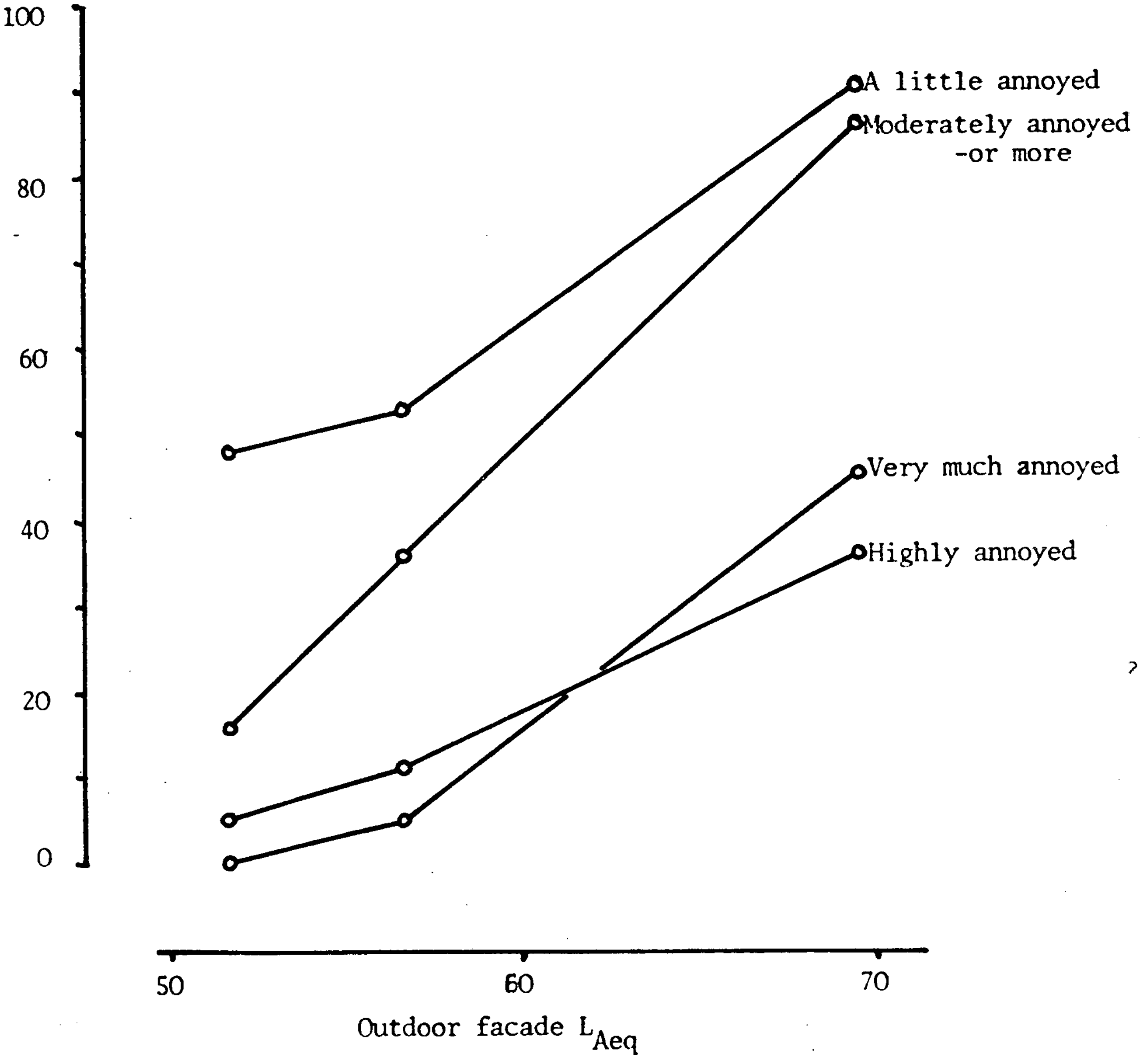


Figure H5

Field annoyance projections

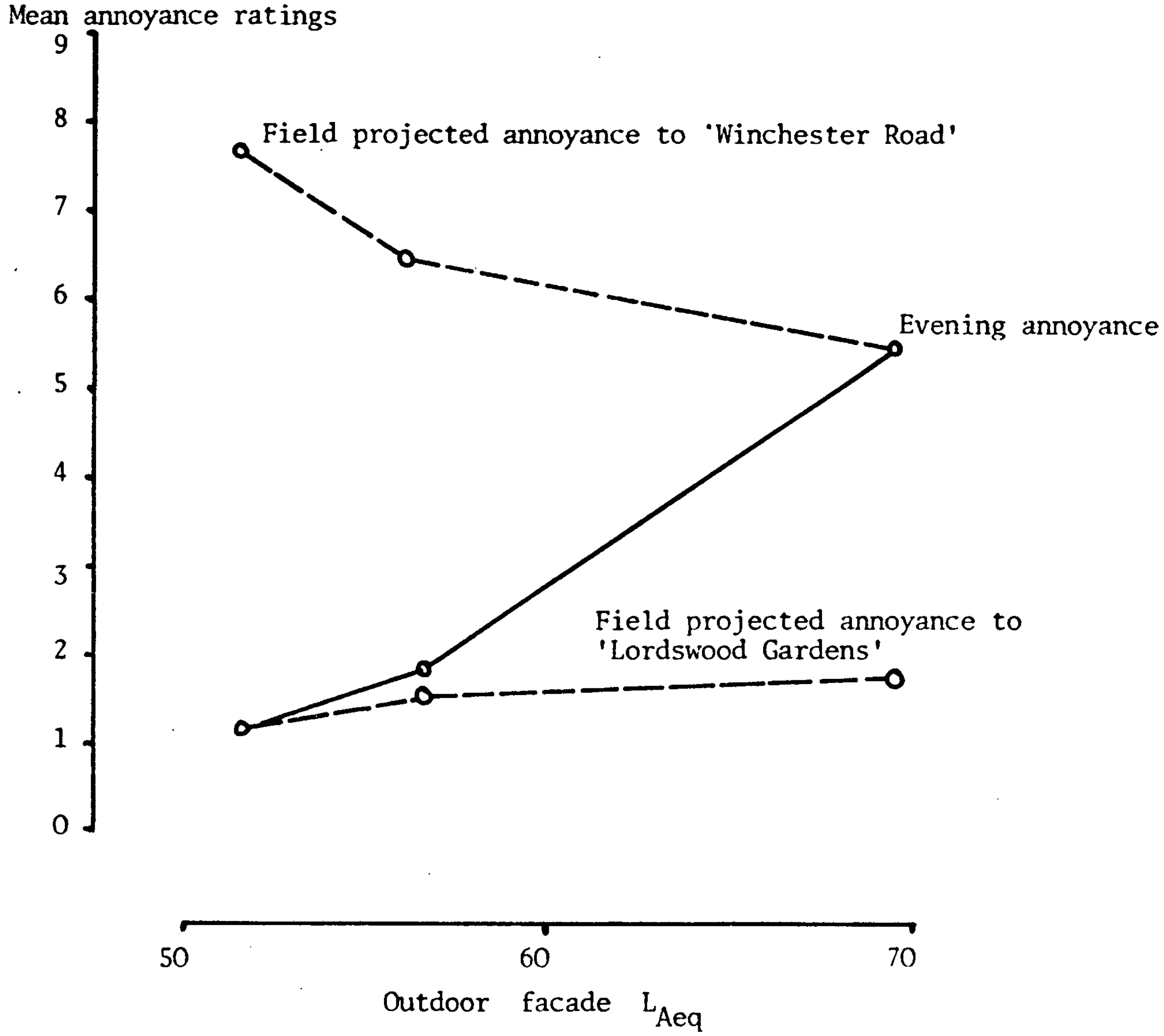


Figure H6

Percentages bothered or annoyed by different noises

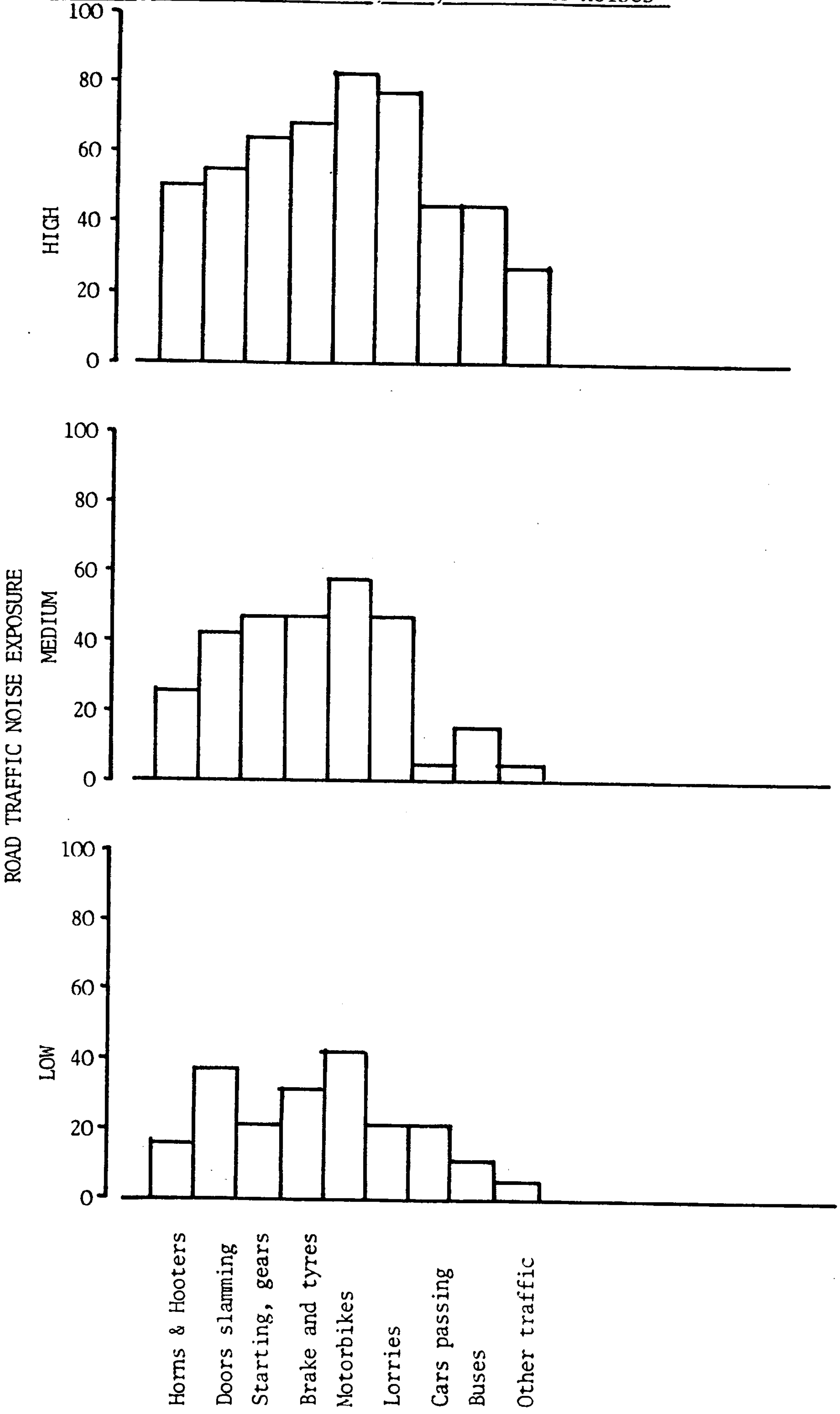


Figure H7

Time of day

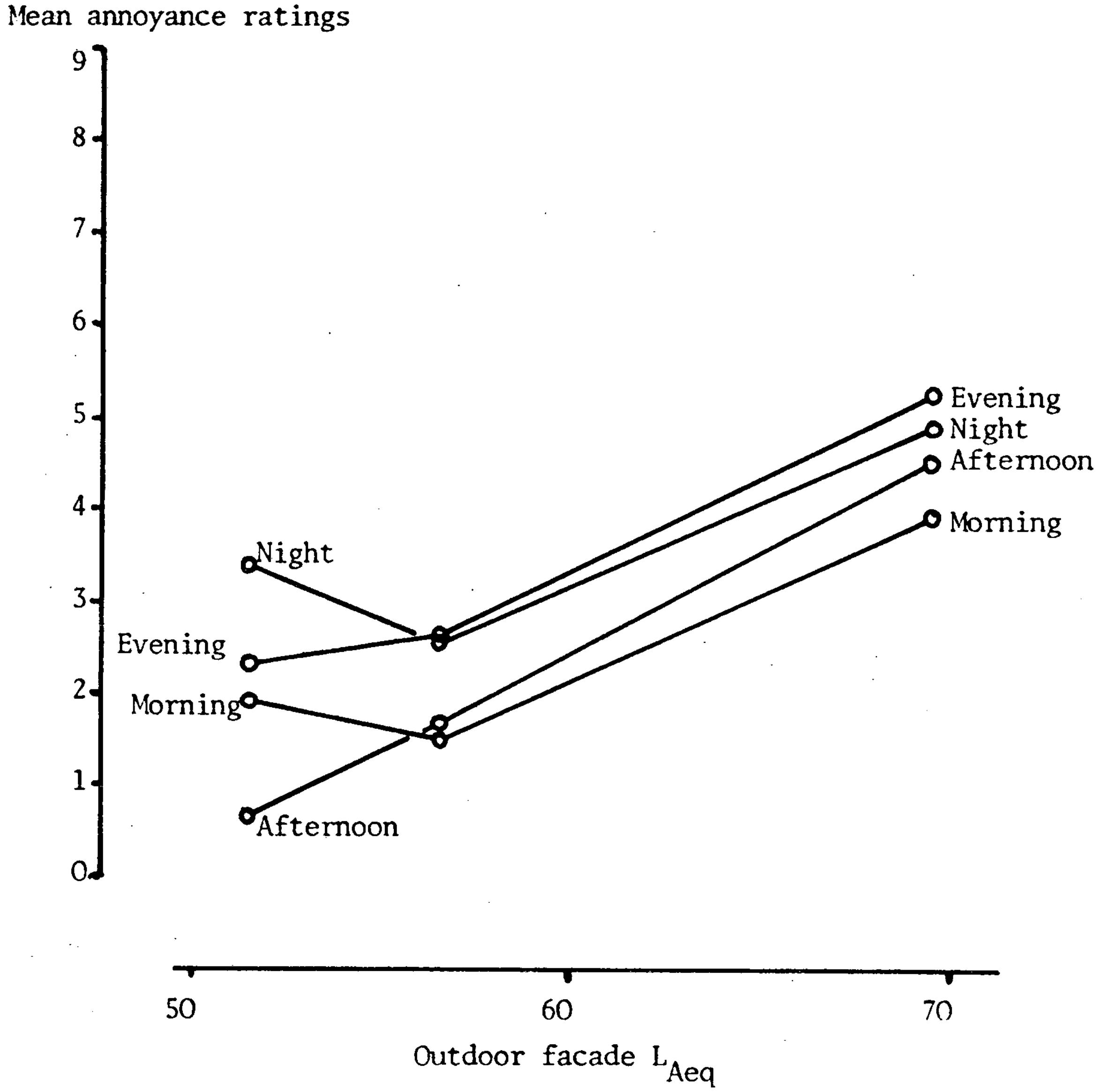
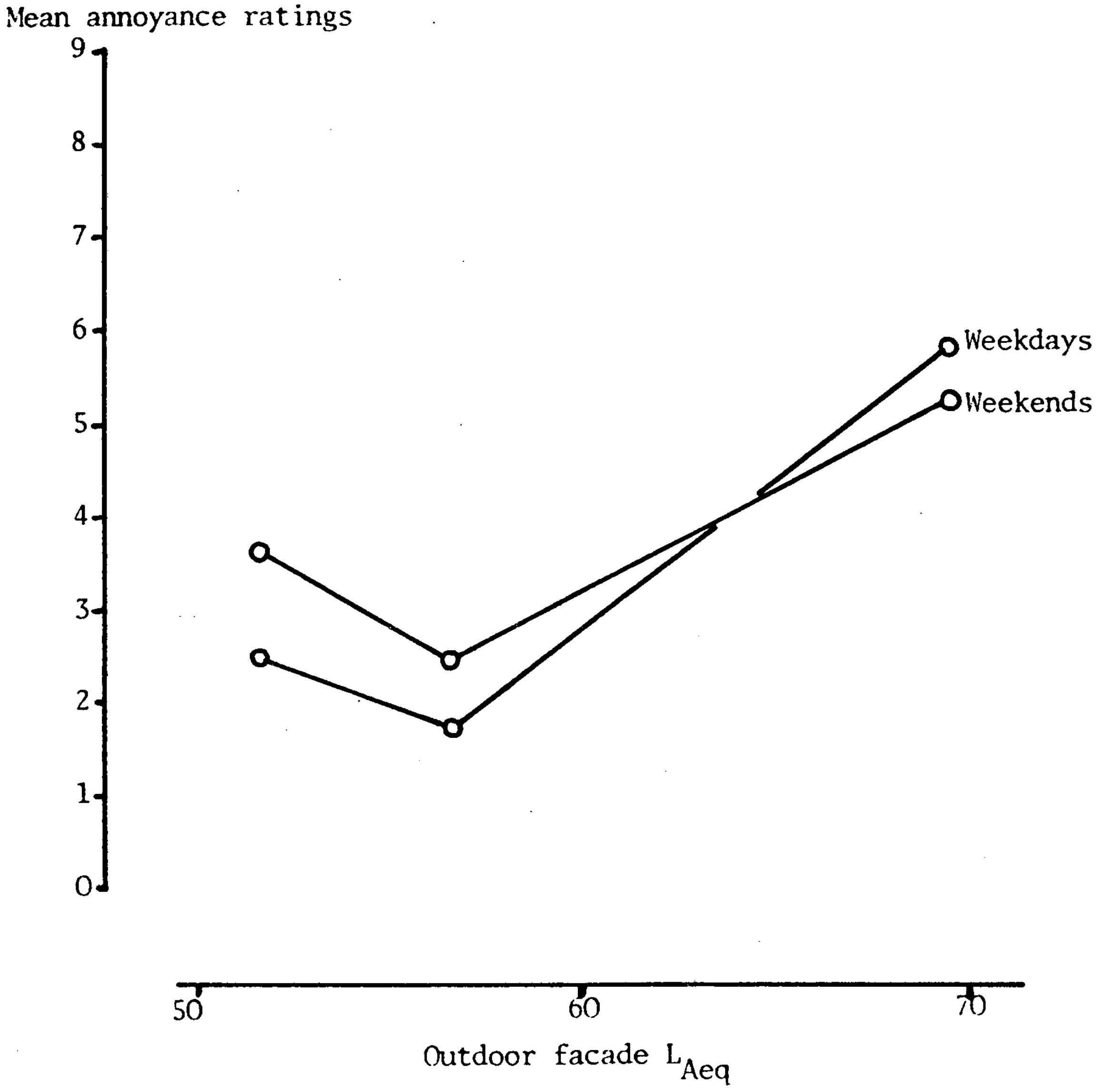


Figure H8

Weekdays and Weekends



The remaining questions did not show any useful relationships. This may have been due to the necessarily restricted sample size. Owing to this small sample size the results of the field survey can in no way be taken as nationally representative. However, there is no reason to believe that a different sample of subjects would have behaved any differently in terms of laboratory-field calibration.

H.2 Laboratory Phase

The results are presented in terms of mean annoyance ratings for the different treatments only, as analysis of variance was inappropriate due to the confounded experimental design (see Appendix E). Typical standard errors would be about 0.26 for $n = 60$ and 0.45 for $n = 20$ on the 10 point annoyance scales.

Table H.4 gives a selection of correlation coefficients between test and retest treatments, individual annoyance ratings and laboratory L_{Aeq}'s, and for the level matching task.

Figure H9 illustrates the effects of presentation order on mean annoyance ratings to Q1 and Q6. It can be seen that the order effects were not systematic, and that the mean of three treatment ratings gave the most linear relationship with noise level. Figures H10 and H11 show the effects of subject group on mean annoyance ratings for Q1 and Q6. Here the low home road traffic noise exposure groups gave higher mean annoyance ratings in the laboratory. However, the mean annoyance ratings for the other two groups did not follow any systematic relationship.

Accordingly, it is reasonable to assume that order effects were not important (especially in the light of the high test-retest correlations) and that mean annoyance ratings were independent of home road traffic noise exposure. Such assumptions recognise that order and subject group effects might have existed but did not follow any systematic relationships. The mean of three treatment annoyance ratings were used in the laboratory-field comparisons on this basis.

Figure H12 shows means of three treatment annoyance ratings for Q1, Q2, Q3, Q4 and Q6 against noise level. Figure H13 shows per cent highly annoyed on Q5 and Q7. Figure H14 shows the percent reporting tapes to

Table H.4 Laboratory Phase - Correlation Coefficients

Test-retest n = 60

Question	r
1	0.778
2	0.795
3	0.813
4	0.758
6	0.810

Mean annoyance ratings and laboratory L_{Aeq}'s. n = 60

Question	r
1	0.657
2	0.672
3	0.486
4	0.623
6	0.667

Level-matching task

Noise levels - laboratory and field facade levels.

	r	n
Outdoors	0.778	38
Closed window indoors	0.516	60
Open window indoors	0.827	22

Laboratory level and mean annoyance ratings

	r	n
Outdoors	0.478	38
Closed window indoors	0.712	60
Open window indoors	0.757	22

Note: all r values significant at better than 1% level.

Figure H9 Order effects

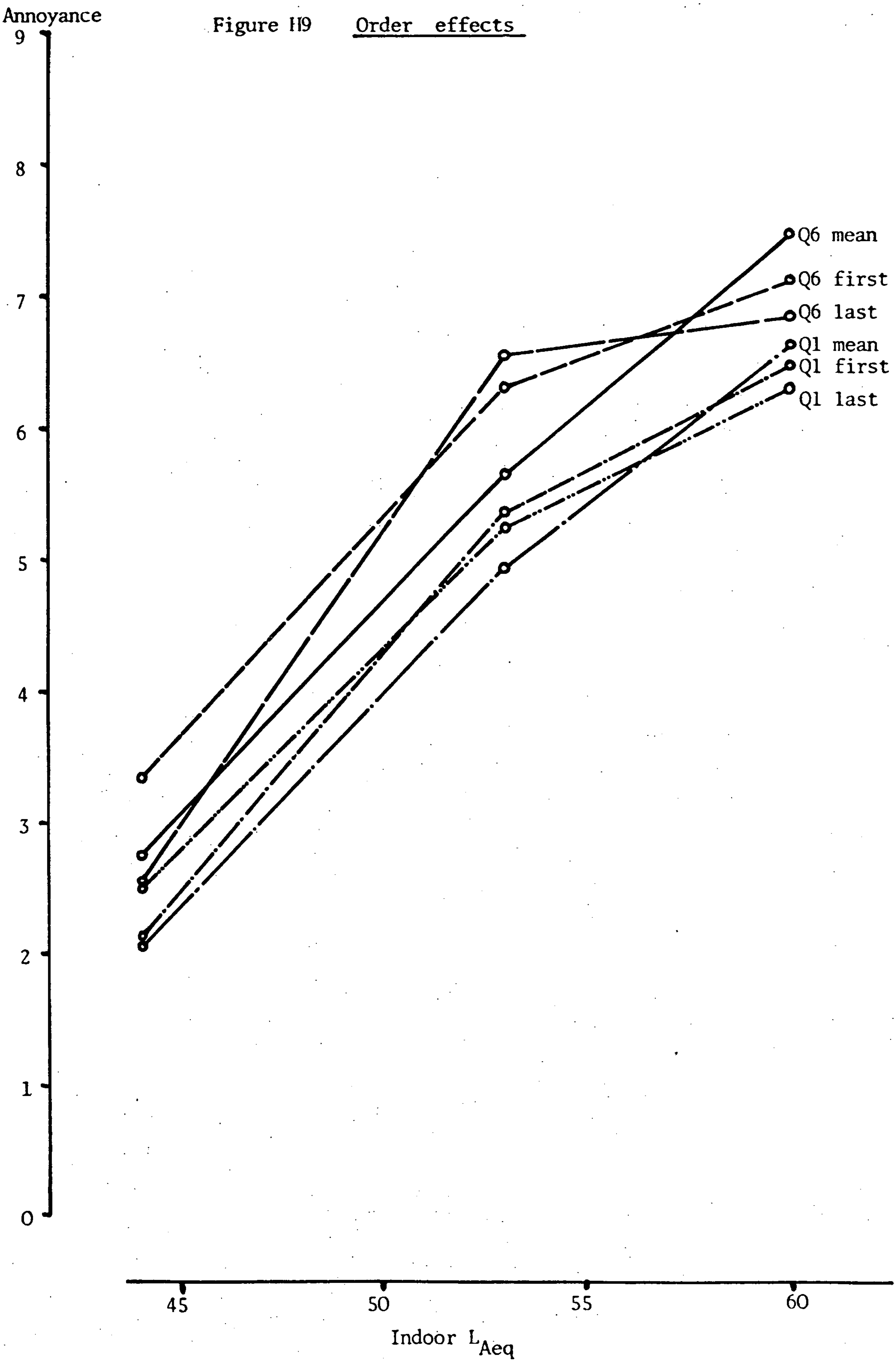


Figure H10 Subject groups and tapes

Questionnaire item 1

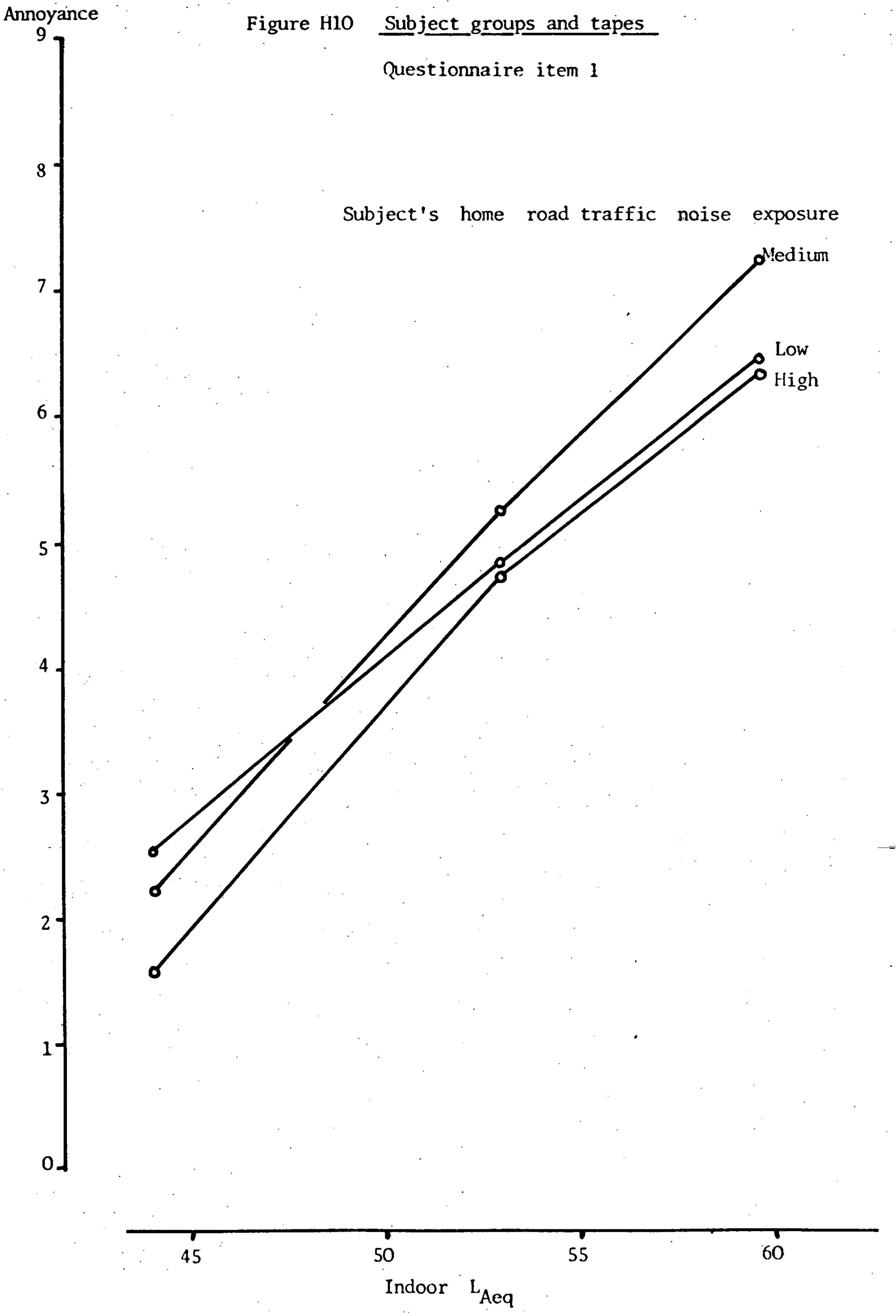


Figure H11 Subject groups and tapes

Questionnaire item 6

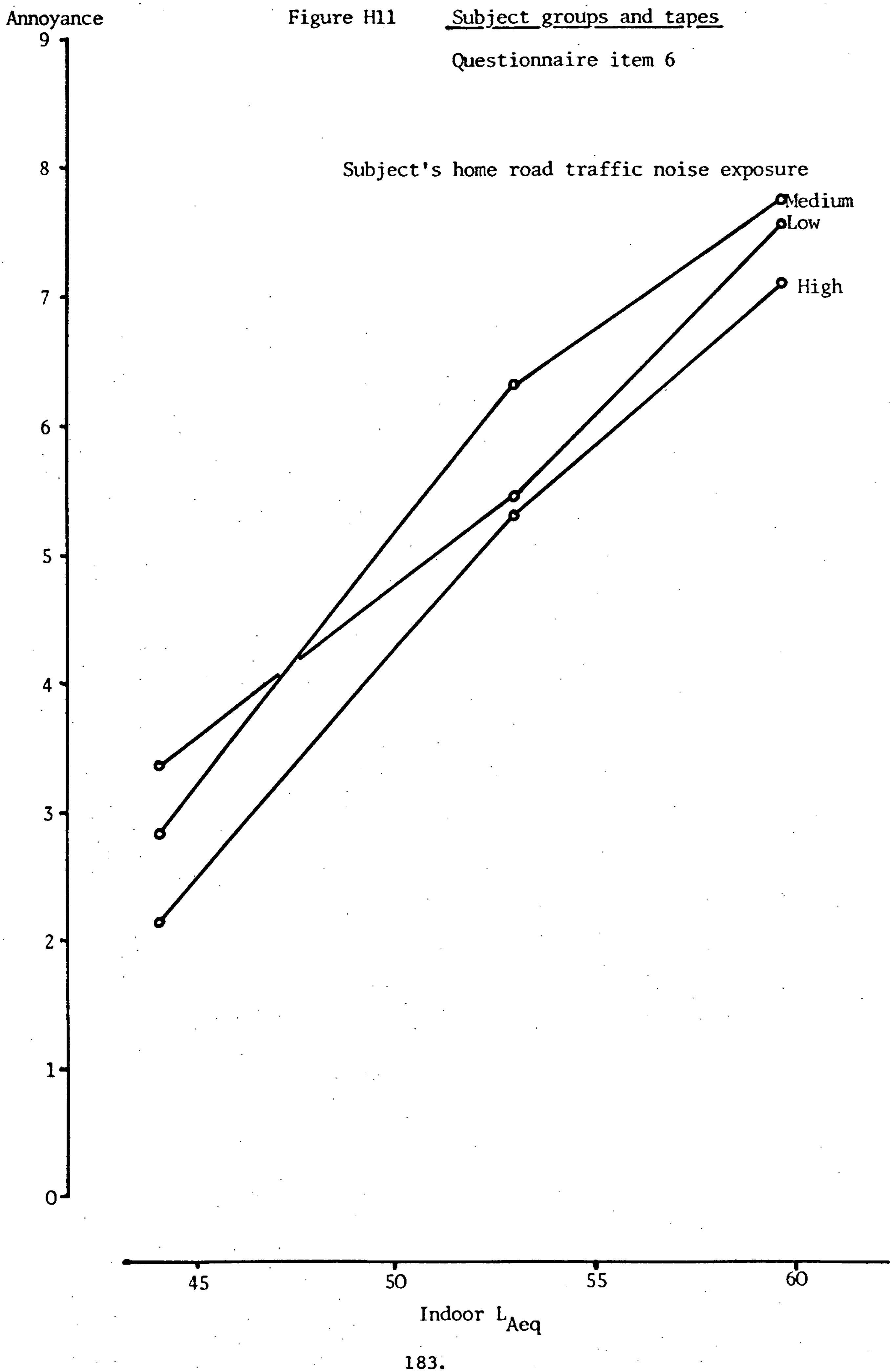


Figure H12 Mean annoyance ratings

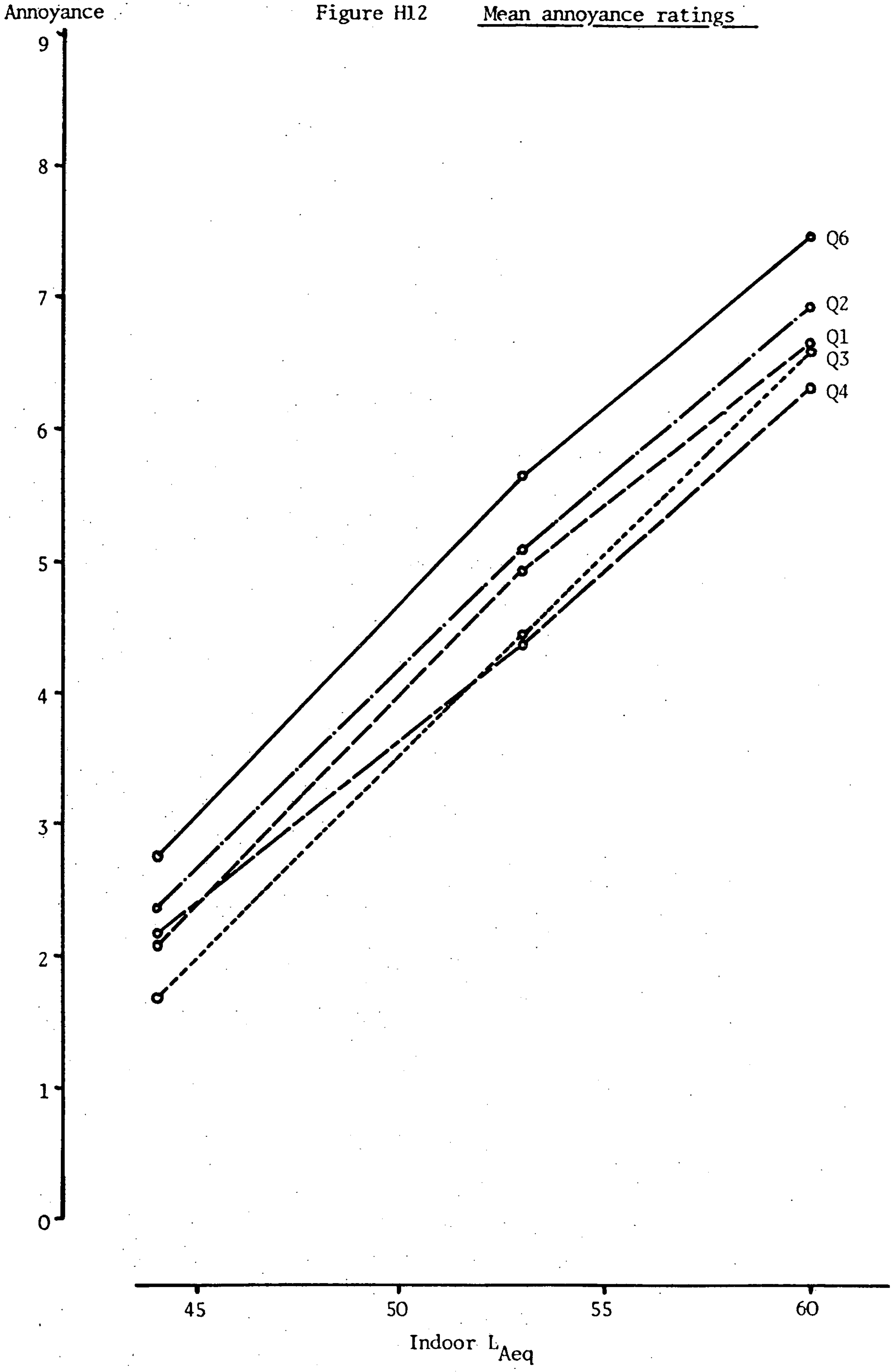


Figure H13 Percentage Highly annoyed

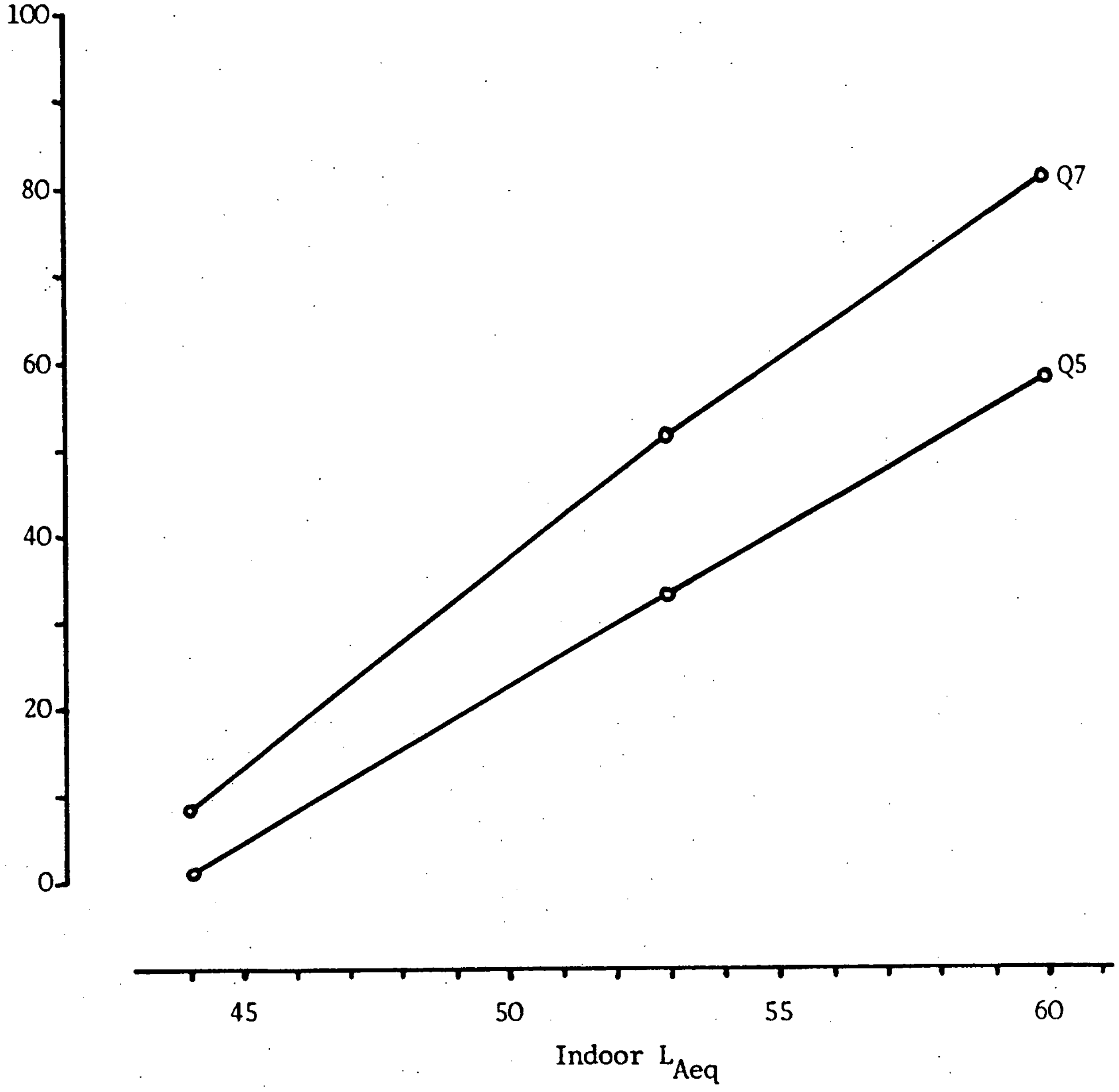
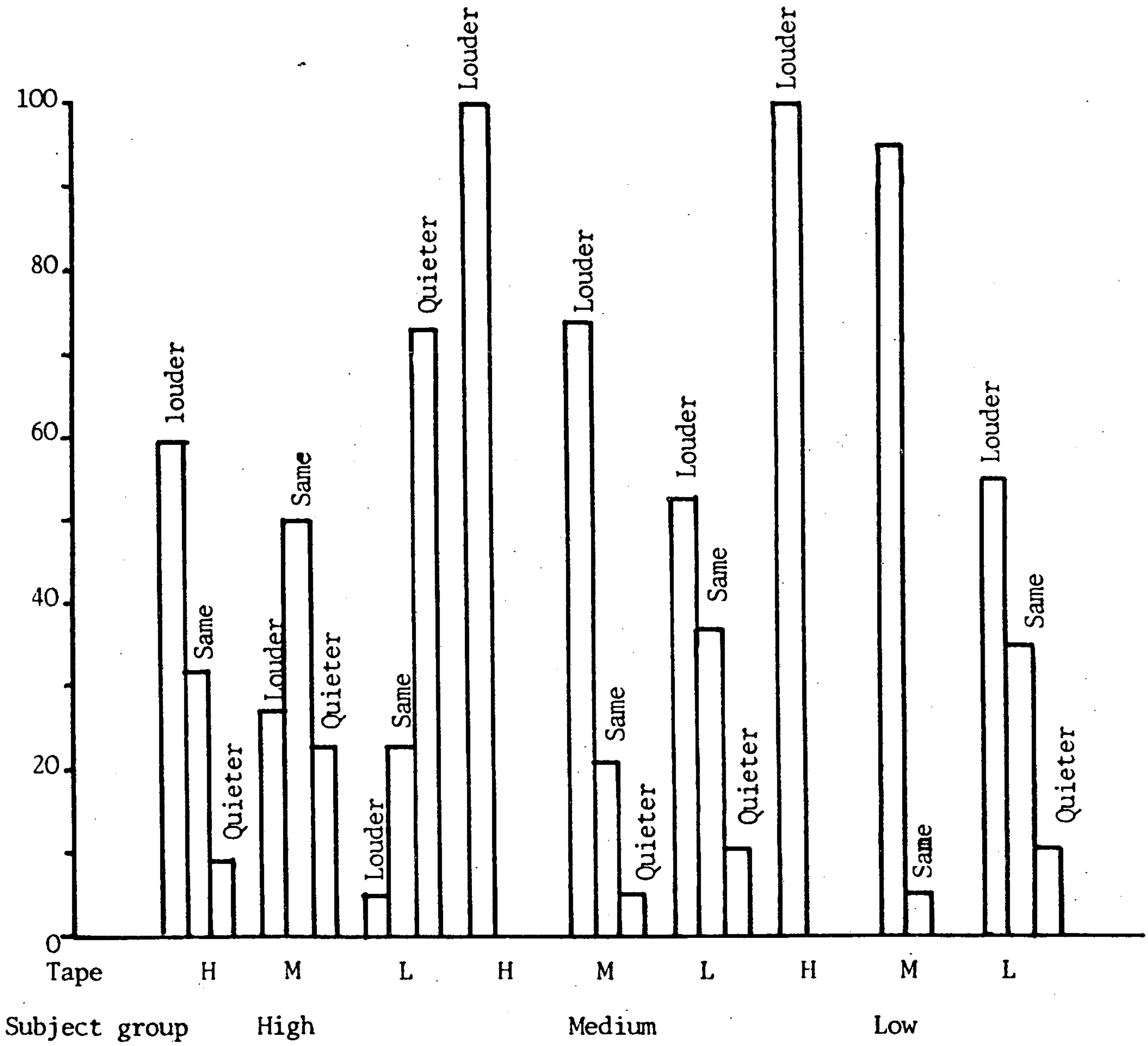


Figure H14

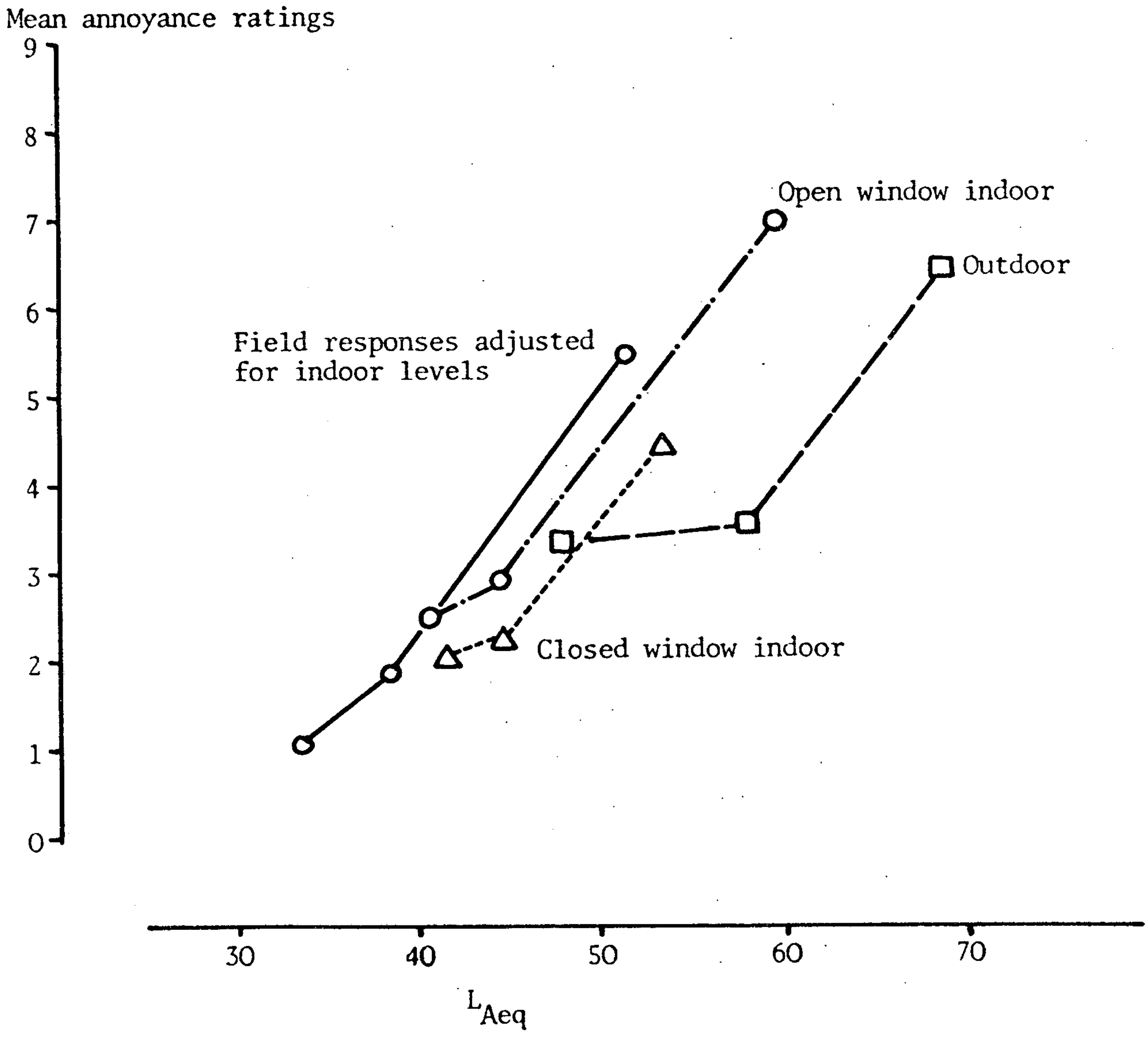
Percentages reporting tapes to be louder or quieter than at home



be louder or quieter than at home. The results were not surprising in view of the insufficient attenuation of 10 dB which was applied in the experiment. Figure H15 illustrates the results of the level-matching task compared against the field survey Q3(a) annoyance ratings plotted at nominal indoor noise levels (-18 dB from outdoor facade levels). The best correspondence is between the field survey responses at nominal indoor levels and the open window indoor matching responses.

Figure H15

Laboratory level matching task



APPENDIX I: Road Traffic and Railway Noise Study - Experimental Design

Road Traffic - ABCDE   Trains - 1 2 3 4 5

Order	Subject Groups									
	1	2	3	4	5	6	7	8	9	10
1	2	3	4	5	1	C	B	A	E	D
2	4	1	5	3	2	B	A	E	D	C
3	1	5	2	4	3	D	C	B	A	E
4	5	2	3	1	4	A	E	D	C	B
5	3	4	1	2	5	E	D	C	B	A
6	A	B	C	D	E	5	2	1	4	3
7	B	C	D	E	A	4	1	3	2	5
8	E	A	B	C	D	3	4	2	5	1
9	C	D	E	A	B	2	3	5	1	4
10	D	E	A	B	C	1	5	4	3	2

1	A1	A4	B2	B5	C3	C1	D4	D2	E5	E3
2	B5	E5	C1	A1	D2	B2	E3	C3	A4	D4
3	E2	B3	A3	C4	B4	D5	C5	E1	D1	A2
4	C4	D1	D5	E2	E1	A3	A2	B4	B3	C5
5	D3	C2	E4	D3	A5	E4	B1	A5	C2	B1
6	E5	D4	A1	E5	B2	A1	C3	B2	D4	C3
7	B3	B1	C4	C2	D5	D3	E1	E4	A2	A5
8	C2	A2	D3	B3	E4	C4	A5	D4	B1	E1
9	A4	C5	B5	D1	C1	E2	D2	A3	E3	B4
10	D1	E3	E2	A4	A3	B5	B4	C1	C5	D2
11	E3	A5	A4	B1	B5	C2	C1	D3	D2	E4
12	A2	E1	B3	A2	C4	B3	D5	C4	E1	D5
13	C5	C3	D1	D4	E2	E5	A3	A1	B4	B2
14	D4	B4	E5	C5	A1	D1	B2	E2	C3	A3
15	B1	D2	C2	E3	D3	A4	E4	B5	A5	C1
16	C3	E4	D4	A5	E5	B1	A1	C2	B2	D3
17	A5	B2	B1	C3	C2	D4	D3	E5	E4	A1
18	B4	A3	C5	B4	D1	C5	E2	D1	A3	E2
19	D2	D5	E3	E1	A4	A2	B5	B3	C1	C4
20	E1	C1	A2	D2	B3	E3	C4	A4	D5	B5
21	A3	D3	B4	E4	C5	A5	D1	B1	E2	C2
22	D5	A1	E1	B2	A2	C3	B3	D4	C4	E5
23	B2	C4	C3	D5	D4	E2	E5	A2	A1	B3
24	C1	B5	D2	C1	E3	D2	A4	E3	B5	A4
25	E4	E2	A5	A3	B1	B4	C2	C5	D3	D1

APPENDIX J: Road Traffic and Railway Noise Study

Instruction sheets and Questionnaires

Noise Experiment at ISVR Listening Room

1. The experiment involves sitting in a comfortable room and listening to some ordinary, everyday sounds. These sounds will be tape recordings of traffic noise and railway train noise.

2. After every five minutes of listening, subjects will be asked to record their opinions on the sounds by filling in a very short questionnaire.

3. Subjects are asked to attend for approximately 1½ hours on the first occassion and approximately 3 hours on the second (and final) occassion. It is possible to arrange for either a morning and an afternoon on the same day, or for the visits to occur on two consecutive evenings.

4. Transport can be arranged if required for evening visitors.

5. Subjects will normally attend in groups of four. They will be asked to bring work, reading matter, knitting etc. in order to occupy themselves whilst listening to the sounds. Thus the time given by subjects can be used productively for their own purposes.

6. Each subject will be paid £5 (£1 per hour plus 50p bonus) on completion of their two visits to the laboratory.

Contact; Ian Flindell Institute of Sound and Vibration Research
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Tel. 559122 ext. 753
Room No. 1.28 Rayleigh Building

Questionnaire

1. Date.

2. Name.

3. Southampton address.

4. Age.

5. Sex.

6. How annoying do you find traffic noise (or railway noise, or both) when you are at home in your own living room, in the evenings?

   Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

7. Would you say you are 'highly annoyed' or not, by traffic noise (or railway noise, or both) when you are at home in your own living room, in the evenings?

   Yes, highly annoyed.......... ☐
   No.......................... ☐

8. Would you say you were more sensitive or less sensitive than other people to noise?

   More sensitive.............. ☐
   Less sensitive.............. ☐
   About the same.............. ☐

Questionnaire

1. How annoying are these noises?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

2. Would you say you are 'highly annoyed' or not, by these noises?

Yes, highly annoyed.............

No.............................

3. Now, thinking about when you are at home, indoors, in the evenings;

How annoying would these noises be in your own living room, in the evenings?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

4. Would you say you would be 'highly annoyed' or not, by these noises in your own living room, in the evenings?

Yes, highly annoyed.............

No.............................

Questionnaire

1. How annoying are these noises?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

2. Would you say you are 'highly annoyed' or not, by these noises?

Yes, highly annoyed.............

No.............................

3. Now, thinking about when you are at home, indoors, in the evenings;

How annoying would these noises be in your own living room, in the evenings?

Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying

4. Would you say you would be 'highly annoyed' or not, by these noises in your own living room, in the evenings?

Yes, highly annoyed.............

No.............................

APPENDIX K: The CAP Model

The [1]CAP model (sometimes known as the [2]CGR model) was devised in order to fit the road traffic noise and railway noise laboratory study data (see Chapter 6) by taking account of an assumed sigmoidal relationship between noise exposure levels and annoyance responses. The concepts of pressure L_{Aeq} and the pressure sum were derived from the CAP model and thus superceded it. However, it is reasonable to assume that the CAP model might still have applicability in those situations where it is desired to compare the disbenefits of exposing a large number of people to moderate noise levels or a small number of people to high noise levels. The CAP model allows for equal increments of noise exposure in terms of decibel levels to have different effects in terms of annoyance responses dependent on the absolute level of noise exposure.

The model assumes that annoyance potential is related to the sum of the average r.m.s. A-weighted sound pressures of the contributing noise sources, as for pL_{Aeq}, psum. Therefore it fits the road traffic noise and railway noise laboratory study data and the airborne aircraft, airport ground and road traffic noise laboratory study data as well as pL_{Aeq}, psum. It was superceded purely because of the complexities involved in its calculation, which are described below.

The CAP of a separate contributing noise source is defined as below:

$$\text{CAP} = \frac{(P)^n}{(P)^n + 1} \qquad \text{(K.1)}$$

where

$$P = \frac{\text{r.m.s. } p_A}{p_{ref}} \qquad \text{(K.2)}$$

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[1] CAP - Community Annoyance Potential

[2] CGR - Community Grievance Rating

where

$\overline{\text{rms}}\ p_A$ is the mean rms A-weighted sound pressure in Pascals

p_{ref} is a reference A-weighted sound pressure

n is a constant

Conversely,

$$P = {}^{n}\!\!\sqrt{\frac{CAP}{1 - CAP}} \tag{K.3}$$

CAP conveniently goes from 0 to 1 when P goes from very small to very large. It equals 0.5 when $\overline{\text{rms}}\ p_A$ equals p_{ref}, thus p_{ref} must be chosen in the middle of the range of exposure levels, in terms of annoyance potential.

The CAP model gave the best fit with the road traffic noise and railway noise laboratory study data when p_{ref} corresponded to an outdoor facade noise level of 66 dB(A) - 0.04 Pascals and n was equal to $\sqrt{2}$. Figure K1 illustrates the relationship between CAP and outdoor facade noise level using these coefficients.

The summation of separate contributing noise source CAP values to yield an overall CAP is given below:

$$CAP_{overall} = \frac{\left(\left(\frac{CAP_1}{1 - CAP_1}\right)^{1/n} + \left(\frac{CAP_2}{1 + CAP_2}\right)^{1/n}\right)^n}{\left(\left(\frac{CAP_1}{1 - CAP_1}\right)^{1/n} + \left(\frac{CAP_2}{1 - CAP_2}\right)^{1/n}\right)^n + 1} \tag{K.4}$$

This equation is not difficult to solve for CAP overall when CAP_1 and CAP_2 are known but it is beyond the author's mathematical ability to solve it for either CAP_1 or CAP_2 when $CAP_{overall}$ and the other of CAP_1 or CAP_2 are known. In such cases the solution can be found by means of a nomogram [K1]. A suitable nomogram is given at Figure K2, constructed using the coefficient of p_{ref} equal to 66 dB(A) - 0.04 Pascals and $n = \sqrt{2}$.

Figure K1

The relationship between CAP and outdoor facade L_{Aeq}

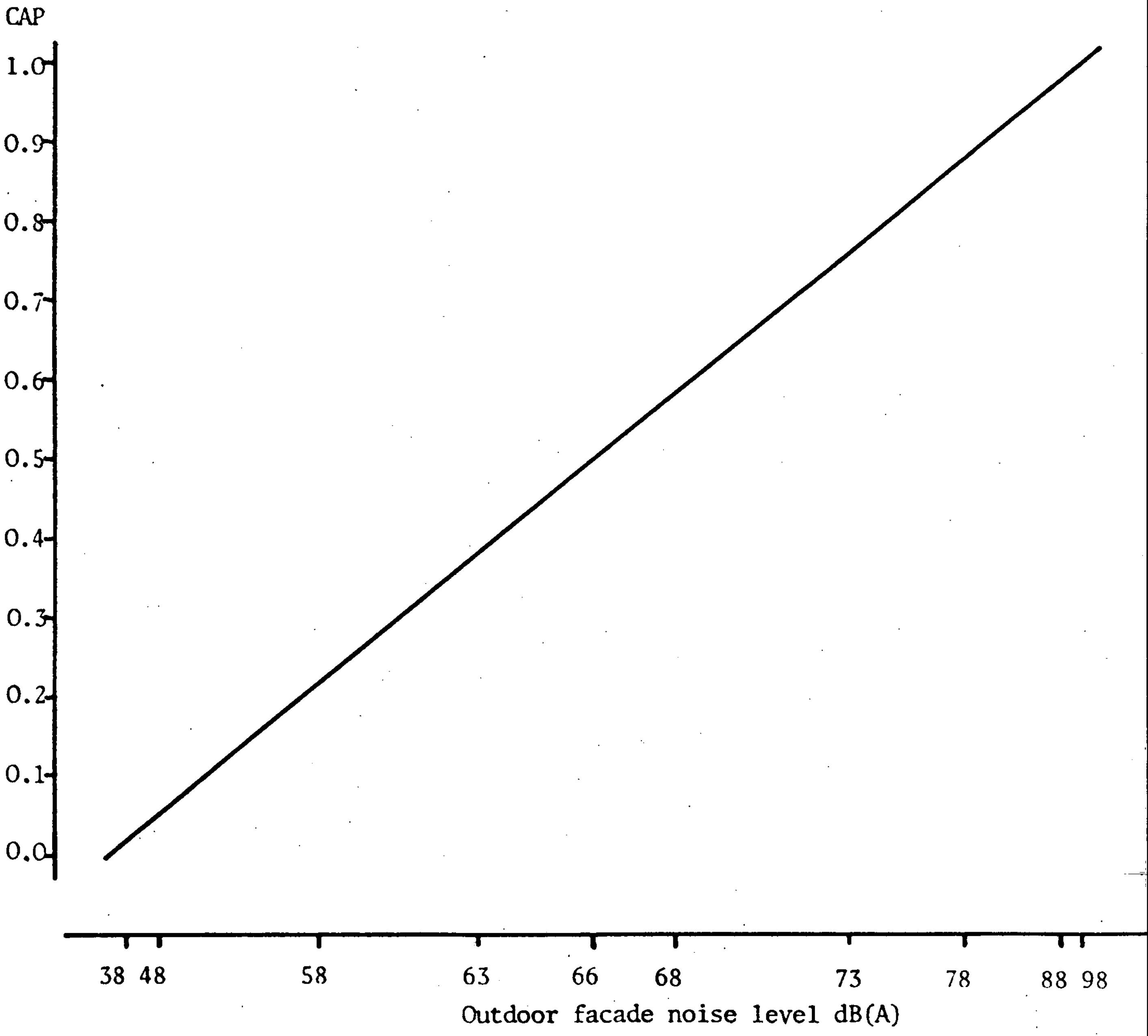
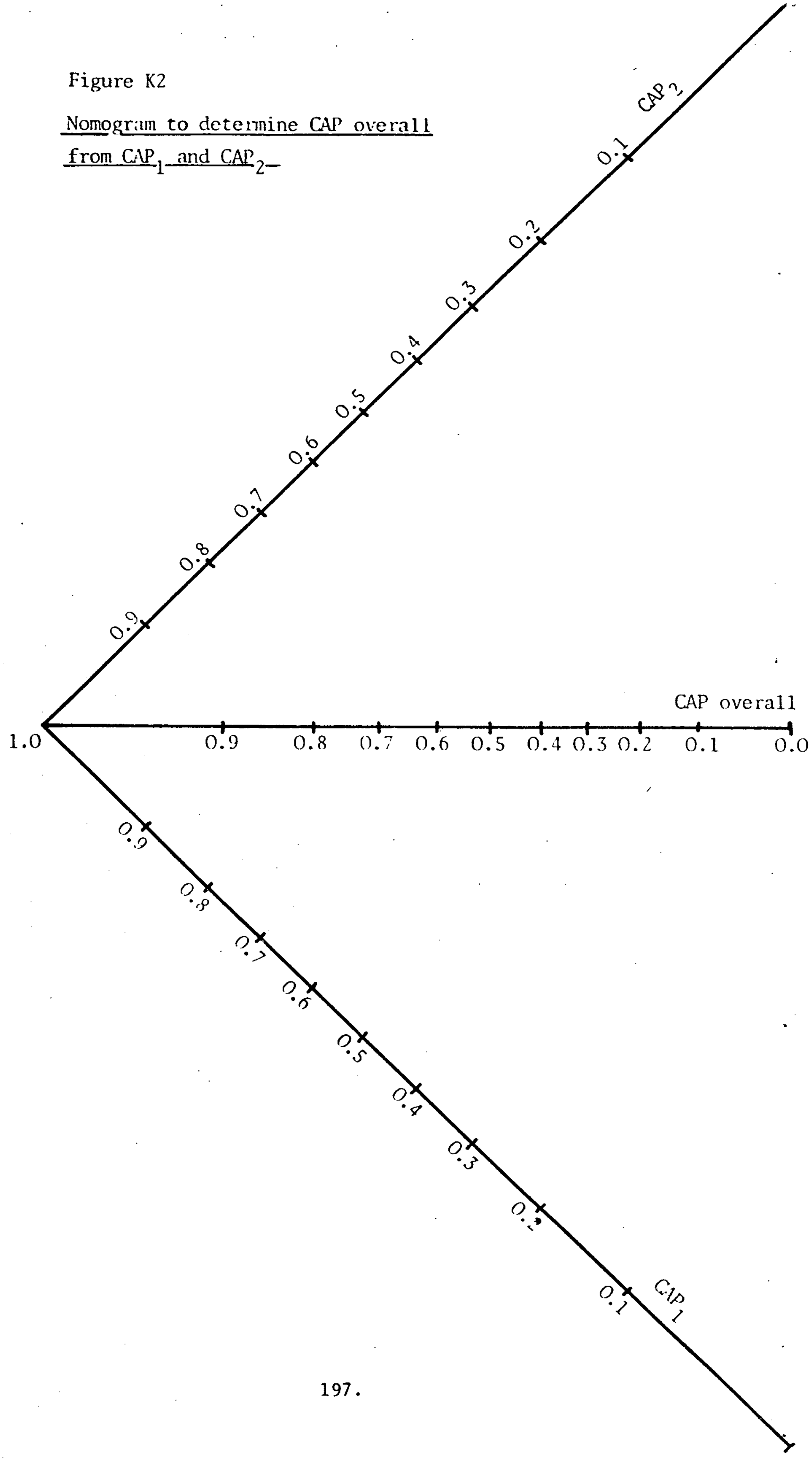


Figure K2

Nomogram to determine CAP overall from CAP_1 and CAP_2



The nomogram is used by picking off the two known values on the appropriate scales and then reading off the third value by lining up a straight edge with the two known points and across the third scale. The nomogram is dependent on the coefficients n and would take a different form were the coefficient n to be changed.

Figure K3 illustrates the increase in $CAP_{overall}$ that occurs when two otherwise subjectively equal noise sources are added together, over and above the CAP of either noise source alone. This illustrates that, in practical terms, a doubling of noise sources might be of no real significance at either very low or very high noise exposure levels. At low noise exposure levels annoyance may be at a low level regardless of the constituents of the noise environment. At high noise exposure levels annoyance may be at a maximum regardless of the number of noise sources. It is only in the middle range of noise exposure levels that combinations of noise sources have a significant effect.

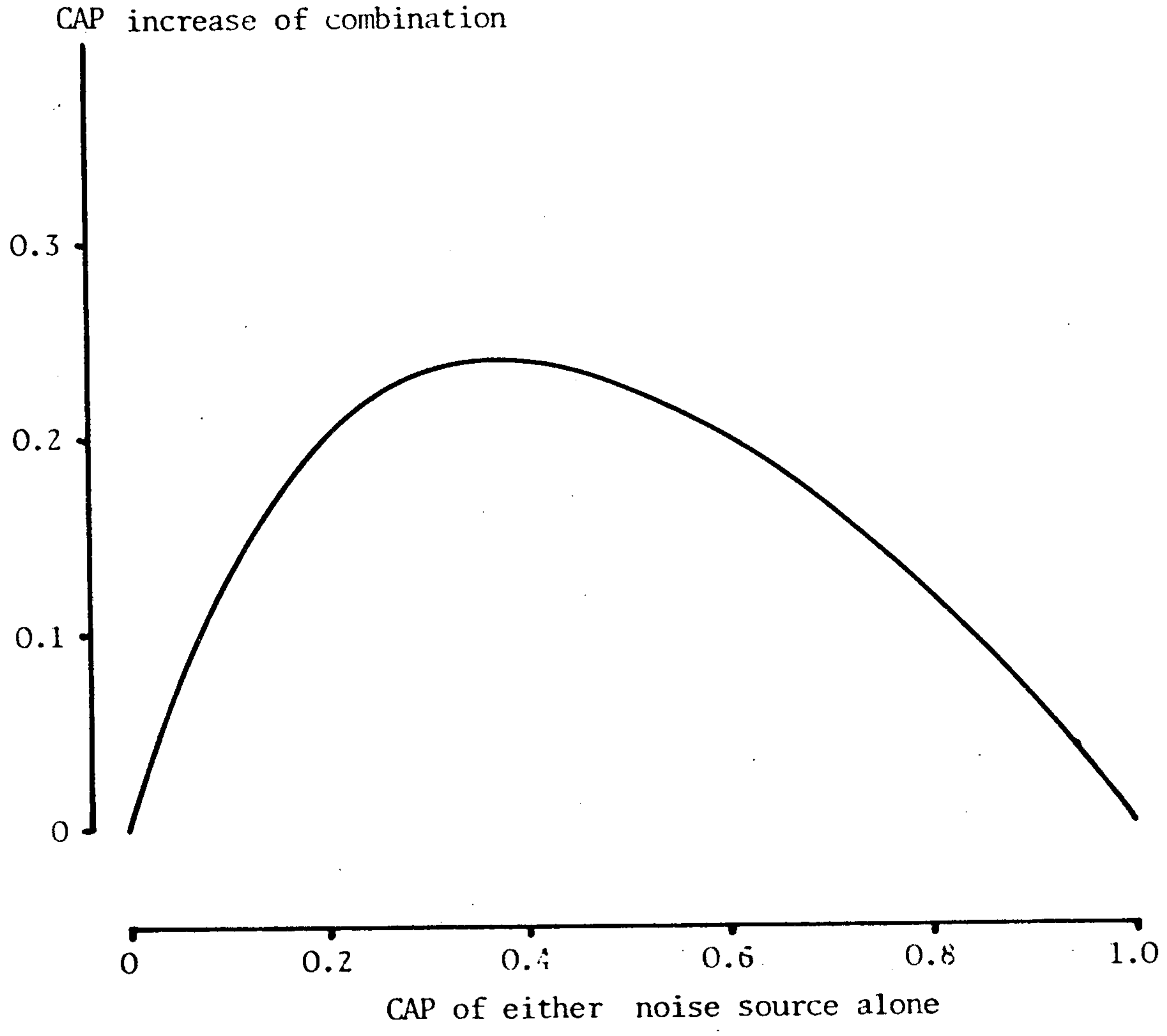
It was not considered worthwhile in terms of the objectives and resources of this study to carry out any empirical comparisons between the CAP model and pL_{Aeq}, psum. However, such comparisons would be possible, if desired. It would be necessary to compare the effects on annoyance responses of equal incremental changes of noise exposure level over a very wide range of absolute noise exposure levels.

References

K1. P. Lyle 1954 'The construction of nomograms for use in statistics'. Applied Statistics 3, 116-125.

Figure K3

The increase in CAP due to the addition of two subjectively equal noise sources



APPENDIX L: The Measurement of pL_{Aeq}

pL_{Aeq} is given by:

$$pL_{Aeq} = 20 \log_{10} \left[\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} 10^{\frac{L_A(t)}{20}} dt \right]$$

pL_{Aeq} can be readily determined from a measured or predicted probability distribution of sample A-weighted sound pressure levels, in exactly the same way as conventional L_{Aeq} is determined. Thus statistical distribution analysers such as the Bruel and Kjaer type 4426 can be used, although pL_{Aeq} cannot be read off directly without internal reprogramming. If a type 4426 noise level analyser is used, pL_{Aeq} can be calculated from the statistical distribution, preferably by using a simple programmable calculator.

True integrating sound level meters, such as the Bruel and Kjaer type 2218 cannot give pL_{Aeq} readings without internal reprogramming. This reprogramming should involve no more than changing the values of a few resistors, in order to integrate rms pressure rather than rms pressure squared.

Instruments are available which will give a pL_{Aeq} readout directly (see enclosed correspondence).

The direct measurement of pL_{Aeq}, psum is a little more complicated. Whichever instrument is used must be continuously manned in order to record which of the contributing noise sources is dominant at any one time. Then pL_{Aeq}'s must be separately determined for each separate noise source in order to calculate the overall psum using the formula given below:

$$\text{psum} = 20 \log_{10} \sum_{i=1}^{n} 10^{\frac{pL_{Aeq\,i}}{20}}$$

The continuous manning procedure is no more inconvenient than the procedure required to measure conventional L_{Aeq} contributions. It is possible to conceptualise relatively simple instruments that would automatically integrate pL_{Aeq}'s in a bank of counters according to the position of a switch which is manually directed depending on the dominant noise source at the time. Advances in micro electronics are likely to make even this task automatic, once different noise sources can be reliably identified by machine.

PRB/MSC/9763

27th May 1981

Professor Flindel
Institute of Sound and Vibration Research
University of Southampton
Southampton

Dear Professor Flindel,

I have today received a letter from Mr Hal Hardenburgh the President of Digital Acostics Incorporated from Santa Ana, California asking me to send you the details of our DA607 Environmental Noise Analyser. He informs me that you are very interested in researching into pressure Leq and as he has undertaken to programme a version 3 DA607 for John Manuel of the Noise Control Section of the Ministry of Environment in Toronto for pressure Leq he felt you might also like to take advantage of the availability of such a piece of equipment.

I've enclosed a brochure and if you have a real interest in the availability of this product, I will be pleased to call to see you to discuss it further. The cost of the instrument would be £4,992.00 plus a suitable microphone. I am leaving for the United States tomorrow and will not be back until the 22nd of June but could come to see you shortly thereafter if you so wish.

Yours sincerely,

Moira Channing

pp Peter R Bull
Managing Director.

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DA 607 P

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- SENEL (L_{AX})
- Interval L_{eq}
- Interval L_{max}
- Interval Time Threshold Exceeded
- Interval Mean
- Interval Standard Deviation
- Interval L_{NP}
- Interval L_{min}
- Eight Interval L_N
- Interval Cumulative Distribution
- Interval Bar Histogram
- Vast Dynamic Range 20-140 dBA
- No Range Controls
- Strip Chart dBA Record
- Manual L_{eq} (from independent time zero)
- Manual Time Threshold Exceeded
- Manual Elapsed Time
- Manual L_{max}
- Manual L_{min}
- HNL
- LDN
- CNEL
- All measurement functions may be operative simultaneously.

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