THE SUBJECTIVE AND OBJECTIVE ASSESSMENT OF INDUSTRIAL NOISE

Bernard F Berry and Nicole D Porter
National Physical Laboratory, Teddington, Middlesex, TW11 0LW, England.

1. BACKGROUND

It is well established that noise with specific temporal or spectral characteristics often produces a heightened subjective response. Existing standard noise rating procedures such as BS 4142 (1) rely on subjective judgments to determine whether or not penalties should be added to a measured level to take into account this heightened response. However, rating methods should ideally provide for consistent decisions which depend as little as possible on subjective personal evaluations of the noise. The current situation is often unsatisfactory since an unreasonable decision can lead to considerable costs and disagreements can lead to litigation. The development of objective noise rating procedures must therefore aim towards providing a measurement tool that increases consistency in decision making. The relationship between objective measurements and subjective response needs to be optimised, whilst still allowing the individual merits of a given situation to be taken into account.

A number of key research projects have been carried out in recent years relating the subjective impact of a noise to its physical parameters in order to assist in the development of community noise rating procedures.

Thus between 1987-1989, the EC's Fourth Environment Programme included a collaborative project on the assessment of impulsive noise (2) led by the Institute of Sound and Vibration Research (ISVR). Listening tests were conducted on the subjective rating of the impulsivity and annoyance of a wide variety of environmental noises. Methods were investigated for physically quantifying the noises, and the relationship between the physical description and the subjective data was studied with the aim of deriving an optimum rating procedure. During the course of the project, NPL focussed on the use of a very short time period, as low as 10 milliseconds, for the measurement of the equivalent continuous sound level, L_{Aeq}. Various ways of processing the resulting time series were investigated and optimum correlation with subjective data was obtained by taking the maximum positive difference between successive values of $L_{Aeq,T}$. This was termed the "Increment" descriptor (3).

On a broader front, work is in hand to develop a general noise annoyance model. It has been recognised that a fully comprehensive model will not be simple and will have to take into account a large number of factors, both acoustical and non-acoustical, which influence noise annoyance. In June 1987 the Department of the Environment (DoE) hosted a seminar on the development of a new noise annoyance model for general use and subsequently commissioned a study of research requirements (4). The Building Research Establishment (BRE) is currently managing a project, on behalf of DoE, to develop this model.

There are a number of individual component projects constituting the development of the model. For example, work has been continuing at ISVR on the feasibility of developing field portable instrumentation to provide an objective assessment of whether or not a tonal penalty is justified, and further to determine the magnitude of the penalty that should be applied. The paper by Robinson at this conference summarises this work (5).

NPL, on the other hand, is assisting in the development of standard rating procedures for industrial noise by studying the subjective and objective assessment of various types of industrial noise. This paper sets out to give an outline of the current work programme at NPL sponsored by the DoE. Additional details about component parts of the research programme have been or will be described in other papers.

2. WORK AT NPL FOR THE DEPARTMENT OF THE ENVIRONMENT

A three year project began in December 1990 with the overall aim of refining current methods for rating industrial noise. The work is divided into three parts.

2.1 Review of various national practices in the rating of industrial noise

It was decided that in order to assist in the refinement of current standard rating methods, it would be beneficial to gain a broader knowledge of other national practices worldwide in the rating of industrial noise. A review is being conducted across 20 countries, using a questionnaire sent to various national laboratories, standards institutions and Environment Ministries. In particular, information is being gathered on how different countries have implemented ISO 1996 (6). Information has been obtained on objective rating methods used and on the treatment of noises with particular characteristics such as tonal and impulsive noise. The results of this review are given in a separate paper at this conference (7).

2.2 Data sheet study on the application of BS 4142: 1990

BS 4142 "Method for rating industrial noise affecting mixed residential and industrial areas" is the most widely used standard method for rating industrial noise in the UK and was revised in 1990 (8). To enable a systematic evaluation of the application of the 1990 revision of BS 4142, and hence provide information to assist in future development, a special data-sheet has been designed and supplied to volunteer users - mainly

THE SUBJECTIVE AND OBJECTIVE ASSESSMENT OF INDUSTRIAL NOISE

Environmental Health Officers and noise consultants - who are documenting case studies of industrial noise complaints and indicating how the assessment method contained in the standard is working in practice. To date 100 completed data sheets have been returned. An interim paper (9), based on forty cases, has been written on this study and a final report is planned.

Updated analysis of returned data sheets has shown that a large proportion of BS 4142 assessments relate to noise problems involving tonal character. In fact 80% of the cases related to noises which were described as exhibiting specific characteristics, with about half of all the noises described as tonal, a quarter as impulsive, and a third as irregular enough to attract attention. This percentage of complaint cases involving tonal noise is similar to that reported by Williams and Robinson in 1988 (10).

From the results, it can be concluded that in about 80% of the cases the BS 4142:1990 rating method gave a good indication of the likelihood of complaint. Of the cases where, in the view of the investigating officer, the BS 4142 rating method underpredicted the likelihood of complaint, about half related to tonal noise.

There are problem areas and ambiguities that have been identified by the users of the standard. These include the actual identification of tonal character for which a 5 dB penalty should be applied. A need has been identified for an objective identification procedure rather than relying on subjective evaluations. Other problems included the assessment of background noise with multiple noise sources, noise inside a dwelling, application to nuisance assessment, differences in population sensitivity, the rating of some particular types of industrial noise, eg impact and impulsive noises, and the limited scope of its application.

Examination of the case studies has confirmed that some aspects of the standard are open to the individual interpretation of the investigating officer and personal judgment is often required. This has demonstrated the importance of the experience of the investigating officer but re-iterates the need for a rating procedure which promotes greater consistency in decision making. Nevertheless, BS 4142 will always be an objective measurement procedure assessing a subjective effect. Although it can be refined in the light of new experience and research, it is still primarily a tool for use in investigating noise complaints and one will always have to take some account of the individual merits of a given situation.

2.3 Subjective listening tests

Laboratory experiments are being conducted on the judged annoyance of specific types of industrial noise to explore the effect of impulsiveness and tonality on subjective annoyance. The emphasis is on the use of actual recordings from existing sites, rather than simulations, and particular attention is being given to cases of combined tonal and impulsive noise.

The noises used in the experiments are to be analyzed by a number of objective methods including those developed at NPL for impulsive noise (eg the Increment descriptor) and those arising from the ISVR studies on tonal noise. Relationships between subjective and objective assessments will be investigated to assist the optimisation of rating methods.

2.3.1 Test facilities
The experiments have been carried out in the NPL listening room. The room is carpeted and furnished to give a reasonable simulation of domestic living room conditions. The set-up of the room and the equipment used are shown in Figure 1. The presentation of the noises was automated using a LabWindows programme on a Toshiba T5200 PC controlling a Sony DAT player. All the test noises were digitally recorded at industrial noise sites and reproduced through a digital filter to account for the attenuation characteristics of a window/wall arrangement. The subjects were monitored by closed circuit TV.

2.3.2 Preliminary tonal experiments
The objectives of the preliminary experiments were:

(1) to clarify a number of operational and methodological problems for later experiments including an investigation into the effects of using different rating scales, and to get feedback about the conditions and the preferred method of questioning the subjects.

(2) to provide subjective data for use in the later stage when assessing the objective techniques.

Two experiments were conducted using the same test noises. The difference between these experiments was in the rating scales used to answer the questions.

The twelve test noises for the first two experiments were made up of three noises - distant road traffic, a relatively broadband compressor noise and a fan producing a distinct tone - presented at the four levels of $L_{Aeq,5min}$ of 35, 45, 55 and 65 dB(A). Third-octave band spectra are given for the two industrial noises in Figures 2.

Twelve subjects were used for each experiment and were tested one at a time. Each subject was given written instructions and was asked to complete a questionnaire on their own individual general sensitivity to noise. This was followed by a short practice session in which they heard a sample of the noises and practised using the rating sheets. Listeners were then played the twelve noises in a sequence based on a balanced Latin Square arrangement. The duration of presentation of each noise was five minutes. At the end of a period of noise, they were asked to rate the noise in the following ways:

Annoyance:

Question 1: Would you be annoyed or upset by the noise you have just heard if it was present all of the time?
Question 2: If you were in your own living room in the evening, do you think that you would be annoyed or upset by this noise if it was present all of the time?

Complaint potential:

Question 3: If you heard this noise all of the time in your own living room in the evening, would you feel justified in complaining?
Question 4: Do you think that you would actually complain? (Yes/No).

The first experiment used a fully annotated rating scale with the following categories:

not at all/a little/quite a lot/very much

In the second experiment a numerical scale was adopted as used in earlier EC work (2) rating the response into:

NOT ANNOYING AT ALL 0 1 2 3 4 5 6 7 8 9 EXTREMELY ANNOYING

After the series of noises, a brief discussion followed with each listener and points were raised about how they felt about the individual noises, session length, laboratory-home projection and the preferred method of questioning.

2.3.3 Results and discussion

A three-factor analysis of variance (noise x level x subject) was performed on the data from each experiment. This showed that each factor was significant in determining the response ie, there was a significant difference between noises, between levels and between subjects. The interactions between these effects were less significant than the main effects so that the main effects dominate.

On comparing the significance of differences between the annoyance ratings for any two noises at a given level, the results from the second experiment gave clearer differences between the noises than for experiment one. This was due to the sensitivity of this analysis to individual data points. It was concluded that one main determining factor was the difference between the rating scales. The four point fully annotated scale of the first experiment appeared to be too coarse with no midpoint and un-equal interval spacing.

During the open discussions at the end of the experiment, 77% of all the subjects gave the opinion that they preferred number scales (50% of all the subjects asked gave this answer before an alternative was suggested or shown to them). It was concluded that the scale used in experiment two would be the preferred scale for all subsequent experiments.

It was interesting to observe how the listeners described the characteristics that annoyed each of them about each noise. The annoying components of road traffic were described as "rumble", "perceived vibration", "drumming" and "bustle". The annoying features of the compressor noise were described as "penetrating", "intrusiveness", "repetitiveness", "pitch", "harsh" and "machinery-like". Many people described the compressor noise as having "nothing distinctive" that could be identified as annoying about it but the overall noise was annoying. The tonal nature of the fan was described as a "whine", "scream", "high pitched noise", "hum", "shrill", "piercing" and a "whistle". At least one subject in every experiment described each noise as an "unwanted drone".

Correlation coefficients were investigated between the answers to the different questions and found to be above 0.9 showing that the responses to questions were not independent of each other. This indicates that the listener may be answering the questions in a set pattern throughout the experiment based on one internal overall response to the noise. In this case the listeners may not be considering the meaning of individual questions after a couple of presentations. Therefore, no benefit is being gained from asking four questions if a listener has one overall response and for subsequent experiments, one rating question may only be necessary.

Obviously, anticipated complaint likelihood is strongly related to the annoyance potential of a noise. These experiments could only attempt to examine complaint potential in limited terms since factors such as apathy, knowledge of complaint procedures, connotation of the noise etc could not be included. It was decided that in subsequent experiments, information about complaint behaviour and likelihood of complaints would be more easily investigated by discussions with each subjects about particular noises.

A frequently quoted statistic is that only one in ten of those people highly annoyed by a noise actually complain. In fact in the first experiment, from the answers to questions 2, 3 and 4, quite the opposite was shown in that nearly all the subjects that were rating themselves as being very much annoyed by a noise indicated that they thought that they would actually make a serious complaint about the noise. This again points to the difference between the laboratory-home projection situation and the real life situation with additional attitudinal and behavioural factors taken into account such as apathy etc.

It also highlights the problem of studying actual number of complaints as an indication of annoyance from a noise source. Whereas in the laboratory these may be related directly, in the real life situation the number of people highly annoyed is underrated.

Using the rating scores from the second experiment and the second question, regression lines relating mean annoyance to level were calculated and are shown in Figure 3. Using the regression lines, it is possible to calculate character penalties for either industrial noise relative to the traffic noise or for the fan noise relative to the compressor noise. The penalty is in effect the difference (in decibels) between the L_{Aeq} of a given noise and the L_{Aeq} of a "baseline" noise of equal annoyance.

If the equation for the regression line for noise 1 is

$$A_1 = m_1L + c_1$$

and for noise 2 is

$$A_2 = m_2L + c_2$$

then the penalty for noise 1 compared to noise 2 = $[(c_1 - c_2) + (m_1 - m_2)L]/m_2$.

The calculated effective character penalties for the noises in these particular experiments are given in Table 1.

TABLE 1: CALCULATED PENALTIES

Noise	Penalty (traffic noise as baseline)			
	35 dB(A)	45 dB(A)	55 dB(A)	65 dB(A)
Compressor	5.8	4.5	3.3	2.1
Tonal fan	10.7	8.2	5.6	3.0
	Penalty (compressor noise as baseline)			
Tonal fan	5.7	4.1	2.6	1.0

The penalties for the tonal fan, with traffic noise as baseline, which vary from approximately 11 dB to 3 dB, are similar, both in their magnitude and their dependence on level, to those observed for analagous cases of impulsive noise in a number of studies. See for example work at NPL under a previous contract for DoE (11) or studies such as those at ISVR (12) or IDAC, Rome (13) at various stages of the EC Joint Project on

Impulse Noise. Robinson, in his experiments using synthesised noises made up of pure tones added to broadband noise, also observed a level dependent effect in that his "net tone penalty" decreased with an increased level of broadband noise.

The results indicate that the compressor noise is more annoying than the traffic noise at the same L_{Aeq} and would warrant an effective penalty. The result could be due to an inherent judgement of "source difference" of a noise of an industrial nature which cannot be attributed to any specific characteristic. We have already observed however that some subjects used the words "pitch" when describing the compressor noise, therefore this may be due to a perceived tonality of compressor noise but at a lesser extent than for the fan noise. This would support the need for an objective measure for tonal identification with an associated quantification of the penalty. Alternatively this result could be due to some other perceived characteristic of the compressor noise. This point will be investigated in further analysis.

The second form of comparison using the compressor as a baseline, is analagous to the BS 4142 assessment where an investigator judges the fan noise as meriting a 5 dB tonal adjustment whilst the compressor noise level is unadjusted.

It should be noted that this is just one set of data using a small selection of noises. However it is encouraging to note that the results have shown agreement with the trends of other research results. The two objectives of the preliminary experiments have been met. Preliminary results have been obtained on subjective responses to various test noises to form base data leading towards the examination of the relationship between the subjective and objective assessment of certain types of industrial noise.

2.3.4 Combined tones and impulse experiments

Whilst the EC research work has lead to the development of rating procedures for impulsive noise and ISVR and NPL are continuing work on tonal penalties, the treatment of noise environments with <u>combined</u> tones and impulses also needs further clarification. Although the method contained in ISO 1996 involves numerical addition of the adjustments for tonal and impulsive noise, the BS 4142 rating method states that only a single 5 dB correction should be added if more than one of the characteristics is present.

A third experiment is now underway to investigate the correct procedure for combinations of tones and impulses. The experiment has been designed to examine the judged annoyance of combinations of tonal, impulsive and traffic noise.

There are three component test noises, the tonal fan and the traffic noise from the preliminary tonal experiments and the third an impulsive industrial type noise. Each component sound is presented at 35, 45 and 55 dB(A) in various combinations. At the end of the main part of the experiments during which judgments of annoyance are made using the numerical scale, there is a short interactive discussion in which the subjects are asked about the relative importance of each component when making an annoyance judgement. The results will be used to test a number of models such as those referred to by Vos (14), eg. the dominance model, energy summation models, independent effects model etc.

More details about the experiment and analysis of preliminary results will be given at the time of the conference.

3. CONCLUSIONS AND FUTURE WORK

Work at NPL for the DoE on the subjective and objective assessment of industrial noise has so far resulted in:

- a review of various national standards,
- a systematic evaluation of the application of BS 4142:1990 and
- subjective data on judged annoyance of various types of industrial noise.

We plan to carry out further experiments using various digital recordings of real noises from industrial sites. Initially these will be designed around other cases of combined tonal and impulsive noise, and then the role of other characteristics will be examined. The noises will be analyzed by a number of objective methods to examine the relationship between subjective and objective response, and this will assist in the optimisation of rating methods.

A new EC programme led by ISVR involving NPL, TNO Leiden, IDAC Rome and IFL Dusseldorf is planned to validate, in real life situations, some of the objective descriptors of impulsive noise developed in the course of the earlier EC Joint Project on Impulse Noise. This will aim towards adopting these descriptors in standards for rating methods.

This research work is expected to lead to specifications for methods of measuring noise which will take into account, in an integrated way, various complex characteristics. Future work will assist the process of updating current standards through the development of new objective methods for rating noises with specific characteristics such as impulsivity and tonality. The development of new measurement techniques which relate objective measures more closely to human response will provide for standards and regulations on noise which are more closely targeted to the needs of exposed populations.

4. ACKNOWLEDGEMENTS

NPL would like to acknowledge the financial assistance of the UK Department of the Environment.

5. REFERENCES

1. British Standards Institution 1990. "Method for rating industrial noise affecting mixed residential and industrial areas ", BS 4142:1990.
2. Rice, C.G. Annoyance due to impulse noise. CEC Studies, Final Report. ISVR Memorandum No. 690, 1989.
3. Berry, B.F. Recent advances in the measurement and rating of impulsive noise, Proceedings 13th ICA Belgrade, Vol 3, pp147-150, 1989.
4. Diamond, I.D., Flindell, I.H., Griffiths, I.D., Ollerhead, J.B and Robinson, D.W. Research strategy for the development of noise annoyance models. ISVR Report 88/7 prepared for the Department of the Environment 1988.
5. Robinson D.W. Annoyance of tonal noise: A Parametric Study. These proceedings, 1992.
6. International Organization for Standardization. "Acoustics - Description and measurement of environmental noise", ISO 1996 Part 1: 1982, Parts 2 and 3: 1987.
7. Porter, N.D. The assessment of industrial noise - A review of various national practices. These proceedings, 1992.
8. Berry, B.F. The 1990 edition of British Standard 4142. Proceedings of the Institute of Acoustics 1991, Vol 13: Part 8 p21.
9. Porter, N.D. Study of the application of revised BS 4142:1990. Proceedings of the Institute of Acoustics 1991, Vol 13: Part 8 p31.
10. Williams. P.R and Robinson, D.W. A survey of practice and opinion of local authorities on the assessment of industrial noises containing tonal components. ISVR Memorandum 686, University of Southampton, 1988.
11. Berry, B.F. The evaluation of impulsive noise. NPL Report Ac 111, 1987.
12. Rice, C.G. CEC joint research on annoyance due to impulse noise: Laboratory studies. Proceedings 4th International Congress on Noise as a Public Health Problem (Turin), Vol 2, pp1073-1084, 1984.
13. Brambilla, G. and Carretti, M.R. Evaluation of annoyance due to impulse noise. Proceedings Noise-Con 90, pp279-284, 1990.
14. Vos, J. Annoyance caused by simultaneous impulse, road-traffic and aircraft sounds: A quantitative model, JASA 91(6), p3330, 1992.

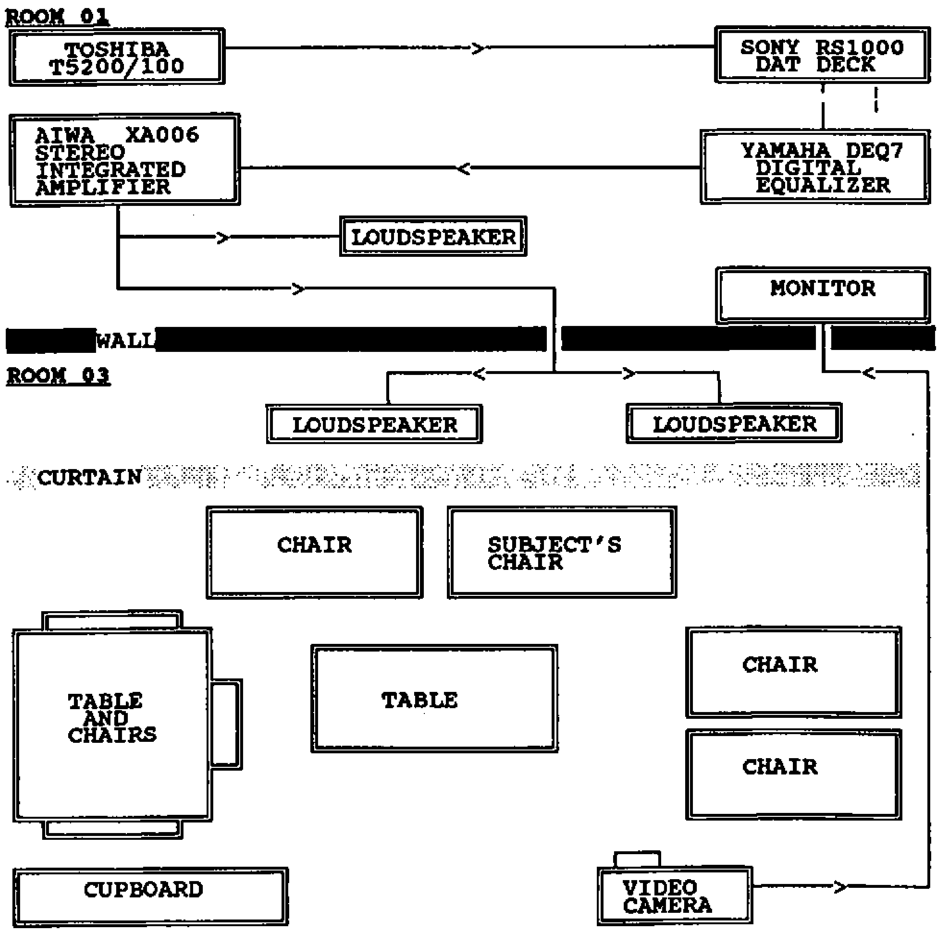


Figure 1: Equipment and room layout for subjective listening tests.

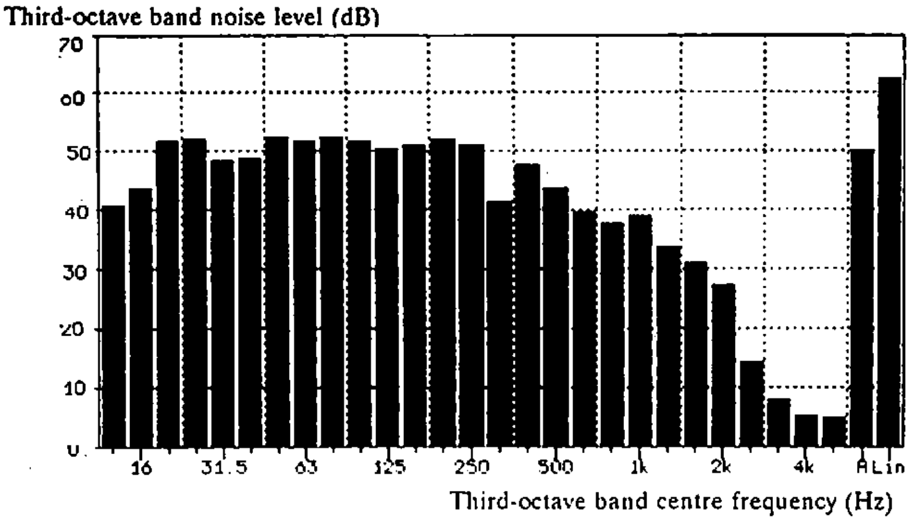


Figure 2a: Third-Octave Spectra for Compressor Noise

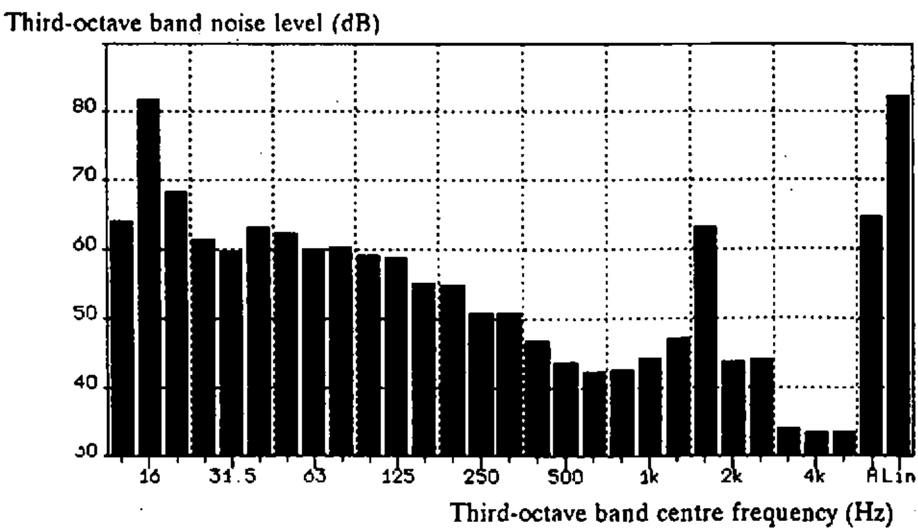
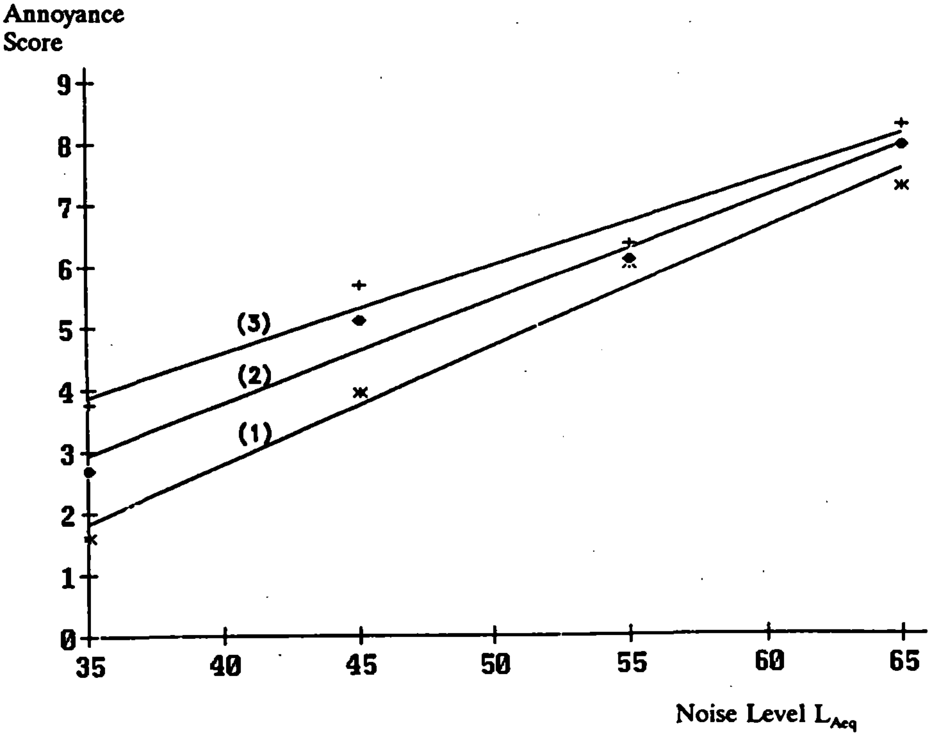


Figure 2b: Third-Octave Spectra for Tonal Fan Noise

IF YOU WERE IN YOUR OWN LIVING ROOM IN THE EVENING, DO YOU THINK THAT YOU WOULD BE ANNOYED OR UPSET BY THIS NOISE IF IT WAS PRESENT ALL OF THE TIME ?



Regression line for traffic noise (1)	A= 0.1908L - 4.854
Regression line for compressor noise (2)	A= 0.1675L - 2.938
Regression line for tonal fan (3)	A= 0.1416L - 1.083

Figure 3: Regression lines for the annoyance score for question 2 for the second experiment.