RATING METHODS FOR IMPULSIVE NOISE

by

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"Of making many books there is no end; and much study is a weariness of the flesh."

The Bible *Ecclesiastes xii.* 12

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ABSTRACT

FACULTY OF ENGINEERING AND APPLIED SCIENCE
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Two laboratory studies have been undertaken to investigate the effect of various physical parameters (repetition rate, decay time and peak level) on the annoyance response to impulsive noise. These suggest that, for the range of parameters considered, the impulsive noises can be represented by a single dose-response relationship, being significantly more annoying than the traffic (continuous) noise. The results agree with other recent research, and indicate a subjective level-dependent correction for impulsive noise, varying between 5 and 10 dB over the range of impulsive noise levels 70-35 dB L_{Aeq}.

However, for application to noise control and planning situations in order to apply such corrections, an objective specification of impulsive noise is required. The physical characteristics which may be associated with the impulsivity of a sound have been investigated, and several objective methods of describing impulsive noise are considered. These include the K descriptor, a newly proposed method based on the maximum rate of change of short-time period L_{Aeq} series, measured over time periods of 10ms or 31.6ms.

A further laboratory study was undertaken to obtain subjective judgements concerning the impulsivity of synthetic sounds heard in isolation. The sounds consisted of trains of impulses of different decay times and repetition rates. The results suggest that both repetition rate and decay time have a significant effect on the impulsivity judgement of a sound, and that an interaction exists between these two factors. Statistical analysis enables the sounds to be classed into three regions; definitely impulsive, definitely non-impulsive and a region of uncertainty.

A software package has been developed which allowed these synthetic sounds to be digitally sampled, and objectively rated by several impulsive noise descriptors. Comparative analysis of the objective ratings of impulsivity, and the subjective ratings from the laboratory study suggest that the K descriptor provides the best indication of the subjective evaluation of the impulsivity of a noise. An initial criterion is proposed, suggesting a sound with a value of $K_{10ms} \geq 26.3$ or $K_{31.6ms} > 6.9$ would be subjectively judged as impulsive.

Further work necessary to obtain a consistent and universally applicable descriptor of impulsive noise is outlined.

CHAPTER 1

INTRODUCTION

1.1 Statement of the Problem

Since the industrial revolution increasing mechanisation, commerce and the development of transportation systems have brought increasing levels of noise within everyday living, working and sleeping environments. As standards of living have improved, so people have found these noises increasingly unacceptable. To counter this, considerable research has been undertaken during the second half of this century, with the principal objective of formulating planning regulations to control the immissions from environmental noise sources. Comprehensive reviews of studies concerned with the effects of noise on man have been given by Burns [1] and Kryter [2]. Many different sources of noise exist, of which transportation, industrial and residential activities form but a few examples. Continuous noise, unsteady noise and noise with a tonal character have been investigated in previous studies. This project, however, is concerned with the specific impact of impulsive noise.

For the past decade, the Institute of Sound and Vibration Research (ISVR), at The University of Southampton, has been concerned with the effect of impulsive noise on human beings. This research, which is discussed fully in Chapter 2, has principally taken the form of laboratory studies with subjects being asked to rate annoyance reactions to different sounds. At the same time, the National Physical Laboratory (NPL) has been involved in studies into the effect on human beings of helicopter noise and, in particular, the impulsive character of helicopter blade slap. As part of an attempt to combine the facilities and expertise, the research described was undertaken at both these Institutions.

1.2 Objectives and Structure

The principal objectives were:

(i) To investigate whether impulsive noise evokes a different annoyance response than non-impulsive (continuous) noise, and if so, to evaluate any 'impulse penalty' or correction necessary to account for this.

(ii) To develop an objective method of physically describing impulsive noise, suitable for incorporation in an instrument for field use. If the noise is rated as impulsive, any correction proposed by relevant studies should be included.

To achieve the first of these aims, it was necessary to review all relevant research on impulsive noise, and this is undertaken in Chapter 2. In particular, studies investigating the annoyance reaction of subjects to types of impulsive and non-impulsive sounds are discussed. Pilot studies were undertaken to investigate the effect of various physical parameters on the annoyance rating of impulsive sound.

The physical characteristics which may be associated with impulsivity of a sound are investigated in Section 3.1. Several methods of objectively describing impulsive noise are considered in Chapter 3, including a measure proposed by the author. Those methods not dismissed by initial research and experimentation were modelled in a software package, described in Chapter 4. By running this package on a compatible computer system, ratings of impulsivity by the objective descriptors were obtained for a test sample of sounds.

Chapter 5 describes a laboratory study undertaken by the author which investigates the effect of certain physical parameters, outlined in Chapter 3, on the subjective judgements of impulsivity for the same test sounds. A comparative analysis of objective and subjective ratings of impulsivity for these sounds is performed in Chapter 6, in order to evaluate the effectiveness of each of the objective descriptors.

Further work suggested to obtain a consistent and universally acceptable descriptor of impulsive noise is described in Chapter 7. The main conclusions are given in Chapter 8.

CHAPTER 2

REVIEW AND PILOT STUDIES

2.1 Impulse Noise Research: Introduction

Throughout the course of this study, a review of literature relevant to impulsive noise was undertaken and more than one hundred references have been classified and stored on floppy disc using a CARDBOX computer software system. The objective of this exercise was to locate work which might influence the overall research aims.

Helicopter blade-slap, for economic and commercial reasons, has received more research effort than other types of environmental impulsive noise. Consequently, a large amount of literature is available on this subject. In particular major studies have been carried out during the past decade by the National Aeronautics and Space Administration (NASA) in the USA, and at the National Physical Laboratory (NPL) in the UK.

In Europe the Commission of European Communities (CEC) has initiated laboratory and field studies on annoyance due to various types of impulsive noise, compared with more steady environmental noise such as road traffic. Apart from this work and more recent Japanese studies impulsive noise has not been extensively researched. Very often parameters considered to be of interest have been under-investigated so that the results are of limited value, and as yet there has not been any attempt to formulate predictive annoyance criteria.

Table 2.1 lists the references particularly relevant to this study. They have been classified in terms of impulsive noise source, type of study, and the objective and subjective descriptors investigated. In Section 2.2, Standards, field studies and laboratory studies are discussed separately. As a consequence of this review the pilot studies described in Section 2.3 were undertaken, and in Section 2.4 the direction of the further objective analysis reported in Chapter 3, and subjective experiments reported in Chapter 5, are outlined.

Table 2.1. A classification of relevant impulsive noise literature and studies

Ref. no.	Type of Noise Source (classification)	Subjective descriptor investigated	Objective descriptors investigated
Standards			
3	3,5,6	Intrusion	L_{Aeq}
6	3,4,5,6	Intrusion	Peak, RMS, L_{Aeq}
7	1,6	Annoyance	L_{AI}–L_{AS}
12	1	Annoyance	L_{ITPN}
14	3,4,5,6	% Highly Annoyed	L_{CE}, L_{Cdn}
19	3,4,5,6	Intrusion	L_{Aeq}
Field Studies.			
11	1	Noisiness	PNLT, EPNL, SEL, L_A
16	2,3,4,5	Annoyance	L_{Aeq}
18	3,4	Annoyance	L_{Aeq}
20	4	Annoyance	L_{AIM}–L_{Aeq}
21	1	Noisiness	Peak, RMS, L_{Ax}
23	3,5	________	Peak, RMS, L_{eq} phase
53	5	% Disturbed	Impulse Weighted Mean Level (L_{AI})
55 (Review)	4	Annoyance	L_{Aeq}
62	2,3,4	Annoyance	L_{Aeq}
72	2,3,4,5	Annoyance	L_{Aeq}

Ref. no.	Type of Noise Source (classification)	Subjective descriptors investigated	Objective descriptors investigated
Laboratory Studies.			
10	1	Annoyance	EPNL
17	2,3,4	Annoyance	Peak, L_{Aeq}
22 (Review)	1,2,4	Annoyance	Peak, RMS, L_{Aeq}
24	3,4	Annoyance	L_{Aeq}
25	2,3,4,5	Annoyance	L_{Aeq}
26	2,3,4	Annoyance	L_{Aeq}
27	2,3	Annoyance	L_{Aeq}, $L_{AI}-L_{AS}$
28	4,5	Annoyance	L_{Aeq}
32	2	Annoyance	Peak, RMS, L_A, SPL, PNL
33	4	Annoyance	L_{Aeq}
34	5	________	Crest Factor, Signal Kurtosis(β)
35	1	Noisiness	Peak, RMS, L_{AX}, Crest Factor
36	4	________	$L_{AIM,T}-L_{AFM,T}$
37,38 39,40	3,4,5	________	Small time period L_{eq} series measures
41	5	________	dL/dt

Ref. no.	Type of Noise Source (classification)	Subjective descriptor investigated	Objective descriptors investigated
47	2	Loudness	Repetition Rate, Peak
48	2	Equal Loudness Detectability	Duration, SPL
59	2	Annoyance	Loudness-Time meter measure
60	2	Loudness	————————
63	2	Noisiness	Phase, Duration, Interval, Repetition
66	2	Loudness	Peak, Rise Time, Decay Time, PL dB
73	2	Noisiness	Peak, RMS, Model 75A
74	2	Noisiness	Model 75A
75	2	Loudness	L_{Ae}
77	2	Annoyance	L_A, Repetition Rate
78	2	Equal Loudness	Peak, RMS, L_{AX}

Classification of impulsive noise sources

1 helicopter blade slap
2 synthetic
3 construction
4 blast/gunfire
5 industrial
6 other: sonic boom, wind turbine, and general

2.2 Classification of Relevant Studies

2.2.1 Standards

Previous studies have indicated that impulsive noise is more annoying than continuous or only gradually fluctuating noise at the same A-weighted equivalent continous sound pressure level (L_{Aeq}). However, there is growing concern that present standards governing this type of noise may be inadequate. These criteria often require an 'impulse penalty' to be applied by adding a specified number of decibels to the measured level of impulsive noise.

The current British Standard for the assessment of impulsive noise, BS4142 [3], is intended for use in industrial noise situations containing several types of impulsive and impact noise. Under this guideline a noise is defined as being impulsive "if there are significant impulsive regularities in the noise (e.g., bangs, clicks, clatters or thumps), or if the character of the noise is irregular enough to attract attention". In such a case 5 dB(A) is added to the measured noise level in the form of an impulse penalty. The Standard was revised in 1975, as a result of a detailed questionnaire [4], but the section concerning impulsive noise remained unaltered. The British Standard, BS5228 [5], concerning construction noise makes no special allowance for impulsive noise, although this is a common feature of building site noise.

Until its recent revision, the International Standard ISO 1996 [6] was used to evaluate environmental noise. This specified the use of 'A' weighted equivalent energy level, L_{Aeq}, to measure the noise. Appendix 2.1 gives a detailed definition of this measure. The Standard stated that "if an impulse is an essential characteristic of the sound within a specified time interval, an adjustment may be applied". This penalty was 5 dB(A), although the revised document soon to be issued refers to an impulse adjustment of an unspecified amount. The need for such a correction is due to the inappropriate way in which L_{Aeq}, an average value, accounts for the large and sudden variance in peak level, which is a characteristic of impulsive noise.

In these standards the definition of what constitutes an impulsive noise is entirely subjective and is left to the opinion of the person applying the guideline. In an attempt to rectify this, the EEC Directive

79/113 [7] suggests an objective method of determining whether or not a noise is impulsive. If the difference between the root mean square (rms) values of the A-weighted sound pressure levels measured with the sound level meter at 'slow' (L_{AS}), and 'impulsive', (L_{AI}), response respectively is equal to, or greater than, 4 dB, the noise is considered to be impulsive.

Appendix 2.2 gives the specifications for the 'slow', 'fast' and 'impulse' time weightings for precision sound level meters as defined by BS 5969/IEC 651 [8]. The 'impulse' time weighting has evolved because the normal 'fast' and 'slow' time constants of the ordinary precision meter are not sufficiently short to give a meter indication which is representative of the subjective human response to isolated impulses or impact noise. The 'impulse' time weighting function has been developed, which contains special circuitry necessary for detecting and displaying transient noise in a way which takes into account the human perception of the impulse sounds [9].

The National Physical Laboratory, in maintaining its rôle to develop measurement standards, has concentrated on the physical characterisation of noise. A major effort has been the involvement with an International Organisation for Standardisation [ISO] Working Group concerned with the development of helicopter noise rating methods. Aircraft noise is rated in terms of Effective Perceived Noise Level (EPNL), and at present, helicopter noise is included in these guidelines. As a result of this NPL research [10], in 1978 a draft proposal was submitted to the ISO suggesting a correction factor, Δ, to be added to EPNL. This varied between 0 and 6 dB depending on the impulsiveness of the helicopter noise. A descriptor was developed to quantify physically this measure of impulsiveness, and an early form of this is defined in Section 3.2.2. The proposal was considered by the International Civil Aviation Organisation Committee on Aircraft Noise Working Group B (ICAO/CAN/WGB), which initially recommended its use.

In the same year the results were published of a specially commissioned programme of psychoacoustic tests [11] conducted under real-life flyover conditions at the NASA Wallops Flight Center, USA. This work concluded that the temporal and spectral characteristics of impulsive helicopter noises were adequately represented by Effective Perceived Noise Level (EPNL) and that the proposed correction was unnecessary. After considering these and other relevant studies, the Working Group decided to re-endorse EPNL without a correction as the basic method of evaluating helicopter noise.

However, in 1979 the UK proposal was accepted by the Working Group and was issued as ISO Draft Addendum DAD 3891. A revised version of this document [12] issued in 1981 outlines a method of obtaining an 'impulse- and tone-corrected perceived noise level' (L_{ITPN}). This procedure is based on the impulsiveness descriptor and impulse correction proposed in the NPL study [10].

Two recent American Standards concerning impulsive noise have been published during the preparation of this thesis [13,14]. The American National Standard ANSI S1.4-1986 [13], proposes a C-weighted sound exposure level to describe high-energy impulsive events, and the day-night average C-weighted level for the cumulative effect of impulsive sounds in a 24-hour period. The Standard states that 'the C-weighting provides a more discriminating measure of the low frequency sound pressures associated with the type of high-energy impulsive sounds under consideration than provided by the A-weighting'. The document also suggests that measurement of such sounds in terms of C-weighted exposure levels provides better correlation with human response than does A-weighted exposure levels. However, in view of the various different sources of impulsive noise that can occur in complex noise environments, it may be that the 'A' weighted equivalent energy level, L_{Aeq}, is a more generally applicable measure.

This brief review of existing Standards illustrates the differences that still exist between guidelines on the quantification of impulsive noise. This project has been undertaken in an attempt to try and resolve these differences and produce a criterion universally applicable to all the different types of impulsive noise present in the environment.

2.2.2 Field studies

Many of the procedures in current use concerning impulsive noise are the result of commissioned research. This generally takes one of two forms: laboratory studies, which will be discussed in Section 2.2.3, and field studies. The advantage of a field study is that the subject is exposed to the noise source as it normally occurs in the environment. This environment is usually in the vicinity of the subject's living or working surroundings. In a laboratory study, an attempt is made to recreate this environment in order to perform a controlled and repeatable experiment. The differences in approach of these two forms of study are outlined in Table 2.2, taken from a report by Rice [15].

FIELD	LABORATORY
Real life situations	Simulated listening facility
Annoyance actually experienced	Annoyance projected to home
Single noise exposure	Repeated measures designs
Long term exposure to noise	Short term exposure durations
Noises heard in combination	Noises in isolation & combination
Absolute judgements	Relative judgements
Physical measures confounded	Accurate noise parameter control
Mediating variables	Fixed reverie task
Stratified sample population	Normal hearing subjects
Time consuming and expensive	Convenient and low cost

Table 2.2 Comparison of field and laboratory techniques.
(Taken from Rice [15])

Field studies generally take the form of a social survey. In some cases, these are used in conjunction with laboratory studies in an attempt to correlate laboratory and field data. An example of this was a field study investigating the effect of impulsive noise on human beings, which forms part of a research programme for the Commission of European Communities. The work was undertaken in 1982/83 and is described by de Jong and Groenveld [16]. Laboratory experiments were run in parallel, and are described by Rice [17]. In the field studies a pilot survey led to the formulation of a questionnaire containing specific questions concerning annoyance from impulsive, continuous and combined noise sources. Following the development of the questionnaire, the main survey was performed in each of four participating countries (France, Ireland, The Netherlands and West Germany). Site measurements of equivalent continuous sound pressure level (L_{Aeq}) were compared with subjective scale values of annoyance to obtain dose-response relationships for the noise sources. In this form, information from the field studies and laboratory studies could be directly compared. Both sets of results indicate that the impulsive noise is more annoying than continuous noise such as traffic noise. However, the impulse penalty of 5 dB suggested by ISO 1996 would appear to be too low, although the need for a level dependent correction was demonstrated in the laboratory studies. The study also concluded that "the importance of the rôle of the background noise in studying the noise annoyance in a field survey is beyond doubt".

The research undertaken in this CEC field study is also discussed in a more recent paper, published in 1985, by Groenveld and de Jong [18]. This confirms that "the average annoyance caused by impulsive noise is higher than that caused by traffic noise". By comparing dose-response relationships obtained for both impulsive and traffic (continuous) noise and observing the points at which the annoyance responses are equal, it is possible to regard the difference in equivalent noise levels as a penalty for impulse noise compared to traffic. From the field study results this value is 11 dB, which differs significantly from the value of 5 dB proposed by ISO 1996 and other guidelines [19].

A paper by Ritterstaedt and Kastka [20] utilises the results obtained in the German section of the CEC field study. The correlation between the subjective annoyance scores and various physical noise descriptors are investigated in an attempt to achieve a new definition of impulsiveness of environmental noise. Previous analyses of the CEC study had used only L_{Aeq} values. The results of this paper suggest that whilst the subjective scores show a good correlation with the L_{Aeq} values, the difference of the impulsive L_{Aeq} and traffic noise L_{Aeq} gives the best correlation with impulsive noise annoyance. However, the inadequacy of L_{Aeq} as a physical descriptor of impulsive noise is recognised by the need for an impulse correction. A practical way of solving this problem is to develop a detection method for impulsive noise directly.

Some Standards however, do not use L_{Aeq} as the noise measure. As discussed in Section 2.2.1, several field studies have investigated if EPNL adequately caters for the impulsive character of helicopter noise. A field study by Powell [11] in 1978, consisted of subjects judging the noisiness of various helicopters with certain controlled physical parameters, namely rotor speed, altitude and side-line distance. These noisiness scores were then used as judgements of annoyance potential. The results indicated that there is no justification for an impulse correction to EPNL, and also stated that the proposed ISO correction [10] had "no significant effect on the noisiness predictive ability of EPNL". A further NASA study in 1981 [21] substantiated these findings. However, this report also concluded that "some characteristic related to impulsiveness is perceived by subjects, but is not accounted for by either EPNL or the proposed impulsiveness prediction". This impulsiveness prediction is the method developed by the NPL study [10] discussed further in sections 2.2.1 and 3.2.2 of this thesis.

In addition to noisiness judgements, subjects in the study [11] characterised each flyover noise in terms of noticeability of six descriptors, using a five point category scale for each predictor. The descriptors "thumping", "slapping" and "hammering" were chosen as best describing impulsive helicopter noise, whereas "swishing", "droning" and "buzzing" were used to describe non-impulsive helicopter noise. These judgements made by the subjects were then converted to numerical scores related to impulsiveness. This concept of obtaining a subjective assessment of the impulsiveness of a noise is discussed in Section 2.4 and in later chapters. The method employed in the NASA report may be confounded due to the large number of separate descriptor assessments subjects are required to make. The results indicated that noisiness judgements did not increase as the helicopter noise became more impulsive. A criticism of both papers is the use of a noisiness judgement, which may differ from an annoyance response [22].

Although there is relatively little literature describing impulsive construction noise, a field study was undertaken [23], which mentions the problem. In the process involving cut and cover tunnelling, the presence of impact noise is discussed, but in accordance with the British Standard [5] no impulse penalty was implemented.

2.2.3 Laboratory Studies

2.2.3.1 *Introduction*

The use of laboratory studies enables experiments to be performed in controlled environments. Thus, they are repeatable and certain physical parameters can be varied to requirements. In the area of impulsive noise, where subjective response appears to be strongly related to the particular physical characteristics of the signal, this second point is an important one.

A comprehensive guide to impulsive noise research performed in the laboratory was published in 1979 by the United States Environmental Protection Agency (EPA) [22]. A review is made of several methods that have been used to physically and subjectively evaluate this type of noise.

2.2.3.2 *Annoyance: its definitions and justifications for its use*

Several different descriptors have been used to obtain subjective evaluations of impulsive noise, primarily annoyance, loudness and noisiness. The EPA report [22], however, concludes that there would appear to be significant differences between each of these judgements of sounds. It would obviously be more consistent to use the same descriptor for all subjective studies.

Over the past decade, the majority of laboratory experiments involving both synthetic and environmental impulsive noise have attempted to obtain dose-response relationships by correlating noise level with reported annoyance responses [10,17,24,25,26,27,28]. Annoyance is considered a good and consistent predictor of the effect of environmental noise, and, indeed, a paper by Large *et al* [29] indicates that "human responses such as annoyance reactions are likely to provide a most suitable basis for meeting environmental quality noise control gains".

McKennell [30] describes annoyance due to noise as the adverse subjective feeling or attitudinal reaction aroused by unwanted noise. The Wilson report [31] gives a simpler description regarding it as "the resentment we feel at an intrusion (by noise) into a physical privacy which we have, for the moment, marked as our own ...".

Annoyance is referred to by Burns [1] as "the displeasure or resentment caused by a sound either by its physical presence, or because of the implications arising out of its presence". Continuing, he states "that annoyance is a manifestation broadly defined from urban living specifically due to the activities of neighbours, their children or their pets, to road traffic, industrial sources of noise in the vicinity, or to the proximity of air traffic; it must be simplified and subdivided to some extent to codify means of assessment and so of control".

In practice, factors such as adaption to the noise environment may affect a respondent's judgement. Conversely, subjects in laboratory studies may have difficulty in projecting relative annoyance response to their actual living conditions.

In field and laboratory studies, the precise definition of annoyance and its meaning is often left to the respondent. McKennell [31a] suggests that a simple category scale requesting the respondent to make a choice between defined degrees of annoyance is generally sufficient.

2.2.3.3 *Annoyance studies in the laboratory*

Several NASA studies have also investigated the relationship between evoked annoyance and objective parameters. Lawton [32] showed that "noise scales commonly used to quantify aircraft noise, linear SPL, A-weighted SPL and perceived noise level, underestimate by approximately 2 dB the annoyance caused by impulsive noises". The stimuli used in this study were simulated helicopter blade-slap noises.

In 1979, an NPL report [10] compared the rating of helicopter noise by an impulsive descriptor to annoyance judgements of the same sounds. The subjects were presented with recorded noise treatments in laboratory surroundings. As mentioned in Section 2.2.1, the results of the report suggested the implementation of a noise penalty, to be added to the EPNL, to account for the impulsive character of the noise. This typifies the experimental procedure necessary for studies attempting to obtain a definition of impulsive noise.

However, most recent research has used the L_{Aeq}, which is recommended in ISO 1996 for the measurement of environmental noise. Examples of this are laboratory studies undertaken as part of the CEC research project on impulse noise [17,24,25,26]. This work concentrated on obtaining dose-response relationships for both impulsive and continuous sounds. Although work on the influence of background noise was performed and is outlined in some of these papers, this will be discussed at a later stage in this section. For the studies of treatments heard in isolation, several different types of impulsive sounds were used, including gunfire noise, pile driver noise, construction noise and synthetic impulse noise. Traffic noise was included in the study as an example of continuous noise. A paper by Rice [17] and a report by Rice and Lower [24], summarising the results of this phase of the work to mid 1984, state that "impulse noises heard in isolation require a level dependent correction which varies 0 to 10 dB over the range 70-35 dB L_{Aeq}". In a more recent CEC report [28] an impulse noise correction is suggested of 10 dB at low equivalent energy levels decreasing to 5 dB at high levels.

Research undertaken at the NPL, supported by the UK Department of Environment, investigated the dependence of annoyance on some basic physical parameters of impulse noises. A paper by Berry [27] outlines an experiment to determine the effect of decay time and repetition rate on human response to impulsive sound. A white noise carrier signal was modulated to give a repeating envelope with sharp onset and exponential decay, by use of a digital synthesis technique. Seven synthetic sounds were generated in this way, a 10 ms decay time with repetition rates of 2, 4, 8 and 16 Hz, and a 100 ms decay time with repetition rates of 2, 4 and 8 Hz. Five other noises were also included: continuous, white noise and recordings of a pneumatic drill, a dump truck, a pile driver and road traffic. The last two of these sounds were copies of signals used by Rice [17], included for intercomparison of studies. For each noise presentation, subjects scored annoyance on a ten point scale from 0 (Not at all annoying) to 9 (Extremely annoying), in response to the question "how annoying would you find this noise if you heard it at home, several times in the evening?" This procedure is similar to the use of questionnaires on annoyance response described by Rice [17]. The results of the NPL study indicate that there may be significant differences in annoyance ratings for different synthetic impulsive sounds. This is investigated further by the author in a pilot study described in Section 2.3.2.

The study also concluded that the $L_{AI}-L_{AS}$ method of defining impulsive noise given in the EEC Directive 79/113 is unsatisfactory. Indeed, using traffic noise as a reference, the increased annoyance due to the synthetic sound with impulses of 100 ms decay time occurring at 4 Hz repetition rate, was equivalent to an impulse penalty of 15 dB to 5 dB, depending on level. However, as this noise has an $L_{AI}-L_{AS}$ value of only 2.5 dB it would not be considered impulsive by the Directive. This measure is discussed further in Section 3. The ratings of the pile driver and traffic noise in this study suggest that the results may be comparable with those from the CEC study [17].

In real life, sounds are seldom heard in isolation. Therefore several studies have been undertaken to consider the way in which people react to combinations of impulse and background noise. Rice [17] describes CEC work using traffic noise and a standard gunfire signal in combination. Subjects were required to give annoyance responses to questionnaires concerning total noise, impulse noise and traffic noise. The results of the studies suggest that responses to impulse and traffic noise are confounded by the manner in which the annoyance questions are asked. For the situation with a low background level, the impulse or source-specific annoyance is surprisingly greater than the total annoyance, whereas in a high background situation, total annoyance appears to be the subjectively perceived sum of the separate source combinations. The studies concluded that "although impulse noise is more annoying in a low than a high background of traffic noise, total annoyance of the combined situation is greatest in the high background situation". Hence, 'source-specific' annoyance to impulse noise increases as background noise decreases. Total annoyance to combinations of noise appears to be the subjectively perceived sum of the separate contributions of the sources and does not correlate uniquely with the total L_{Aeq}, but appears to be a function of background noise level.

A further study, described by Rice [33], was undertaken in an attempt to resolve differences between earlier CEC laboratory [17] and field study [18] findings. Experiments had been performed in which four L_{Aeq} levels of impulse and traffic noise in combination formed sixteen treatments. Subjects in one experiment heard only one treatment; in the other, based on a balanced Latin square design, sixteen subjects rated each of the sixteen sounds. Results showed "the main effect of traffic noise on impulse noise annoyance is highly significant confirming that annoyance is indeed reduced in the presence of background noise". The paper concludes that the laboratory and field studies discussed indicate evidence of a significant interaction between impulse noise annoyance and road traffic noise level.

Rice [17] states that the results of the CEC combination studies reported 'should seriously call into doubt the ways in which annoyance response data are obtained'. In particular, the difference was noted between a repeated measures laboratory experiment, which represents a 'dynamic' situation, in which subjects listen to all conditions and accumulate wide experience, and the single exposure experience, or 'static' situation encountered in social surveys.

In 1985, a paper by Berry [27] describes an experiment investigating the effect of peak/background ratio on annoyance reaction. Three synthetic impulse sounds (some of those discussed previously in the isolation study) were combined with three levels of white noise, giving peak/background levels of 10, 20 and 30 dB, to form nine synthetic noises. Three other sounds were included for comparison purposes. The experiment suggested that background noise level has an effect on the annoyance of the total noise. For the synthetic sounds studied, a change of 10 dB in the peak/background ratio produced an average change of 6 dB in impulse penalty.

The findings of the laboratory and field studies described in this literature review are summarised in Section 2.4. It is clear from research previously undertaken that any definition of impulsive noise must obtain boundaries, defining when a sound becomes significantly more annoying due to its impulsive character. Berry [27] and Rice [17] show that for sounds heard in isolation the type of impulse noise may affect annoyance response. In order to investigate this further, the physical parameters of several types of synthetic sounds were varied in some pilot studies described in the next section. In Section 2.3.1, a CEC laboratory experiment is outlined which investigates the effect of randomness and regularity of repetition rate and peak level of impulses on annoyance response. Section 2.3.2 discusses a laboratory study performed by the author, which continues the theme of work by Berry and considers the effect of repetition rate and decay time of synthetic impulse sounds on annoyance reactions.

2.3 Pilot Studies

2.3.1 Pilot Study 1: EEC Joint Impulse Noise Study

A pilot experiment was carried out by the author in conjunction with the joint European Economic Communities (EEC). This laboratory experiment was undertaken using the Institute of Sound and Vibration Research (ISVR) listening room facility. The aim of the study was to investigate the judged annoyance evoked by the regularity and randomness of two impulsive parameters:- peak level and repetition rate. Twenty subjects with normal hearing (re ISO 389) participated in the experiment in which treatments were presented in accordance with a balanced Latin Square experimental design. The twenty treatments consisted of five sounds each presented at four L_{Aeq} levels: 35, 45, 55 and 65 dB. Four of the sounds were synthetic gunfire noise, generated using the National Physical Laboratory (NPL) computing facility, and consisting of combinations of random and regular level and repetition rate. The fifth sound was traffic noise. Each noise was heard in isolation for a period of five minutes. An outline of the typical apparatus used in this type of experiment is given in Figure 2.1.

Minitab and Genstat statistical packages were used to perform analyses of variance on the subjects' annoyance scores. Analysis of variance of the impulse noise scores alone and the plot of the mean annoyance scores for each sound against level indicate no significant difference between four impulsive sounds. This is substantiated by further analyses using the standard error of differences of means (SED). If the diffeence between the respective means of any two sounds is more than 3 × SED then the two sounds can be said to be significantly different. There is no significant difference between any of the impulsive sounds although all are significantly different to the road traffic noise.

Thus it can be concluded that the randomness or regularity of either repetition rate or peak level of impulse noise would appear to have no significant effect on the annoyance produced for the range of parameters studied. Figure 2.2 shows that the results reduce to two dose-response relationships; one for all impulsive noises, and one for traffic noise. The results indicate a level-dependent impulsive noise penalty varying between 10-5 dB over the range 35-65 dB L_{Aeq}.

2.3.2 Pilot Study II: Investigation of the effect of repetition rate and decay time on the annoyance rating of synthetic impulse noise

A second pilot experiment was conducted by the author at the NPL in which 36 subjects judged 36 noise treatments, eight impulse sounds and road traffic each heard at four levels in accordance with a balanced Latin Square experimental design. Each noise lasted for approximately 1 minute and the whole test lasted approximately 1¼ hours. The experimental apparatus is shown in Figure 2.1.

Analysis of variance given in Table 2.3 shows that there is a significant difference between level, repetition rate and some of the sounds. The mean annoyance scores for all nine sounds are ranked in Table 2.4, with brackets indicating groups of sounds that are not significantly different.

Table 2.3 Complete analysis of variance of annoyance scores for all eight synthetic sounds used in NPL experiment.

Due to	DOF	SS	MS	F	Significance
Subject stratum	35	1496.739	42.764	29.50	1% level
Level	3	2796.072	932.024	641.854	1% level
Decay time	1	4.626	4.626	3.186	
Repetition rate	3	30.051	10.017	6.898	1% level
Level/decay time interaction	3	8.419	2.806	1.933	
Level/repetition rate interaction	9	15.529	1.725	1.188	
Decay time/repetition rate interaction	3	36.037	12.012	8.273	1% level
Level/decay time/ repetition rate interaction	9	7.598	0.844	0.581	
Residual	1085	1575.507	1.452		
Total	1116	4473.836	4.009		
Grand total	1151	5970.574			

Table 2.4 Mean SSVs: NPL study.

Sound	Repetition Rate (Hz)	Decay Time (ms)	Mean SSV
B	5	10	5.556
E	2	50	5.472
F	5	50	5.347
C	10	10	5.340
D	20	10	5.146
A	2	10	5.049
H	20	50	4.986
G	10	50	4.778
T	Road traffic noise		4.028

The interpretation of the results becomes somewhat confused at this point. For example, sound C is not significantly different from sound A or sound B, but sound B is significantly different from sound A. Similar comparisons can also be made between other sounds. Thus the only definitive conclusions that can be drawn from this approach is that the traffic noise (T) is significantly different from all the impulsive sounds.

The analysis of variance also shows at the 1% level of significance a significant interaction between repetition rate and decay time. This is illustrated in Figure 2.3, where it may be seen that annoyance judgements do not vary with repetition rate in the same way for the two decay times. In the case of sounds with a 10 ms decay time there is a peak in annoyance response in the region of the 5 Hz repetition rate, in agreement with Berry's findings [27]. However, this effect is small and likely to be only of secondary importance. Thus, the impulsive noises used in this experiment can be represented by a single dose-response curve, shown in Figure 2.4. The results of the EEC experiment are shown in Figure 2.2 and correlate well with the findings of the NPL study. This suggests that the impulse noise parameters investigated in these experiments have no significant effect on annoyance evoked. These conclusions conflict with predictions using the $L_{AI}-L_{AS}$ measure, given in the EEC Directive 79/113 [7], which rated some sounds as impulsive, and some as non-impulsive. This point is discussed further in Section 3.3.1.

The road traffic noise is significantly less annoying than the impulse sound. A level-dependent correction of 9-5 dB over the range of impulsive noise levels of 35-70 dB L_{Aeq} is recommended.

2.4 Conclusions and Summary

The main conclusions of this literature review and pilot studies are stated below:

1. Current standards [3,6] are inadequate for the quantification of the physical characteristics of impulsive noise for which there appears to be a need for an objective description. The $L_{AI}-L_{AS}$ method given in one Directive [7] appears to be unsatisfactory.

2. The 5 dB impulse penalty quoted in certan standards [3,6] as accounting for the additional annoyance due to impulsive noise would appear to be inadequate. The results of laboratory studies undertaken by the author suggest a level-dependent correction of 5-10 dB over a range of impulsive noise levels 70-35 dB L_{Aeq}, in agreement with Vos [28]. This compares with the level-dependent correction varying beween 0 and 10 dB over the same range of equivalent energy levels proposed by other CEC studies [17].

3. Pilot studies demonstrated that variation of several physical parameters of synthetic impulse noise appeared to have no significant effect on the annoyance response evoked. These conclusions agree with the inference of some EEC data [17], suggesting that all impulsive sounds can be plotted on a single dose-response line, being significantly more annoying than traffic (continuous) noise.

4. In studies dealing with combinations of impulsive and steady noise, it is clear that the presence of background noise has some effect on the impulsive noise annoyance reaction. A study by Berry [27] using combinations of synthetic sounds suggests a change in peak/background ratio of 10 dB, producing an average change of 6 dB in impulse penalty.

In summary, it is clear that a universally applicable definition of impulsive noise is urgently needed for incorporation into noise standards. For this reason the work outlined in this thesis concentrates on obtaining a distinction between impulsive and continuous sounds. In Chapter 3 of this report, various objective descriptors of impulse noise are studied, and Chapter 4 outlines the design and use of computer software to apply these models to noise signals. Although it is recognised that impulsive sound can evoke a significantly more annoying response than a continuous sound at the same noise level, this does not in itself constitute a quantitative definition of impulsive noise. Chapter 5 describes a laboratory experiment to obtain judgements concerning the impulsivity of synthetic sounds heard in isolation. The sounds consist of trains of impulses of different decay times and repetition rates. Some of the sounds are clearly impulsive, whilst some are clearly continuous. The same sounds are also objectively analysed by the descriptors modelled on the computer, described in Chapters 3 and 4. In Chapter 6 the objective and subjective ratings of impulsiveness can then be compared.

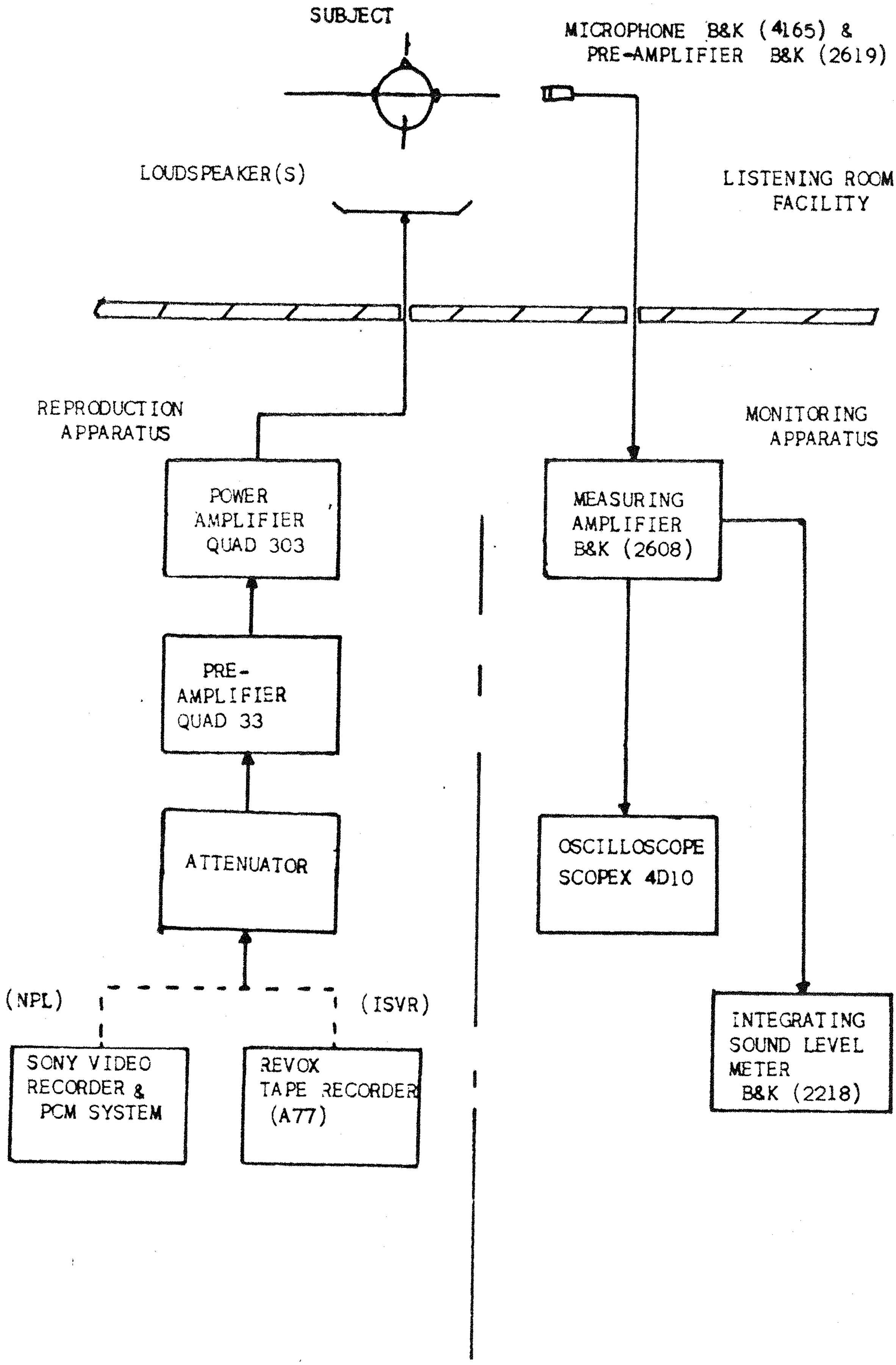

FIGURE 2.1 Generalised apparatus for subjective listening experiments.

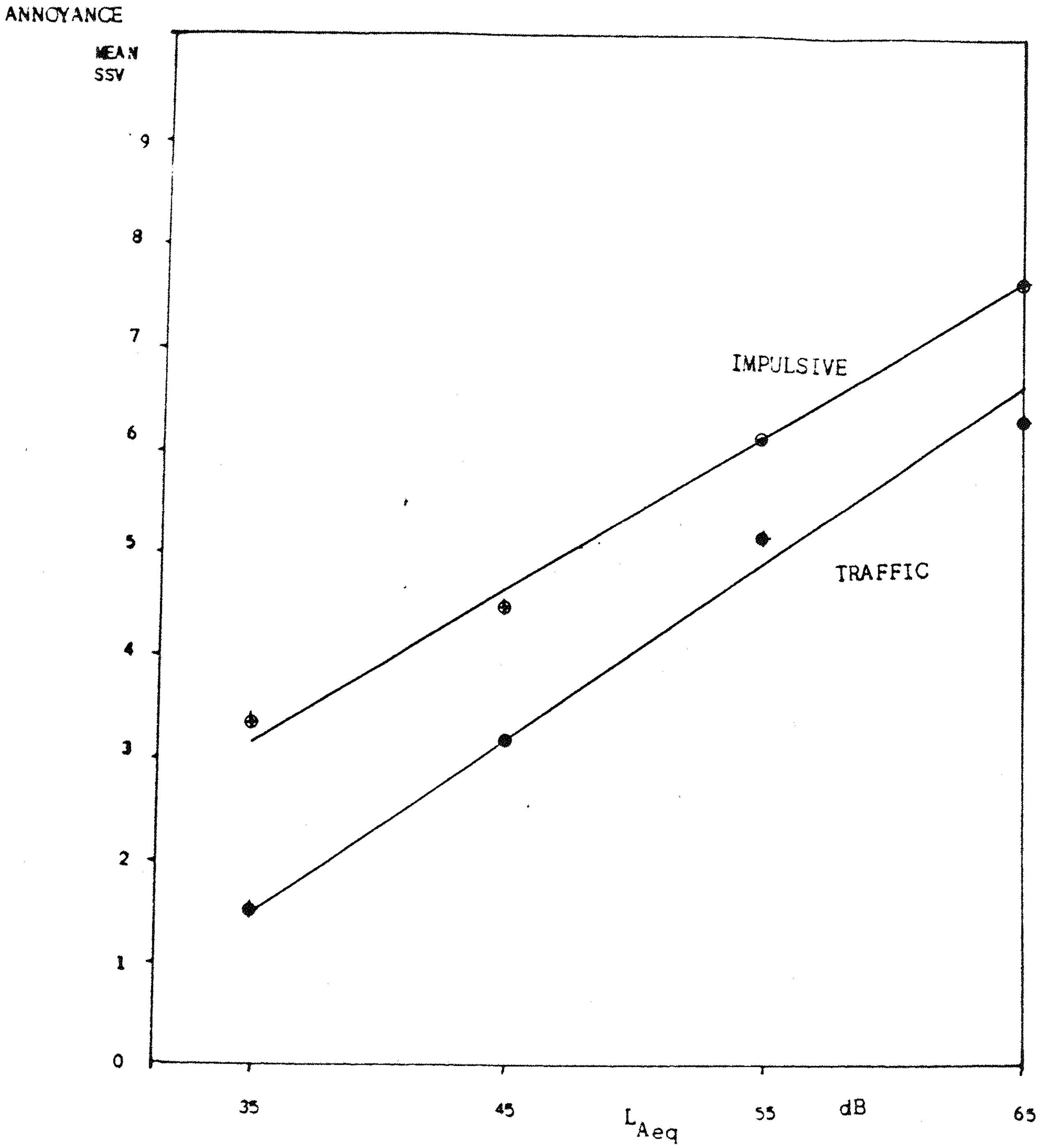

FIGURE 2.2. Results of Pilot Study I: CEC experiment. Plot of annoyance rating (mean SSV) against level (L_{Aeq}), for impulsive and traffic noise.

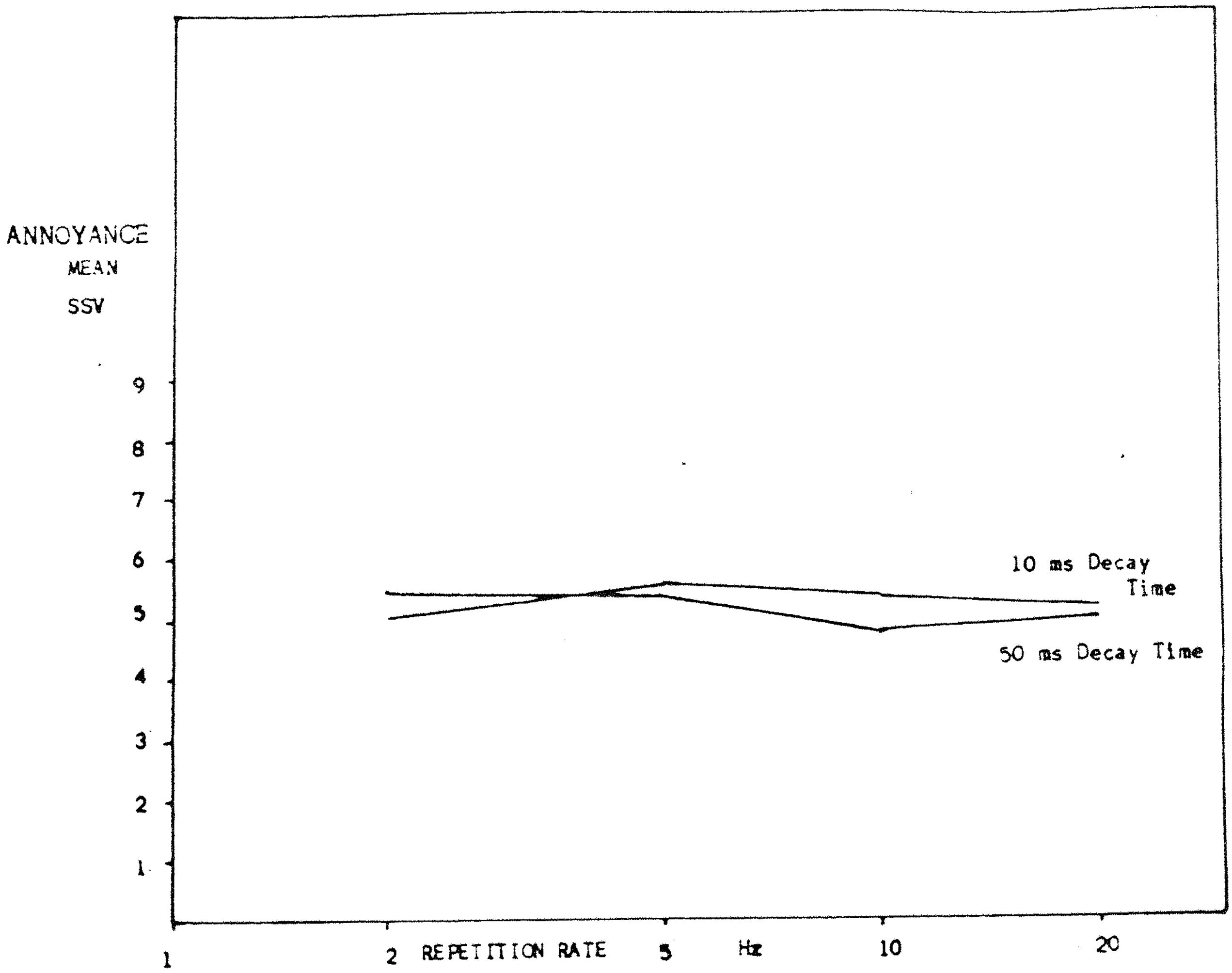

FIGURE 2.3. Results of Pilot Study II: NPL experiment. Plot of annoyance rating (mean SSV) against repetition rate (Hz), for either decay time (ms) of synthetic sounds.

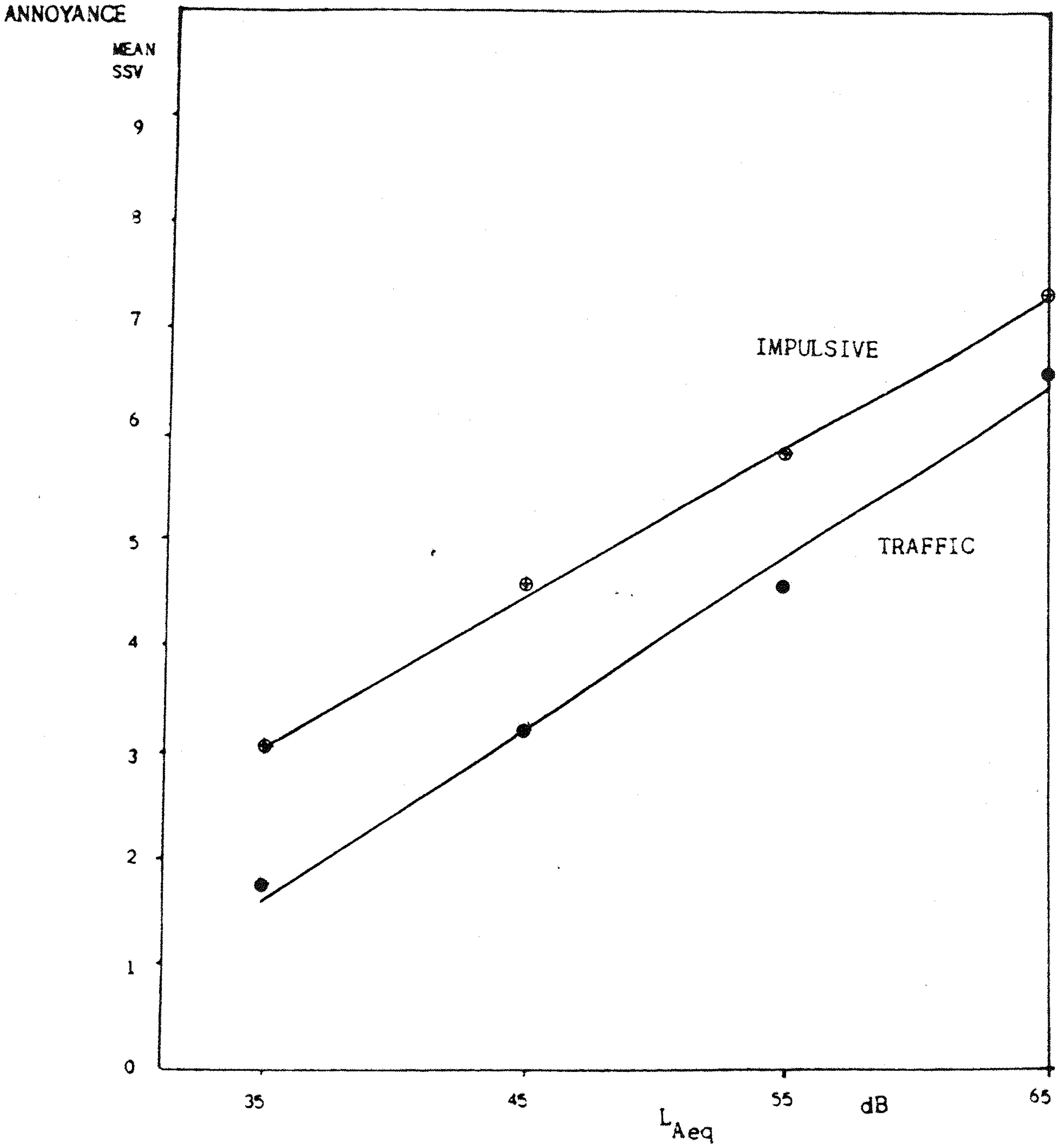

FIGURE 2.4. Results of Pilot Study II: NPL experiment. Plot of annoyance rating (mean SSV) against level (L_{Aeq}), for impulsive and traffic noise.

CHAPTER 3

OBJECTIVE METHODS OF IMPULSIVE NOISE DESCRIPTION

3.1 Physical Characteristics of Impulsive Noise

In a modern society there are many possible sources of environmental impulsive noise. Table 3.1 categorises the principal sources, together with references to relevant literature.

Table 3.1: Typical environmental sources of impulsive noise.

Environmental Noise Source		Reference no.
Helicopter Noise:	Blade slap	11,21,35,51,77
Other Transportation Noise:	Sonic boom	49
	Motorcycle noise	22
Blast Noise:	Quarry blasting (civil)	56
	Military charges and blasting	71
Gunfire Noise:	Starting pistol	76
	Rifle shooting	52,57,61,65,71
	Clay pigeon shooting	52
	Tank and heavy artillery fire	57,58
Construction Noise:	Piledriver	23,27,64,65
	Pneumatic drill	23,64,65
	Hammering, drilling	22
Industrial Noise:	Impacting machines	4,34,41,50,54,65
	Riveting machines	4,34,50,65
	Punch presses	4,34,50,65
	Drop forging	4,22,53,65
Wind Turbine Noise:		67,68,69,70

In order to define the requirements of an objective descriptor for impulsive environmental noise, it is necessary to investigate the physical parameters which determine the character of such sounds.

A report [22] by the United States Environmental Protection Agency [EPA] provides a physical definition of impulsive noise. This states, "sounds can be defined as impulsive when they exhibit some form of rapid and substantial variation in the envelope of the time history of the instantaneous peak pressures". The envelope can be considered to be a line connecting the instantaneous peaks of a noise signal measured on an oscilloscope.

The following quantities, which are illustrated in Figures 3.1–3.3, can be used to characterise a single impulse or train of impulses.

(a) ***Rise Time*** (τ_r): (ms) — The time for the signal envelope to rise from zero level to maximum level for a single impulse.

(b) ***Decay Time*** (τ_d): (ms) — The time for the signal envelope to decay from maximum level to zero level for a single impulse.

(c) ***Level Change*** (ΔL): (dB) — The difference between peak level and zero level for a single impulse or between maximum level and minimum level for overlapping impulses.

(d) ***Repetition Rate***: (Hz) — The rate of occurrence of the impulses

(e) ***Spectrum***: — The frequency distribution of acoustic energy in the impulse.

Whilst the frequency composition of a noise will influence its impulsive character, this study has concentrated on investigating the temporal definition of impulsive noise. Although impulses occurring in a real-life environment may not possess easily definable parameters it is convenient initially to assume that impulsive sounds consist of idealized impulses.

At this point it is important to make the distinction between 'single' impulses and trains of impulses, or 'multiple' impulses.

Single impulses

Figure 3.1 shows the envelope of a single idealised impulse. It is clear that its temporal characteristics are determined by the rise time, τ_r, the decay time, τ_d, and the level change, ΔL. If any of these quantities is varied, a change will occur in the envelope shape, and hence the energy content and subjective impression of the impulse. Each of these parameters can vary within a certain range of values, beyond which the signal may cease to constitute an impulse. For a constant rise time and decay time, the level change ΔL must exceed a certain value determined by the values of the other two parameters, for the noise to be an impulse.

In practice, the situation is more complex, as an impulse rarely occurs in isolation and it is necessary to consider the case of multiple impulses.

Multiple impulses

When a train of impulses occurs another parameter, the repetition rate, has to be considered. Although environmental noise signals are never simply composed, it is convenient to assume at this stage that impulses possess a constant repetition rate and decay time. The time between the maximum levels (peaks) of any two impulses can be defined as the separation time, τ_{sep}. For impulses with a regular repetition rate this is equal to the time period.

If an impulse has fully decayed before the following impulse occurs, the two impulses will not interact. In theory this will occur when the separation time, τ_{sep}, is greater than the sum of the decay time, τ_d, of the first impulse and the rise time, τ_r, of the second. The consecutive impulses can be evaluated as if each were a single impulse, illustrated in Figure 3.1.

If an impulse has not fully decayed before the following impulse occurs, then superimposition will take place, as shown in Figure 3.2. In this situation there is no zero level, because of the overlapping mechanism. The level change is taken as the difference beween the maximum level of the impulse and the minimum level. The minimum level is defined as the point at which impulse rises above the decaying envelope of the previous impulse. This is shown in Figure 3.2, and it is intuitively obvious that the level change, ΔL, provides a measure of the degree of superimposition that occurs between consecutive impulses.

It can thus be concluded that the rise time, decay time and repetition rate of ideal impulses determine the degree of superimposition of the impulses and the level change.

If a background noise is introduced in combination with the impulsive sound, the influence on the level change is dependent on the background level. If this exceeds the zero level in the case of the single impulse or the minimum level, for overlapping impulses, then the level change, ΔL, is given as the difference between the maximum level of the impulse and the background level, as shown in Figure 3.3.

It is clear that all temporal parameters described can contribute to the physical description of an impulsive sound. Studies need to be performed in order to investigate whether these parameters also affect the subjective judgement of a sound. In Chapter 5 of this thesis, a laboratory experiment is outlined in which the subjective impulsiveness of several synthetic sounds was studied. Synthetic sounds were used in order to obtain a controlled range of values for each parameter. Each sound consisted of a train of identical impulses. A constant rise time of less than 1 ms was used. The decay time and repetition rate were varied for different sounds and the effect on the subjective evaluation of the impulsiveness of the sounds was studied. The maximum level was kept constant for all sounds so that the degree of interference beween consecutive impulses was indicated by the level change.

Section 3.2 outlines several objective methods of impulsive noise description that have either been proposed or are in present use. Particular attention is paid to how these measures incorporate any form of analysis or quantification of the parameters discussed in this section. Where possible, initial objective experiments have been performed and these are described in Section 3.3. As a result of these studies and the research outlined in this and the previous chapter, a new method for impulsivity description is suggested in Section 3.4.

3.2 A Review of Impulsive Noise Descriptors

3.2.1 Kurtosis Based Descriptor

A recent paper [34] suggests that a 'classification of impulsiveness based on the sample Kurtosis meets the requirements of a generally acceptable impulse definition'. The Kurtosis of a sampled noise signal is the ratio of the fourth moment to the second squared moment of the distribution of the sampled noise amplitudes. The expression is given below:

$$\beta = \frac{\frac{1}{T}\int_{0}^{T} v^4(t)dt}{(\frac{1}{T}\int_{0}^{T} v^2(t)dt)^2}$$

where $v(t)$ = instantaneous voltage

T = total duration of signal

For a sampled signal this can be rewritten

$$\beta = \frac{\frac{1}{n}\sum_{i=1}^{n} \bar{v}^4(i)}{\frac{1}{n}\sum_{i=1}^{n} \bar{v}^2(i)}$$

where $\bar{v}(i)$ = sampled voltage amplitude

n = number of samples in total signal (250,000)

The measure is an indication of the 'peakedness' of the noise, and has the advantage of accounting for all peaks present in the noise sample, in addition to incorporating the relative difference between maximum peak and background levels. Erdreich [34], suggests that the kurtosis measure may be applied to studies evaluating the comparative effects of 'impulsiveness' which are designed to control the effects of other parameters such as spectrum, level, and duration. Impulsive parameters (rise time, decay time, level change, and repetition rate) which contribute to the temporal distribution of an impulsive sound will influence the kurtosis value obtained.

A normally distributed variable will have a Kurtosis of 3.0, and the report suggests that a noise with a value greater than this could be classed impulsive.

3.2.2 The NPL descriptor

The descriptor given in the NPL report [10] is illustrated below, the assumption being that the deviations between running values f(j) and the long term mean square S, was envisaged as a measure of impulsiveness.

$$I = \sum_{j=1}^{n} \left[\frac{f(j) - S}{S}\right]^2$$

where

$$f(j) = \frac{1}{m} \sum_{i=1}^{m} v_i^2$$

v_i = sampled values of the signal amplitude

m = number of samples in the small time period (10 ms, 200μs)

$$s = \frac{1}{n} \sum_{j=1}^{n} f(j)$$

n = number of f(j) values in the long time period (0.5 s)

After several experiments outlined in the report, a final value of 200μs was chosen. By averaging these values over a 0.5 second of signal a value of $\bar{I}$ (=I/n) was obtained. This was then used to obtain a value of X, as given below, which was directly related to a correction factor.

$$X = 10 \log_{10}\bar{I}$$

For the purposes of this thesis it is only necessary to investigate the impulsivity descriptor, I, in comparison with other objective methods. In order to incorporate this descriptor into the software package developed in Chapter 4, a small time period of 10ms was used, and not 200μs as proposed in the NPL report. Ten seconds of signal were to be analysed by each of the descriptors, and hence an average of each of the 0.5 second I values was taken as a measure of the descriptor. However, for synthetic sounds composed of identical impulses regularly repeating at repetition rates of 2.5 Hz or more, there will be little difference between consecutive values of I.

Of the four measures investigated in the NPL study, X gave the best correlation with the annoyance responses obtained from an accompanying laboratory experiment.

This descriptor is not based on any direct quantification of the rise time, decay time, repetition rate or level change. However, these parameters will affect the descriptor, although these values are obtained from the noise as a whole and not only from the impulsive component.

3.2.3 Crest factor type measures

Several studies, predominantly those investigating the problem of helicopter blade-slap noise, have attempted to relate crest factor (F_C) measurements to annoyance judgements [11,32,35]. The crest factor of a signal can be defined as the ratio of the peak level to the root mean square (rms) value of the signal. However, Erdreich [34] states that 'a single crest factor cannot be representative of a multiple peak nonstationary waveform'. This is because a crest factor is only sensitive to the amplitude of the single largest peak and to the duration over which the waveform is measured. No consideration is taken of the parameters discussed in Section 3.1, which define the time history of an impulsive sound, except for their contribution to the root mean square level. For example, a car pass-by of approximately 1 second may well constitute an impulsive sound for a model based on a single crest factor measured over a time period greater than this.

In an attempt to alleviate this problem, consecutive small time period crest levels were studied by the author. The maximum of these levels was taken as a descriptor of impulsivity. By performing this analysis over small time periods (less than 50 ms) it was hoped to obtain an approximate indication of the decay time and rise time of an impulse in addition to the repetition rate and level change. A fault with this measure is that over a short time duration large variations in amplitude are present in many stationary sounds, and it is these which are detected and not the presence of impulses.

It is also probable that any crest factor type method will have difficulty differentiating between impulsive sounds and those composed of sinusoidal waveforms of a similar peak value.

3.2.4 L_{AI}-L_{AS} Method

The EEC Directive 79/113 [7] gives a method of quantifying impulsive noise based on the difference between the L_{AI} and L_{AS} measures given on a precision sound level meter. These are the root mean square (rms) values of sound pressure levels, measured at the 'impulse' and 'slow' time weightings, respectively. The specification concerning the circuitry for precision sound level meters containing these time weightings is given in Appendix 2.2.

This measure does not directly quantify the parameters that physically determine the temporal characteristics of a noise. These will, however, contribute to the levels measured.

A value of $L_{AI} - L_{AS} \geqslant 4$ dB is given as a criterion for defining impulse noise.

3.2.5 German study

A recent paper [36] suggests the use of several different noise levels to quantify the impulsive character of noise in the neighbourhood of shooting ranges. These are defined as:

$L_{AFM,1h}$ - [db(A)]	Equivalent continuous A-weighted sound pressure level with the time weighting "fast" during an averaging time of 1 hour of both the total noise and the shooting noise alone.
$L_{AFTM,1h}$ - [dB(A)]	Equivalent continuous A-weighted sound pressure level with time weighting "fast" during an averaging time of 1 hour, using the maximum values in time intervals of 5 seconds for the averaging process of the shooting noise.
$L_{AIM,1h}$ - [dB(A)]	The same levels as above but with the time weighting
$L_{AITM,1h}$ [dB(A)]	"impulse" instead of "fast".

$L_{AF\ 1\%}$ – [dB(A)] 1% level of the cumulative distribution of the $L_{AF}(t)$ levels of total noise.

Appendix 2.2 gives details of the sound level meter specification for "fast" and "impulse" time weightings.

None of these measures relates directly to the parameters discussed in Section 3.1, and a sampling time of 5 seconds is too large to provide any characterisation of single or consecutive impulses.

Obviously, the values of these temporal parameters will contribute to determining the energy levels measured.

3.2.6 <u>A French description method</u>

Studies have been undertaken by Commins *et al* into the quantification of impulse noise as part of the CEC project on the effect of impulse noise on human beings [37,38,39,40]. These reports outline how several quantities can be obtained by the use of short-term L_{eq} time series, in particular the physical parameters described in Section 3.1. Provided the time series was measured over small enough intervals (discussed in Sections 3.3 and 3.4), it is possible to obtain an estimate of the rise time and decay time of the impulse.

The work used a data acquisition and analysis system. Three seconds of signal was sampled at a rate of 10,000 samples/second. In addition to the quantities mentioned previously, the minimum, mean, and maximum L_{eq} levels and the standard deviations of these levels can be obtained. Analysis could also be performed on the raw time signal.

An interesting method for 'zooming' in on impulses present in noise was proposed using an Auto Regressive Moving Average (ARMA) [39]. This enables the detection of impulses even in rather complex signals, containing various types of environmental noise. It is then possible to obtain a clear indication of the repetition rate or separation times of the impulses present.

The report then introduces the concept of 'adaptive impulse noise cancellation', and suggests how this can 'remove' the impulsive content of a noise.

3.3 Initial Objective Studies

3.3.1 L_{AI}-L_{AS} Method

Berry [27] suggests that this method is unsuitable for quantifying impulsive noise. Objective experiments by the author substantiate this view. The results of Pilot Study II, a subjective study undertaken at the NPL by the author, indicated that there was no difference in annoyance response for the synthetic impulse sounds involved, yet an L_{AI}-L_{AS} measure rated only those sounds with a repetition rate of 2 Hz or 5 Hz impulsive. In contrast, the traffic noise which was included as non-impulsive was also rated impulsive with an L_{AI}-L_{AS} value of 5.5 dB. The L_{AI}-L_{AS} values for all eight synthetic sounds used in the experiment are illustrated in Figure 3.4.

Further experimental analysis of synthetic sounds was performed by the author at the ISVR. The sounds studied include some of those used in a subjective laboratory study into impulsivity, described in Chapter 5. The L_{AI}-L_{AS} values are shown in Table 3.2, where the boundary between impulsive and non-impulsive sounds defined by the EEC Directive 79/113 is illustrated. Some sounds that appear to be subjectively judged as clearly impulsive in the laboratory study are not rated so by this measure. A comparison between this boundary for impulsive sounds and the conclusions of the subjective experiment in Chapter 5 reiterates this point.

3.3.2 German measures

In an objective experiment performed by the author at the ISVR, the measures outlined in Section 3.2.5 were applied to a number of synthetic sounds. The most sensitive of the descriptors was the $L_{AIM,T}$-$L_{AFM,T}$ value, suggested by Assmann [36]. However, these differed only slightly from the L_{AI}-L_{AS} values, as Table 3.2 shows.

Table 3.2: Values of $L_{AI} - L_{AS}$ and $(L_{A(IMT)} - L_{A(FMT)})$ for various repetition rates and decay times

Repetition rate (Hz)	Decay Time (ms) 5	10	20	40	80	100	160
1	(14.9) 14.5	15.0	14.0	12.0	(11.5) 12.0	10.0	10.0
2	11.5	11.5	11.0	10.0	9.0	7.5	7.0
5	8.5	8.0	6.5	6.5	5.0	4.0	(3.1) 3.0
10	6.0	4.0	(7.2) 4.0	3.75	2.5	(2.9) 2.0	1.5
20	4.0	3.5	(3.3) 3.0	(2.6) 2.0	1.5	(2.0) 1.0	1.0
40	(3.9) 2.0	2.0	1.5	(1.9) 1.0	1.0	1.0	1.0
50	2.0	1.5	1.5			$L_{AI} - L_{AS} < 1.0$	
100	1.5	1.0	1.0				

3.3.3 Short-term L_{eq} time-series

Reports documenting this French study outline how various impulsive noise sources have been analysed using very short-term L_{eq} time series. For L_{eq}s measured over time periods of 8 ms and 50 ms, combinations of maximum L_{eq}, minimum L_{eq}, the standard deviation and the single event level (SEL) were studied. Analysis concentrates on parameters occurring over a large time period, such as the difference in minimum and maximum $L_{eq,8\ ms}$ in a 3 second sample, as opposed to the small temporal displacements which are likely to be responsible for the impulsive character of the noise.

Unfortunately, as yet there are no subjective results to compare to the objective analysis undertaken in these French studies.

Some initial objective analyses were performed by the author at the ISVR in an attempt to replicate the work described. These proved successful, leading to the development of a software package for use on the VAX computer system. This work showed that it is possible to obtain estimates of all the parameters given in Section 3.1. From these results, together with other objective studies and further theoretical considerations, a new descriptor for impulsivity was devised by the author, which is described in the following section.

3.4 A Proposed Impulsivity Descriptor: K

From simple descriptions given in Section 3.1 it is clear that the repetition rate, decay time, rise time and level change are among the principal parameters describing the time history of an impulsive sound. The quantities can be measured from the envelopes of ideal impulses. The level change alone can provide an indication as to the degree of interaction which may occur between consecutive impulses. As earlier theory showed for a sound to be impulsive the rise time and level change must be within a certain range of values. Therefore the level change ΔL must be measured over a defined time period ΔT as shown in Figure 3.5. Here the level change, ΔL, is the same in each case but the period, ΔT, over which the level is taken differs. Beyond a certain value of ΔT, dependent on the value of the level change, the sound will cease to be subjectively judged as impulsive.

A paper by Dornseiffen [41] suggests a dL/dt measure may be suitable for detecting impact noise in machinery. This is based on the rate of change of ΔL, but with respect to an instantaneous signal, rather than an averaged signal. The use of a dL/dt measure on a time signal means large amplitude variations, which are often present in stationary signals over extremely short time periods, will be detected.

Some form of averaged signal should be obtained in order to give an indication of the 'smooth' waveform. If a suitably small time period is chosen an estimate for the level change between each time period can provide an indication of the impulsivity of a sound. Figure 3.6 shows how an estimate of ΔL can be obtained from a very short-term L_{eq} time-series. Many studies have suggested that the ear possesses some energy averaging process [42,43], and a careful choice of the time period over which to average may obtain a closer approximation to the sound perceived by the ear. This substantiates earlier suggestions that the choice of time period over which to average is an important factor.

One analogue method to obtain an estimate of the signal envelope is the use of a sound level meter with an exponential circuit, as suggested by Dornseiffen [41]. This was not modelled on the computer system because the storage space needed to hold the arrays required to generate the moving time window was not available. Instead a digital method of averaging was employed by obtaining a consecutive small time period L_{eq} series, as described in work by Commins [37-40].

For an acoustic signal, P(t), the equivalent continuous sound level at time t, on a period T, is defined by

$$L_{eq,T}^{t} = 10 \log_{10}\left(\frac{1}{T}\int_{t}^{t+T} \frac{P^2(t)}{P_o^2} dt\right) \qquad (3.1)$$

This is a measure of the energy of the signal between t and $t + T$. The replication of this procedure over successive periods generates a time series ($L_{eq,T}^{t}$, $L_{eq,T}^{t+T}$, ..., $L_{eq,T}^{t+nT}$) which is related to the evaluation of energy. Commins states that "to take into account and analyse specific acoustic events it is convenient to use a period T related to the duration of the phenomenon". As earlier theory in this section suggested, when T is shorter than this duration it is possible to differentiate the phenomenon with the $L_{eq,T}$ time series. Whether any large fluctuation in amplitude, which may be associated with an impulse, is represented in the averaged signal is dependent on the period T. Hence if the time period taken is very small, the resulting output will closely resemble the raw instantaneous signal, and as the averaging period is increased the measure will become less selective. As previously mentioned, the time period required must attempt to model the way in which human subjects would 'perceive' the sound. From previous studies, and from literature concerning the mechanism of the ear [42,43], it would appear that a feasible duration lies within the range 8-200 ms. Initial experimental work by the author undertaken at the ISVR, together with a study of the French results [37-39] indicated that a value of less than 50 ms may provide a better approximation. In an initial study by the author, periods of 8ms and 35 ms were used. For the purpose of the main study, time periods of 10 ms and 31.6 ms [$10^{3/2}$ ms] were chosen.

Using a computer model discussed in Chapter 4, the A-weighted noise signal was sampled at a very high frequency (25 kHz), to obtain voltage amplitudes $\bar{v}(j)$. A reference value of I μv was used, and not 2×10^{-5} Pa specified in the definition of L_{eq} given in Appendix 2.1. For the chosen time period, T, there are m sampled values and equation (3.1) can thus be rewritten to describe the i'th L_{Aeq_T} term in the series of n terms.

$$L_{Aeq_T}(i) = 10 \log_{10} \frac{1}{m} \sum_{j=1}^{m} \left(\frac{\bar{v}(j)}{v_{ref}}\right)^2 \quad \text{dB (rel } \mu\text{V)} \qquad (3.2)$$

An approximation to the level change, ΔL, was obtained by measuring the difference between consecutive L_{Aeq_T} levels, over a duration ΔT which which is equal to T. On the assumption that the presence of one impulse in a ten second duration would constitute an impulsive sound, the maximum of the positive differences was taken as a predictor of impulsivity. An estimate of the 'impulsive decay' or turn-off of a sound can be obtained by taking the maximum of the negative differences.

For a series of n $L_{Aeq_T}(i)$ terms defined in equation (3.2), each of the time period T, the impulsivity descriptor, K_T, is given as:

$$K_T = \max[L_{Aeq_T}(i) - L_{Aeq_T}(i-1)] \quad \text{for } i = 1,2,3,\ldots, n \qquad (3.3)$$

The difference in consecutive L_{Aeq_T} levels evaluated over a constant time period T, provides an indication of the rate of change of L_{Aeq_T} level; dL_{Aeq_T}/dt. This is an absolute measure and is thus not influenced by input signal amplitude unlike a relative measure. The model thus uses the method of dL/dt suggested in earlier work [41], applied to an envelope of the signal, obtained from an averaging process.

3.5 Conclusions

From the initial experiments undertaken by the author outlined in Section 3.2, the measures given in the EEC Directive 79/113 [7] and by Assmann [36] can be dismissed as inadequate for objectively describing impulsive noise. The following descriptors were modelled on the computer system discussed in Chapter 4.

1. A kurtosis measure of the 10 second signal: (β)
2. A crest factor measure of the 10 second signal: (F_C)
3. An average of consecutive NPL impulsivity descriptor measures, I , over the total 10 second segment of signal. Each value of I is calculated over a 0.5 second period.
4. The maximum small time period crest level in a 10 second signal, measured over a period of:
   (a) 10 ms
   (b) 31.6 ms
5. The K descriptor measured over a period of:
   (a) 10 ms
   (b) 31.6 ms

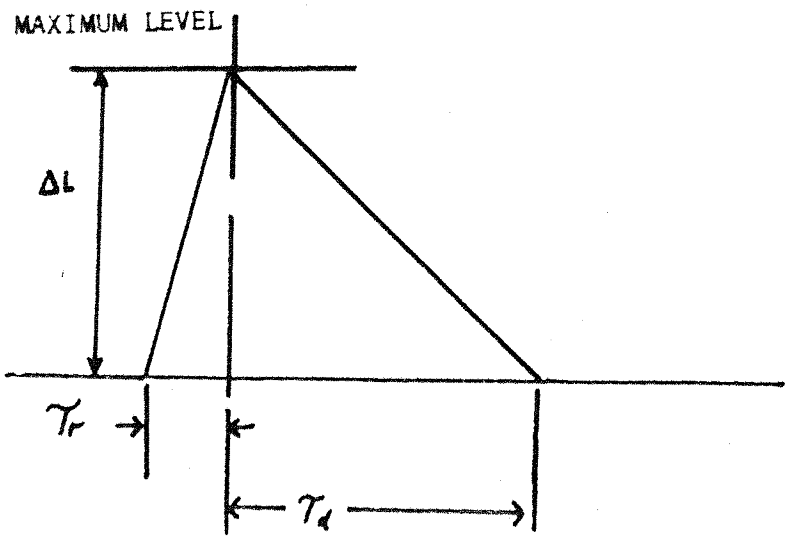

FIGURE 3.1. Time envelope of an idealised single impulse.

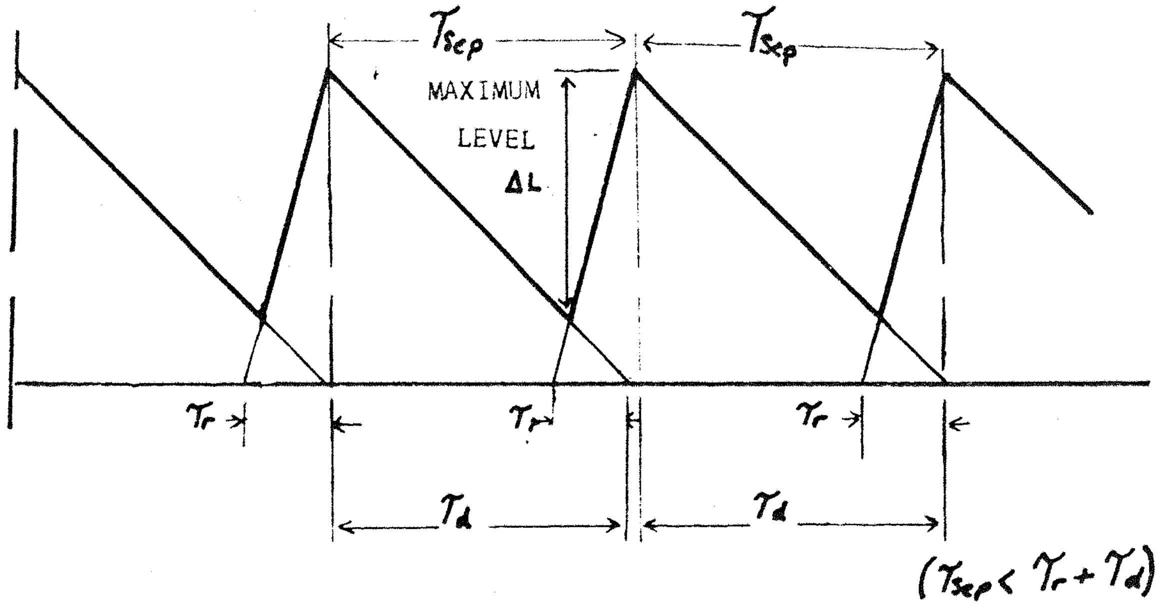

FIGURE 3.2. Overlapping envelopes of idealised impulses.

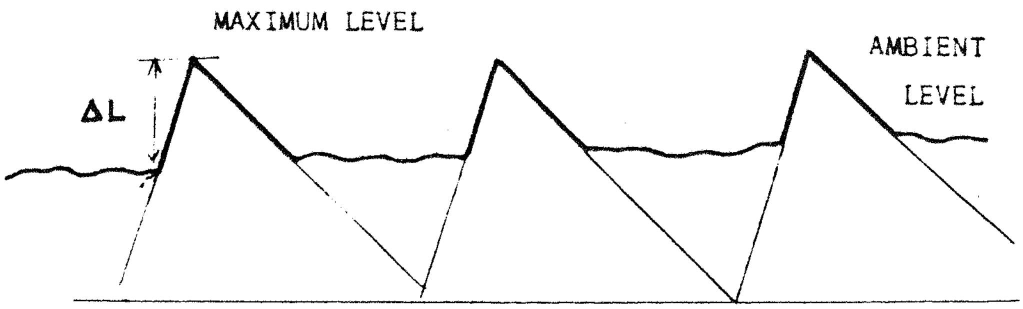

FIGURE 3.3 Idealised impulses in combination with background noise.

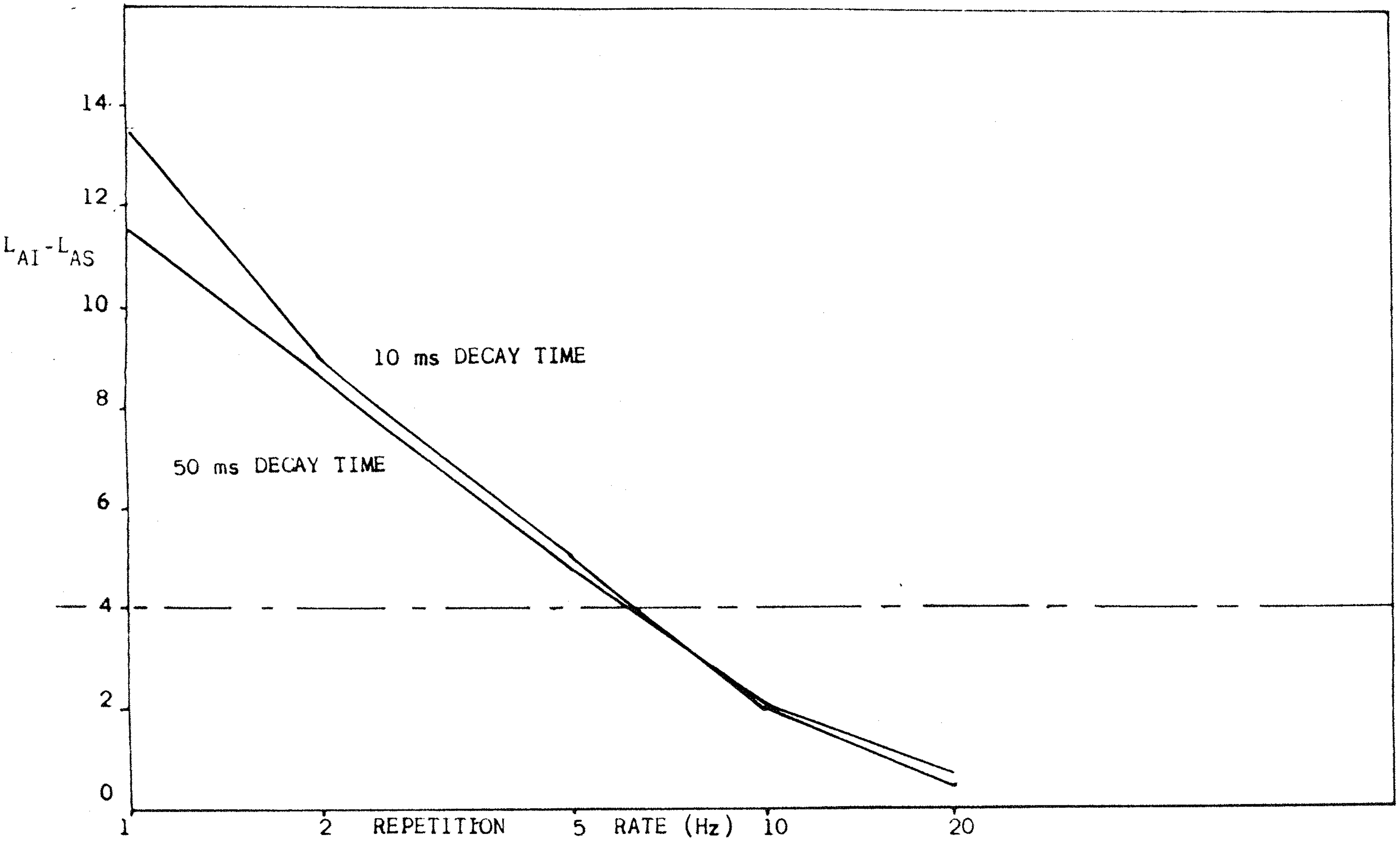

FIGURE 3.4. **Results of Pilot Study II: NPL experiment. Plot of $L_{AI}-L_{AS}$ against repetition rate (Hz), for either decay time (ms) of synthetic sounds.**

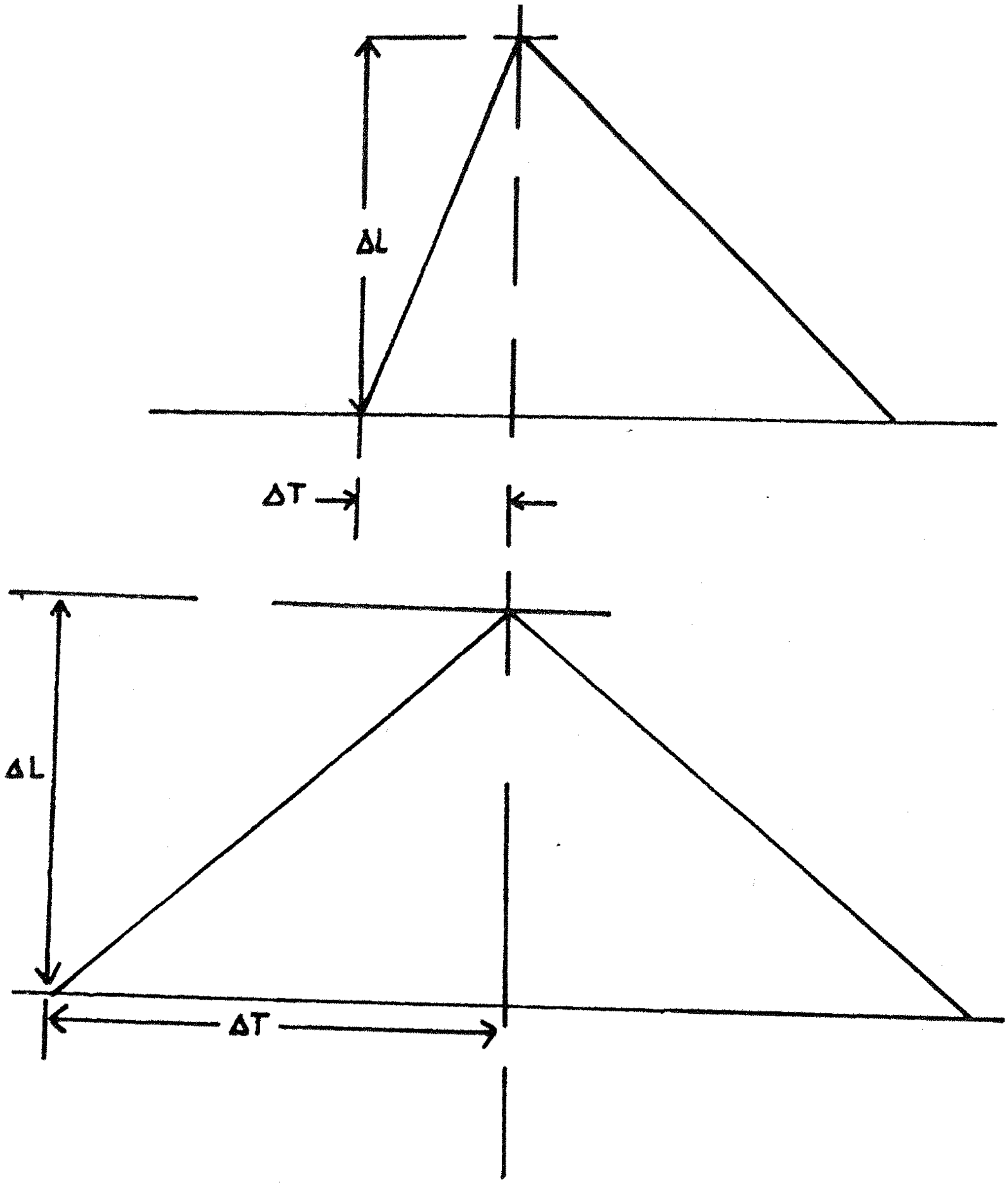

FIGURE 3.5. Level Change and duration for idealised impulses.

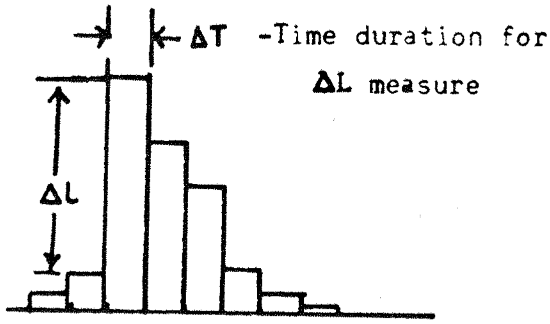

FIGURE 3.6. The averaged waveform of a typical impulse.

CHAPTER 4

COMPUTER MODELLING OF OBJECTIVE METHODS OF IMPULSIVE NOISE DETECTION

4.1 The Software Package Structure

The software package outlined in this section is intended to simulate human perception of the impulsivity of a sound, using the objective methods outlined in Section 3.5. It is hoped that the package can be considered to be a 'black box' device, which can replace the subject in a noise environment. It is therefore important that the input to the computer system is compatible with the sounds heard by subjects. Recordings of the synthetic sounds use in the subjective laboratory experiment described in Chapter 5, were made at the subjects' head position in the experimental environment, and were A-weighted to approximate the human reaction to the frequency content of the noise.

The objective descriptors of impulsive noise are modelled in a specially written FORTRAN file. This forms part of the software package illustrated in Figure 4.1, which operated on a VAX/VMS computer system. This chapter is intended to provide a basic user guide to the use of this package, the structure of which is outlined below.

(a) The input signal is sampled and digitally stored in a data file.

(b) A FORTRAN file (JIM1.FOR) calls the sampled values from this data file. These are then used in the algorithms which model the objective descriptors. Further subroutines send the computed values to output data files.

(c) The output data files can be graphically displayed on the screen and a hard copy plot can be obtained. Tabulated data and results can also be obtained in hard copy.

Both input (a) and output (c) stages employ existing files developed by the DAC (Design and Analysis Centre) as part of the DATS (Data Analysis of Time Series) facilities available at the ISVR. These are suitably acknowledged in the text.

4.2 A User Guide to Input Handling

Before any analysis is performed on a sound, a segment of the signal must be sampled using an analogue to digital converter (ADC) and stored in a data file. The values in this file can then be input into the main FORTRAN program. The procedure for obtaining a stored sampled signal of a sound is outlined in this section.

In this study the sounds to be analysed by the software package were digitally recorded on video cassette using a Bruel and Kjaer microphone (type 4165) situated at the subject's head position (approx. 1.2 m above floor level). The microphone signal was fed through a Bruel and Kjaer preamplifier (type 2619) into a Bruel and Kjaer measuring amplifier, where the signal was A-weighted. The output of this amplifier was recorded on one channel of video cassette, using a Sony Video Cassette Recorder/Digital Audio Processor system. A one minute recording of each of the sounds was made in this way.

Before the noise signal is acquired it must pass through an anti-aliasing filter. This is necessary to avoid the phenomenon known as 'aliasing', which can occur when signals are sampled. In simple terms it is the misinterpretation of high frequencies (above half the sampling frequency) as lower frequencies, but a more detailed explanation can be found in a publication by Randall [44]. Due to a restriction on storage of the 10 second segment of noise signal the sampling frequency used was 25,000 samples per second. The anti-aliasing filter was thus set to a low pass filter with an attenuation of 48 dB/octave, commencing at 8 kHz. The signal was amplified by a factor of 10 but still lay within the input range of ± 10 V required.

With the removal of all frequency components at more than half the sampling frequency, the output signal of the filter can now be sampled and was input to channel 1 of a terminal interface. In order to control the sampling process, a DATS file 'AQUIR' was required. With the video cassette recorder controls set to 'play', a 10 second segment of signal was sampled when the trigger button on the terminal interface was pressed. This was stored in a data file labelled '1' by default but the use of DATS files enabled the data file to be suitably renamed, e.g., '2050' for a synthetic sound comprising of impulses with a 50 ms decay time at a 20 Hz repetition rate.

This file, containing the sampled signal, can be graphically displayed on the terminal screen by use of the DATS 'DISPLY' file. It is good practice to verify that the desired signal has been captured. Use of the cursor controls enables any offset in the voltage signal, which may result from the recording process, to be evaluated. If this is the case, the use of the DATS 'ARITH' file allows the signal to be normalized to zero voltage.

4.3 Documentation of the FORTRAN Program

A main program, written by the author in FORTRAN, is fully listed in Appendix 4.1. The use of statement lines throughout the program and the labelling of subroutines makes this listing self-explanatory. However, a brief description of the purpose of each of the main subroutines is given in this section, together with definitions of the principal variables. A program specification is also given.

4.3.1 Subroutine to handle input and output files and to define parameters

In this initial subroutine, the following arrays are dimensioned, and are used throughout the program:

(A) – stores the input data file values

(B) – stores the small time period rms values

(W) – stores the small time period peak levels

(C) – stores the small time period crest levels

(V) – stores the small time period L_{Aeq}

(D) – stores the changes in small time period L_{Aeq}

(O) – stores small time period values for NPL descriptor

(Q) – stores large time period values for NPL descriptor

(F,G,H) – stores values for output data files.

An output file 'OUT.DAT' is opened and written to throughout the program, using the device code number 99. Several DO-loops are set up in the next main subroutine which model a discrete windowing process to obtain values measured over varying time periods as well as the total 10 seconds of signal. The DO-loops operate using counters computed from the time periods input by the user and the rate at which the input signal has been sampled. The counters are as follows:

N = number of sampled values in the small time period

J = number of small time periods in the large time period

J3 = number of large time periods in the total 10 second signal

J4 = number of small time period in the total 10 second signal.

4.3.2 Subroutine to calculate small time period L_{Aeq}s, crest levels and other values from input signal

This subroutine consists of three nested DO-loops, which operate using the aforementioned counters. The inner of these computes the small time period value of L_{Aeq} and crest level from the sampled values of the input signal. In addition, several other values (v^2, v^4, $\sum_{i=1}^{N} v^2$, max peak) are also computed by simple arithmetic operations. These are used for obtaining the kurtosis, crest factor and NPL descriptor.

This DO-loop lies within a second loop which calculates the value of I, the NPL descriptor for each 0.5 second time period.

A third, outer, DO-loop enables a series of small time period crest levels and L_{Aeq}s to be generated for the overall 10 second signal. A flow chart, illustrated in Figure 4.2, shows the procedure by which small time period L_{eq} series are obtained. This outer loop enables an average of the I values to be computed for the 10 second period. In addition, all of the 250,000 sampled values of the input signal can be analysed in order to obtain kurtosis and crest factor measures for the 10 second signal.

4.3.3 Subroutine to perform calculations on values obtained from the input signal

Using the values obtained in the previous subroutine, the following results are calculated:

- AKUR – kurtosis
- CRET – crest factor
- APL – NPL descriptor (I)
- COUNT – max. crest level
- TOTAL – K measure
- RAT – 10 second L_{Aeq} of signal

The arrays containing the data values for the small time period crest levels, L_{Aeq}s and differences in consecutive L_{Aeq}s are sent to the output data files labelled in the first subroutine.

4.3.4 Subroutine to send results to screen (6) and output file 'OUT.DAT' (99)

In this subroutine the small time period values of L_{Aeq}, rms, peak and $[L_{Aeq(i)} - L_{Aeq(i-1)}]$ are written in tabular form to the screen, device number 6, and to a FORTRAN output file 'OUT.DAT', device number 99. In addition, the results obtained in the previous subroutine are sent to these locations.

4.3.5 Program specification

Name of program: JIM1.FOR
To obtain a 'run', type '/JIM1' when in the DATS mode.

Language and location: FORTRAN, VAX 11/750
Faculty of Engineering, University of Southampton.

Error action: There are standard system error messages for the DATS package used. In addition, there are some methods to check for errors, although the program does not generate any error messges. For example:

(1) Input ranges for the small and large time periods are specified to the user by the program at the start of a 'run'.

(2) If the program is running correctly the small time period rms and L_{Aeq} values should be identical, although they are obtained by different methods.

Timing: The time for the program to run is dependent on the duration of the signal to be analysed. For the 10 second segments of signal used in this study, the approximate run time was 25 minutes.

Storage: Although the storage space occupied by the main program is relatively small (under 3k), a large amount of space is necessary to store the input data file, and the three output data files (almost 500k each).

4.4 A User Guide to Output Handling

The output from a 'run' of this FORTRAN program is available in two forms. The three output data files can be manipulated by any DATS files. Using the 'DISPLY' file discussed in Section 4.2, the input and output data files can be displayed graphically on the terminal screen. A hard copy of this graph can be obtained using PLOT command to create a VMS system PLOT file, which can be drawn by a high resolution plotter. Because of the high sampling rate and the relatively long duration of the signal sampled, the resolution between impulses is bad if the whole signal is considered. Therefore, only the first second of the signal is displayed. Figure 4.3 shows the raw signal, and the series of consecutive L_{Aeq} and $[L_{Aeq(i)} - L_{Aeq(i-1)})]$ values measured over a 10 ms time period, for the first second of the sampled signal. This sound comprised synthetic impulses with a 40 ms decay time repeating at a rate of 20 Hz. Figure 4.4 shows the raw signal, the L_{eq} and $[L_{Aeq(i)} - L_{Aeq(i-1)}]$ values, and the crest levels, for the same sound, measured over a small time period of 31.6 ms.

The FORTRAN file 'OUT.DAT' contains the tabulated results which are written to the terminal screen at the end of a program 'run'. A hard copy of these results can be obtained by printing this file. Appendix 4.2 is a printout of 'OUT.DAT' for the aforementioned synthetic sound. The large time period used was 0.5 second, the small time period was 10 ms, and the total duration of the signal was 10 seconds.

4.5 Summary.

Using the software package described in this chapter, the objective impulsive noise descriptors described in Section 3.5 were applied to all thirty-six sounds used in the laboratory experiment discussed in Chapter 5. A comparative analysis between the findings of the objective and subjective studies is performed in Chapter 6.

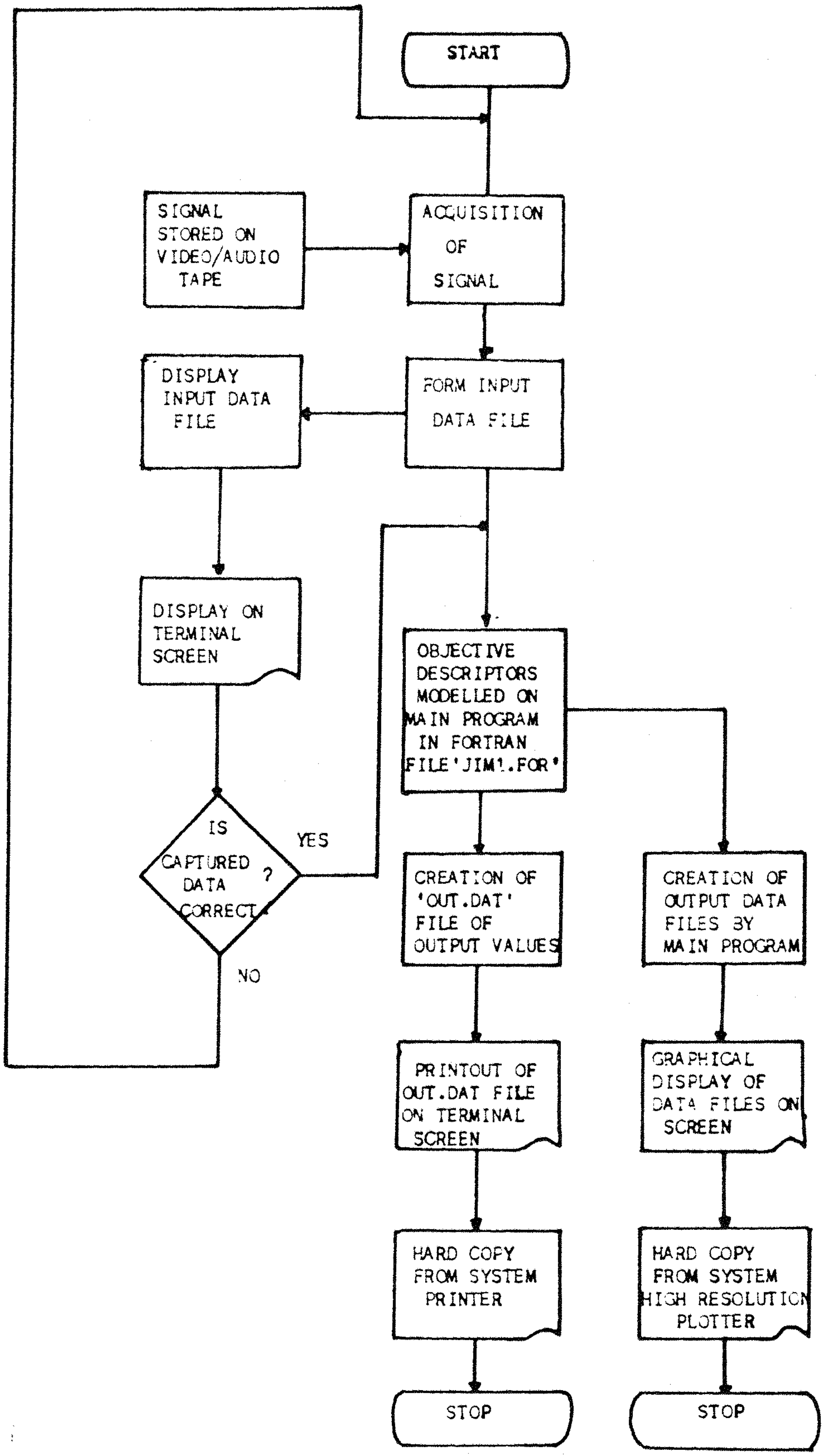

FIGURE 4.1. The software package structure.

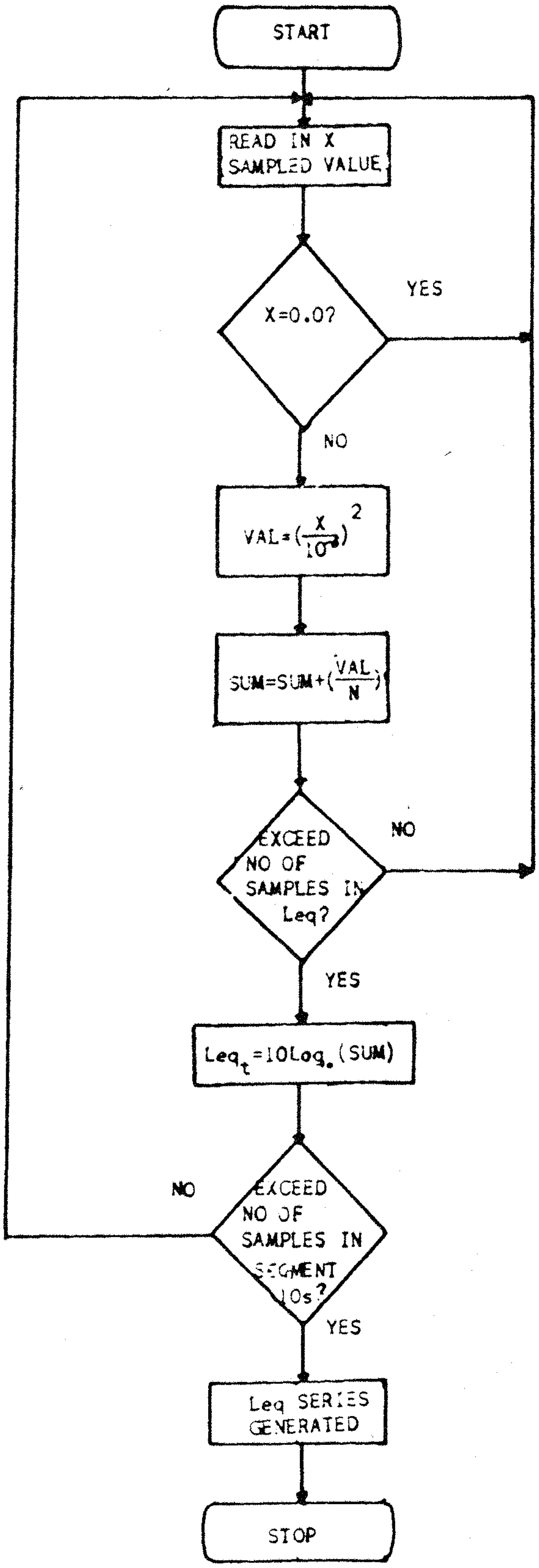

FIGURE 4.2 A simple flow diagram to illustrate the generation of the small time period L_{eq} series.

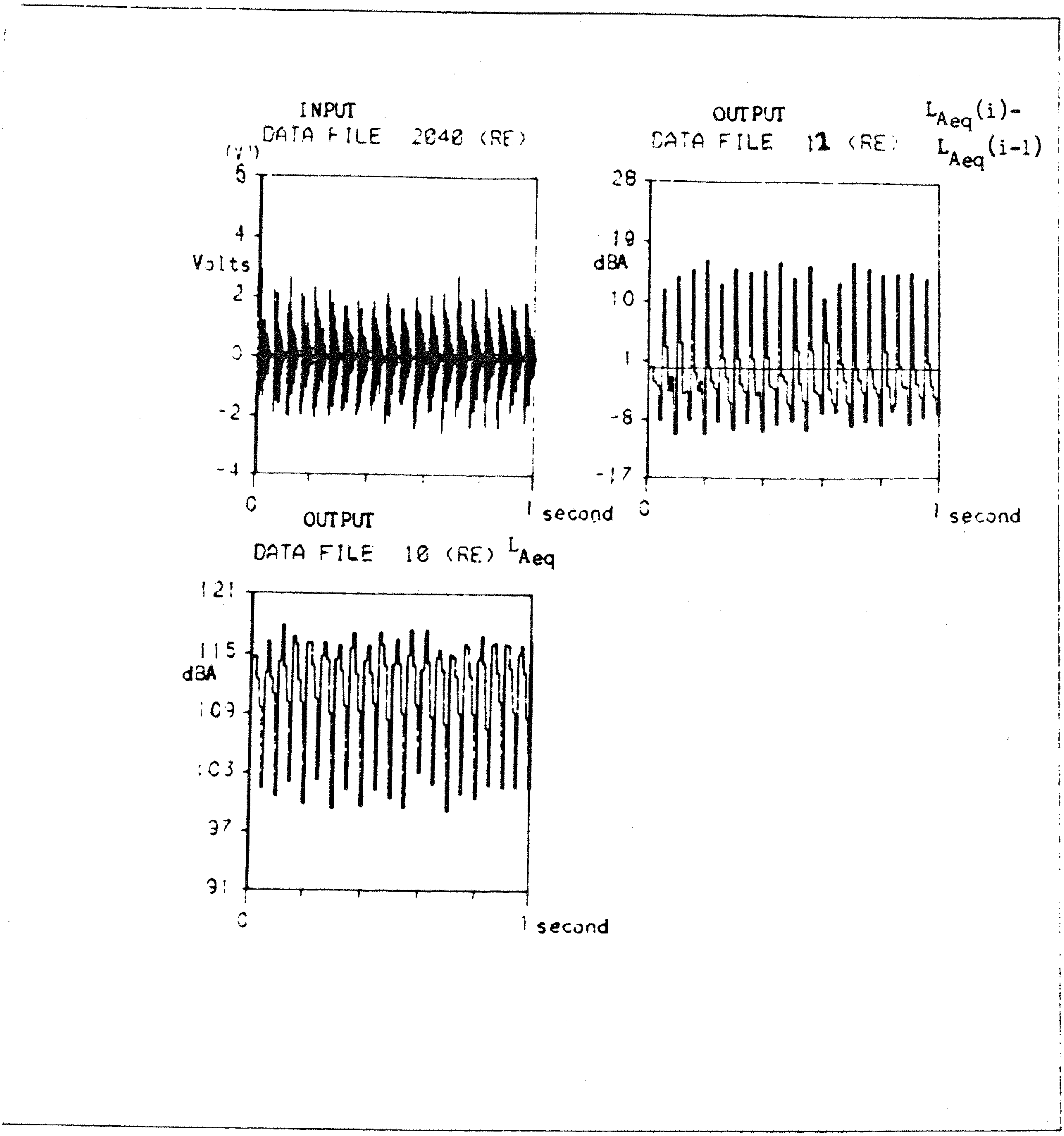

FIGURE 4.3. Plots of input and output data files.
Input signal; synthetic impulse sound (20 Hz repetition rate, 40 ms decay time). Small time period; 10 ms.

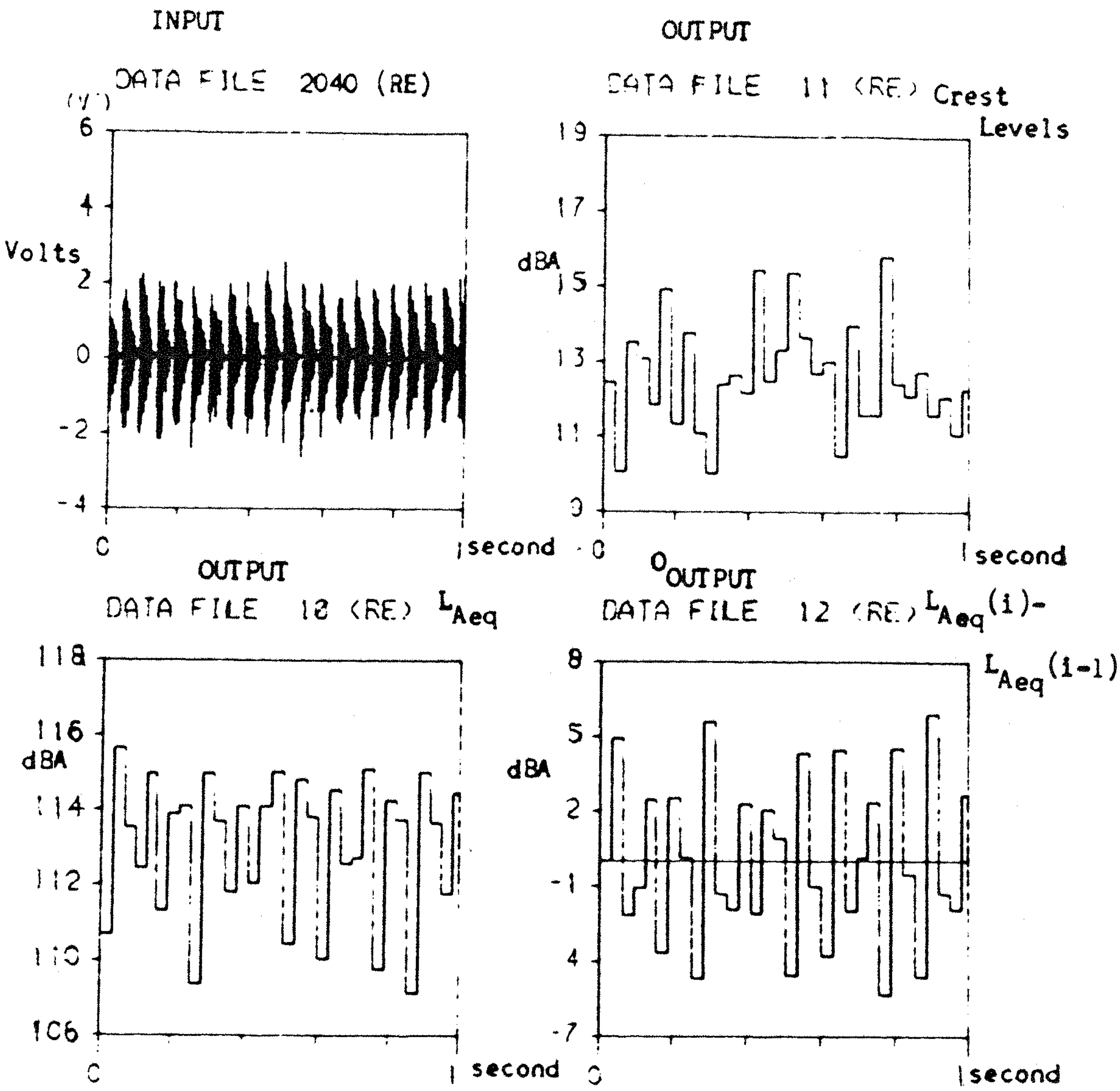

FIGURE 4.4 Plots of input and output data files. Input signal; synthetic impulse sound (20 Hz repetition rate, 40 ms decay time). Small time period; 31.6 ms.

CHAPTER 5

LABORATORY EXPERIMENT TO INVESTIGATE THE IMPULSIVENESS OF VARIOUS SYNTHETIC SOUNDS

5.1 Introduction

Previous experiments have been performed to rate the annoyance of impulsive noise. This study was undertaken by the author at the ISVR in an attempt to obtain a subjective assessment of the impulsive character (or impulsivity) of sounds.

The experiment consisted of subjects rating selected synthetic sounds comprising trains of impulses having different decay times and repetition rates. No account was taken of the level dependence of the sounds.

5.2 Method

5.2.1 Stimuli

Using a noise generator in conjunction with a gating network a pink noise carrier signal was modulated to give a repeating envelope with a rise time of less than 1 ms and a linear decay rate. Combinations of six repetition rates (2.5, 5, 10, 20, 40, 80 Hz) and six decay times (5, 10, 20, 40, 80, 160 ms) produced a total of thirty-six different sounds. Each decay time represented the period taken for the amplitude of the envelope to reach one-tenth of its maximum value. Examples of the sounds used are shown in Figure 5.1.

5.2.2 Apparatus

The signal leaving the gating network was passed through an exponential switch, in order to produce a smooth 'fade-in' and 'fade-out' at the beginning and end of each noise treatment period. After the necessary attenuation and amplification, the signal was presented to the subject via a KEF 101 series loudspeaker. The subject sat 2 m away from the loudspeaker in an anechoic room illustrated in Figure 5.2. Details of the frequency response of the room are given in Appendix 5.1. A Brüel and Kjaer measuring amplifier (type 2608) and a Scopex oscilloscope were used to monitor the sounds at a calibrated reference position in the room.

5.2.3 Experimental design

Thirty six subjects (25 males, 11 females) took part in the experiment. Subjects were checked for eligibility by use of a simple health questionnaire (Appendix 5.2) and audiometrically tested for 'normal' hearing (re ISO 389/1985). The experimental design was a 36 × 36 (SUBJECTS *vs* TREATMENTS) balanced Latin Square constructed according to the 1,2,n,3,n-1, etc. rule, each of the sounds being randomly assigned to one of the thirty-six treatments.

5.2.4 Experimental procedure

Before commencing the experiment, which had received approval from the ISVR Human Experimentation Safety and Ethics Committee, each subject was asked to complete a consent form and to read an instruction sheet (Appendix 5.3).

In order to clarify the concept of what constitutes an impulsive noise, examples of a clearly impulsive noise and a clearly non-impulsive noise was demonstrated before starting the experiment. As an additional guide, the definition of an impulsive noise as given in the British Standard BS4142 was included in the instruction sheet. However, it was stressed that it was the subject's personal judgement of the noise that was required.

Each of the noise treatments to be rated was heard for a period of 30 seconds, including fade-in and fade-out times both of 5 seconds. The subject was asked to wait until the end of this period before rating the sound. Three sets of twelve sounds were presented, with a period of 20 seconds between sounds in each set and of 60 seconds between sets. For each treatment the subjects were asked to indicate 'how impulsive you consider the noise character to be', using the scale below:

Not at all impulsive	0	1	2	3	4	5	6	7	8	9	Definitively impulsive character

All sounds were played at a constant maximum level and equivalent energy levels for all thirty-six sounds were in the range 46-69 dB L_{Aeq}.

A final question was asked after all the treatments had been heard in an attempt to dichotomise the subjective scale values into groups for impulsive and non-impulsive noises. The subject was asked 'in your view at what point on the scale of impulsivity would an impulsive noise become significantly more annoying than a non-impulsive noise of the same loudness'. The response was indicated on the same scale as used for the previous questions.

5.3 Results

5.3.1 Initial analysis of variance

The subjective scores for each of the thirty-six sounds are given in Appendix 5.4. However, instead of performing the complete analysis for a balanced Latin Square design, an analysis of variance using only the mean subjective score values shown in Table 5.1 was carried out. This ignores the subject and treatment variations making the assumption that repetition rate and decay time are the primary factors influencing subjective judgements.

Table 5.1: Mean subjective score values for the thirty-six sounds

Repetition rate (Hz)	Decay Time (ms) 5	10	20	40	80	160	SUM
2.5	8.138	8.000	8.000	8.056	8.306	8.028	48.528
5	7.861	8.111	8.000	7.890	8.000	7.278	47.140
10	7.750	8.030	7.750	7.305	6.722	5.222	42.779
20	6.639	6.889	6.833	6.333	4.528	2.389	33.611
40	5.889	5.389	5.028	3.194	1.139	0.500	21.139
80	4.417	3.083	2.250	0.778	0.361	0.250	11.139
SUM	40.694	39.502	37.861	33.556	29.056	23.667	204.336

The mean subjective score values (SSV) are plotted against repetition rate for each of the six decay times on Figure 5.3. From Table 5.1 the sums of squares can be calculated; the procedure used is given in John and Quenouille [45] and the analysis of variance is shown in Table 5.2.

Table 5.2: Analysis of variance for mean subjective score values

Source of variation	DOF	SS	MS	F	Sig
Repetition rate	5	191.492	38.298	37.169	1% level
Decay time	5	36.897	7.380	7.162	1% level
Residual	25	25.760	1.030		
Total	35	254.148			

Figure 5.3 indicates that a change in repetition rate for a constant decay time has a significant effect on the subjective judgement of some sounds, and Table 5.2 shows that this effect is significant at the 1% level. The decay time also has a significant effect on the mean subjective scores at the 1% level.

Only two independent factors have been considered in the analysis of variance; the repetition rate and the decay time. The interaction between these two factors is thus contained within the residual term. It is therefore not possible to quantify the degree of significance of the interaction without performing a full analysis on all individual subject scores.

An indication of the interaction is given in Figure 5.3, and is discussed further in Section 5.4.

5.3.2 Grouping of sounds

The standard error of the mean (SE) and the standard error of the difference of the means (SED) can be calculated from Table 5.2, giving values of 0.1692 and 0.2393 respectively. Obtaining t values from tables for the 5% level (2.031) and the 1% level (2.727) for a 'double-tailed' test enables the sounds to be sorted into significantly different groups. A difference between two means of 0.4860 (= 2.031 (SED)) indicates that they are significantly different from each other at the 5% level. A difference between two means of 0.6526 (= 2.727 (SED)) indicates that they are significantly different from each other at the 1% level.

All thirty-six sounds are grouped so that any sound is significantly different from any sounds in any other groups. Tables 5.3 and 5.4 show these groups for the 5% and 1% levels of significance respectively.

Table 5.3: Significantly different groups of sounds at the 5% level

Repetition rate (Hz)	Decay Time (ms) 5	10	20	40	80	160
2.5	A	A	A	A	A	A
5	A	A	A	A	A	A
10	A	A	A	A	A	B
20	A	A	A	A	C	E
40	A	B	B	D	F	F
80	C	D	E	F	F	F

Table 5.4: Significantly different groups of sounds at the 1% level

Repetition rate (Hz)	Decay Time (ms) 5	10	20	40	80	160
2.5	A	A	A	A	A	A
5	A	A	A	A	A	A
10	A	A	A	A	A	A
20	A	A	A	A	A	C
40	A	A	A	B	D	D
80	A	B	C	D	D	D

In answer to the question 'In your view at what point on the scale of impulsivity would an impulsive noise become significantly more annoying than a non-impulsive noise of the same loudness?' the mean subjective score given was 5.694 (denoted $\bar{a}$). Group A, formed at the 5% level of significance, consists exclusively of the sounds whose mean impulsivity SSVs exceed this value. Sounds within the other five groups have mean SSVs below this value. This indicates that subjects experience increased annoyance due to the impulsive character of the sounds in group A, but do not for any of the other sounds tested.

5.3.3 Dichotomised impulsivity scores

Each subject gave a rating in response to the question 'In your view at what point on the scale of impulsivity would an impulsive noise become more annoying than a non-impulsive noise of the same loudness', and this value will be denoted 'a'. The successive treatment scores, listed in Appendix 5.4, were then compared to this value for each subject in turn. If the impulsivity score for a sound exceeded, or was equal to 'a', the sound was rated '1'. If the impulsivity score was less than 'a', the sound was rated '0'. The revised ratings are given in Appendix 5.5.

The judgement by each subject for each sound has now been dichotomised so the ratings indicate whether or not a sound is judged to be more annoying than a non-impulsive sound of the same loudness. From Appendix 5.5 it is clear that some sounds, which from earlier analyses of SSVs could definitely be stated as being impulsive, are consistently rated '1' by most subjects. Similarly, some sounds which appear to be definitely non-impulsive are consistently rated '0'. For sounds whose impulsive character cannot be so clearly defined this is not the case. It is possible to perform further statistical analyses on these revised scores to see if they are the result of a chance binomial distribution, or if subjective choice is significantly influenced by the noise character. For this purpose the chi-squared (χ^2) test, recommended for 'goodness of fit' problems, and the Student t test, to test a sample mean with a population mean, have been used. Examples of the procedure in each case are given below.

t test for binomial distribution

Example: Synthetic sound with 20 Hz repetition rate and 40 ms decay time

Null hypothesis: distribution is binomial

Score	1	0	mean
Actual frequency	26	10	0.722
Binomial frequency	18	18	0.500

Degrees of freedom (DOF) = n - 1 = 35

Actual mean $(\bar{x})$ = 0.722

Binomial mean (μ) = 0.500

Standard deviation (s) = 0.4479

$$t = \frac{\bar{x} - \mu}{s/\sqrt{n}}$$

$$t = \frac{0.722 - 0.5}{0.4479/6}$$

$$t = 2.974$$

For a double-tailed test $(t_{35}(5\%)) = 2.03$
$(t_{35}(1\%)) = 2.73$

The t test rejects the null hypothesis that the subjects' judgements are binomially distributed at the 5% and 1% levels of significance.

χ^2 test for binomial distribution

Example: synthetic sound with 20 Hz repetition rate and 40 ms decay time
Null hypothesis: distribution is binomial

Score	1	0
Observed frequency (o_i)	26	10
Actual frequency (e_i)	18	18
$\lvert o_i - e_i \rvert$	8	8
$\lvert o_i - e_i \rvert^2$	64	64
$\frac{\lvert o_i - e_i \rvert^2}{e_i}$	3.556	3.556

DOF = n - 1 = 1

$$\chi^2 = \sum_{i=1}^{2} \frac{|o_i - e_i|^2}{e_i} = 7.111$$

For a double-tailed test $(\chi_1^2(5\%)) = 3.84$
$(\chi_1^2(1\%)) = 6.63$

The χ^2 test also rejects the null hypothesis that the scores are binomially distributed at the 5% and 1% levels of significance.

For either test, if the assumption of binomial distribution was rejected due to the predominance of '1' scores, as in the examples, the sound was classed 'I'. This infers that additional annoyance would result due to the impulsive character of the sound. If the assumption of binomial distribution is rejected due to the predominance of '0' scores, the sound was classed 'NI', inferring that its non-impulsive character would not evoke additional annoyance. However, some sounds cannot be classified in this way as the possibility of subjective scores being binomially distributed cannot be rejected. In this case the sounds are classed '-'. For each sound the t test and χ^2 test classifications, and the significantly different groups mentioned in the previous section at both the 5% and 1% levels of significance are listed in Table 5.5.

5.4 Discussion

From Figure 5.3 it can be seen that both the repetition rate and the decay time of a sound have a significant effect on the subjective judgement of the impulsive character of the sound. What is particularly evident is that for a sound consisting of impulses of a given decay time, subjective scale judgements decrease as the repetition rate increases. However, there is an interaction between these two parameters, and the range of repetition rates over which this decrease occurs is thus dependent on the decay time. The mean impulsivity score at which subjets experienced additional annoyance due to the impulsive character of a sound is denoted $\bar{a}$. The repetition rate at which this value occurs is plotted against each decay time in Figure 5.4. This indicates that the interaction at this point takes the form of an approximately reciprocal relationship, suggesting that the additional annoyance may result from sounds composed of clearly separated impulses with a very short rise time. Conversely, as the envelopes of consecutive impulses begin to overlap so the sound takes on a more continuous character, and is perceived by the listener as being less impulsive.

TABLE 5.5: Comparisons of the results of statistical analysis on impulsivity scores and dichotomised scores.

Repetition rate (Hz)	Decay time (ms)	SED groups 5% level	SED groups 1% level	χ^2 5% level	χ^2 1% level	t 5% level	t 1% level
2.5	5	A	A	I	I	I	I
	10	A	A	I	I	I	I
	20	A	A	I	I	I	I
	40	A	A	I	I	I	I
	80	A	A	I	I	I	I
	160	A	A	I	I	I	I
5	5	A	A	I	I	I	I
	10	A	A	I	I	I	I
	20	A	A	I	I	I	I
	40	A	A	I	I	I	I
	80	A	A	I	I	I	I
	160	A	A	I	I	I	I
10	5	A	A	I	I	I	I
	10	A	A	I	I	I	I
	20	A	A	I	I	I	I
	40	A	A	I	I	I	I
	80	A	A	I	I	I	I
	160	B	A	–	–	–	–
20	5	A	A	I	I	I	I
	10	A	A	I	I	I	I
	20	A	A	I	I	I	I
	40	A	A	I	I	I	I
	80	C	A	–	–	–	–
	160	E	C	NI	NI	NI	NI
40	5	A	A	–	–	–	–
	10	B	A	–	–	–	–
	20	B	A	–	–	–	–
	40	D	B	NI	NI	NI	NI
	80	F	D	NI	NI	NI	NI
	160	F	D	NI	NI	NI	NI
80	5	C	A	NI	–	–	–
	10	D	B	NI	NI	NI	NI
	20	E	C	NI	NI	NI	NI
	40	F	D	NI	NI	NI	NI
	80	F	D	NI	NI	NI	NI
	160	F	D	NI	NI	NI	NI

The effect of the repetition rate and decay time of the impulses on the subjective judgement of a sound can also be shown by sorting sounds into significantly different groups. This enables the effect of both factors on the subjective score values to be evaluated to within certain limits of statistical confidence. For example, from Table 5.3, it is clear that at the 5% level of significance all sounds comprising impulses with a 5 ms decay time fall into the same significantly different group (A), with one exception. This is the sound with impulses of a 5 ms decay time occurring at a repetition rate of 80 Hz. The division of sounds into such groups may well be associated with the listener's judgement of the apparent interaction between repetition rate and decay time which occurs in synthetic impulsive sounds.

Further analysis was performed by utilising the dichotomised scores obtained in the previous section. The groups indicated by these results are given in Table 5.5, and can be compared with the significantly different groups. Section 5.3.2 showed that group 'A', formed at the 5% level of significance, consisted exclusively of those sounds with mean impulsivity scores greaer than the $\bar{a}$ value. This is suggested as a tentative boundary, above which sounds appear to have an impulsive character. The results of t and χ^2 tests at the 5% level of significance show that all but one of these sounds (40 Hz repetition rate, 5 ms decay time) evoked increased annoyance as a result of their impulsive character. A 'grey' region of uncertainty exists where binomially distributed scores occurring from chance cannot be ruled out, and it is in this region that this sound falls. At this significance level, sounds from significantly different groups, 'D', 'E' and 'F', are classed in the region where no increased annoyance is induced by the sound and is hence used as a boundary for non-impulsive sounds. Figure 5.5 illustrates the regions of impulsivity, uncertainty and non-impulsivity, which can be defined by collating the results of all three methods of analysis given in Table 5.5 at the 5% level of significance.

At the 1% level of significance, the 'NI' ratings of sounds by the χ^2 and t tests equates with the 'B', 'C' and 'D' groups formed from SED analysis. This category is stated as non-impulsive. The remaining sounds have all been classed in the same significantly different group, 'A'. Those which are also rated 'I' by the t and χ^2 tests are classed as impulsive, whilst others fall into the uncertain 'grey' region. This is illustrated in Figure 5.6.

These boundaries defined for impulsive and non-impulsive sounds are conservative estimates. It may be that the precise boundary between impulsive and non-impulsive (continuous) noise lies within the 'grey' uncertain region. However, only boundaries constructed around sounds inferred to be clearly impulsive or clearly continuous by this experiment can be defined.

5.5 Conclusions

The main conclusions of this laboratory study were as follows:

(a) Both repetition rate and decay time of a sound have a significant effect on the subjective judgement of the sound's impulsivity.

(b) There is an interaction between repetition rate and decay time over the range of either factor studied.

(c) Subjects were asked where, on the scale of impulsivity, increased annoyance was experienced due to the impulsive character of the noise. The sounds with a mean SSV above this value formed an exclusive group at the 5% level of significance. The boundary of this group may constitute the dividing line between impulsive and other sounds if the definition of 'impulsive' is that used in previous work [17,18].

(d) The use of a question asking the subject to relate the impulsive character of sounds to the annoyance evoked, enables the subjective score values for impulsivity to be dichotomised to indicate whether or not the impulsivity of the sound causes increased annoyance. The results of further analysis using these values tentatively modify the initial boundary of impulsive sounds given in (c). Whilst this may still be applicable, slightly more conservative boundaries are also produced, as illustrated in Figures 5.5 and 5.6 for the 5% and 1% levels of significance, respectively. Within these boundaries, initial classification of sounds is substantiated by the analysis of these dichotomised scores. A 'grey' region of uncertainty is present, in which sounds cannot be clearly defined as impulsive or continuous. It is in this region that a true boundary must lie.

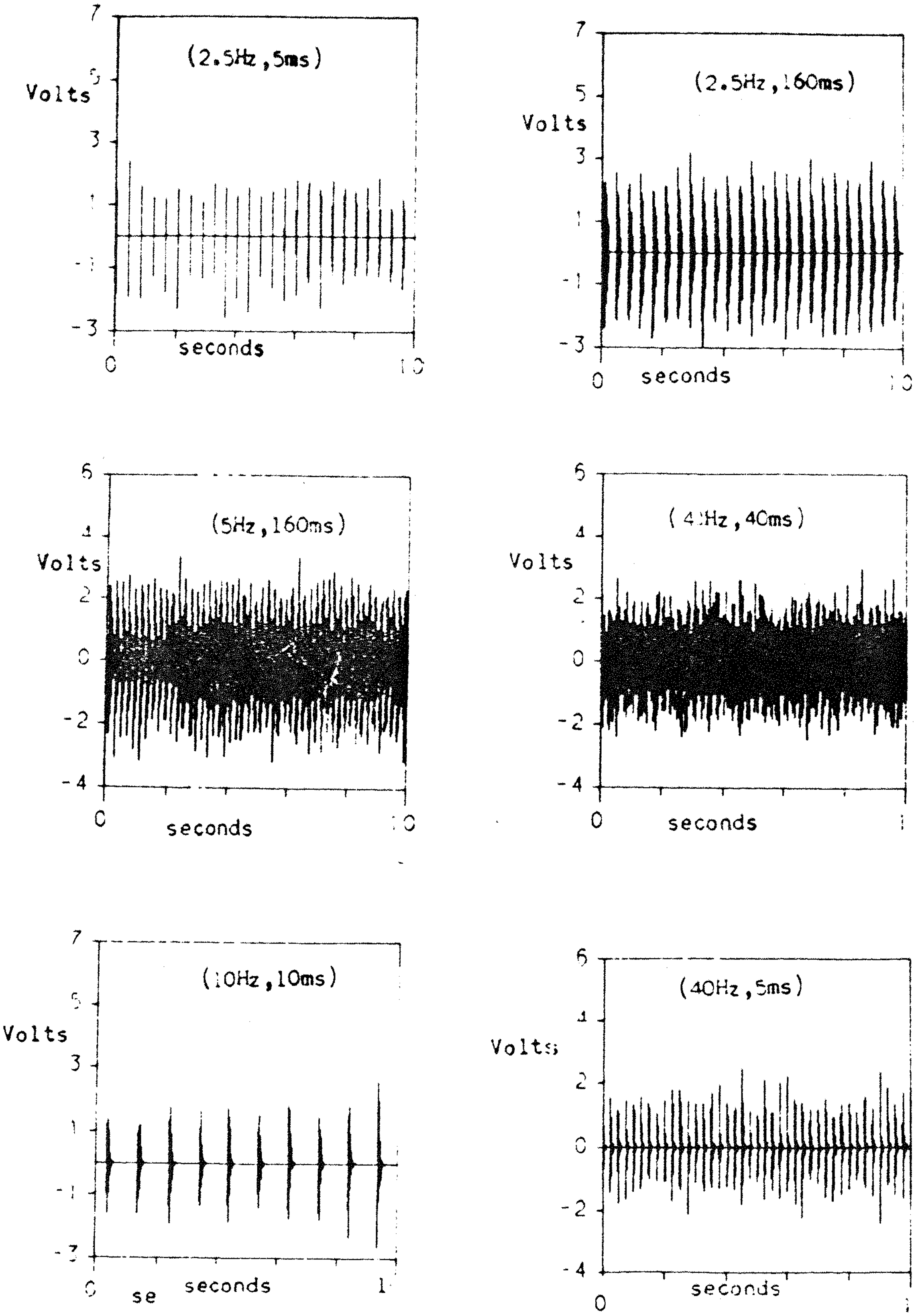

FIGURE 5.1. Examples of waveforms of synthetic sounds (repetition rate in Hz, decay time in ms).

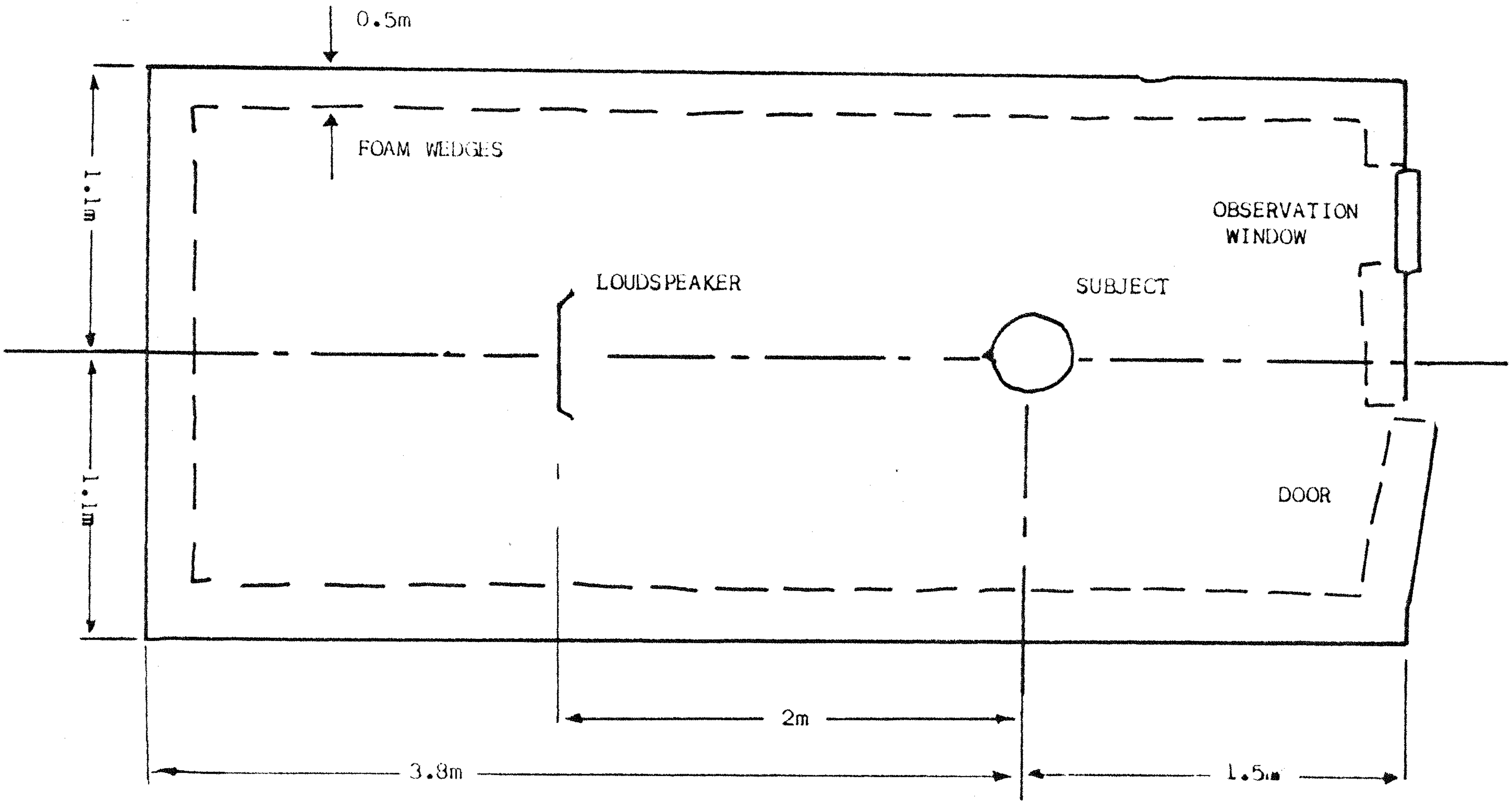

FIGURE 5.2. Listening facility in the anechoic room.

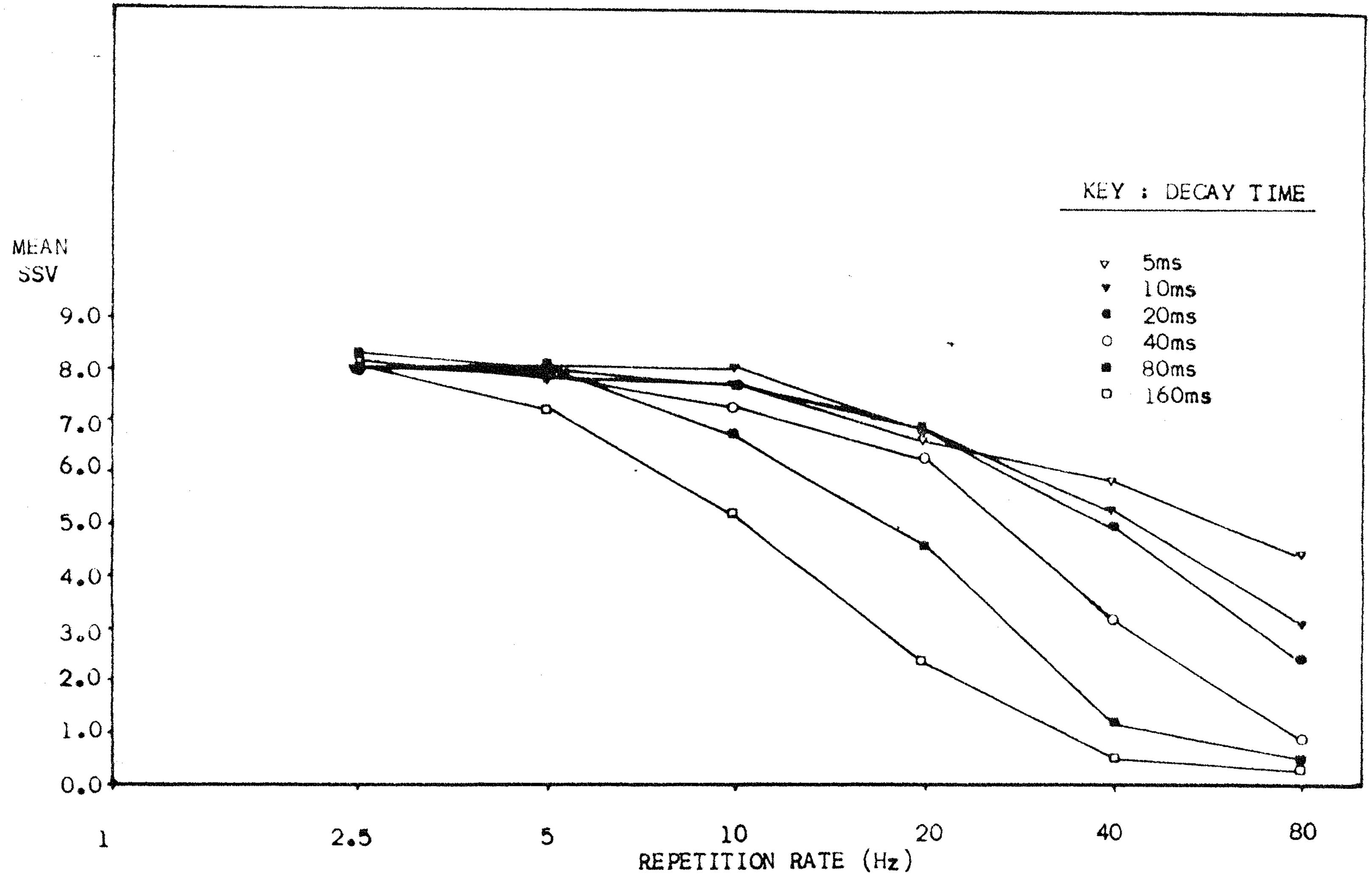

FIGURE 5.3. Graph of mean impulsivity SSVs against repetition rate, for all six decay times.

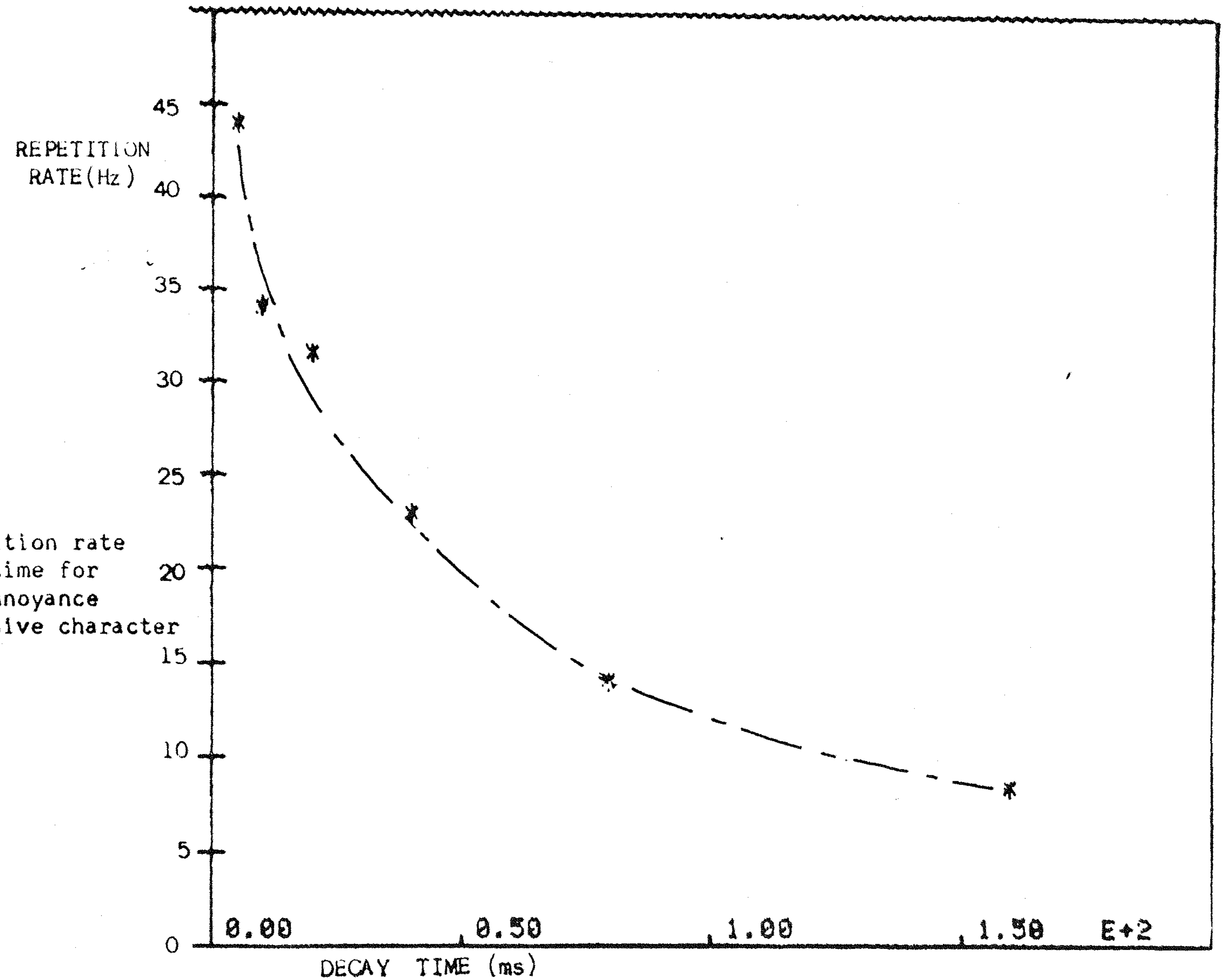

FIGURE 5.4. Plot of repetition rate against values of decay time for SSV at which increased annoyance occurs, due to the impulsive character of the synthetic sounds.

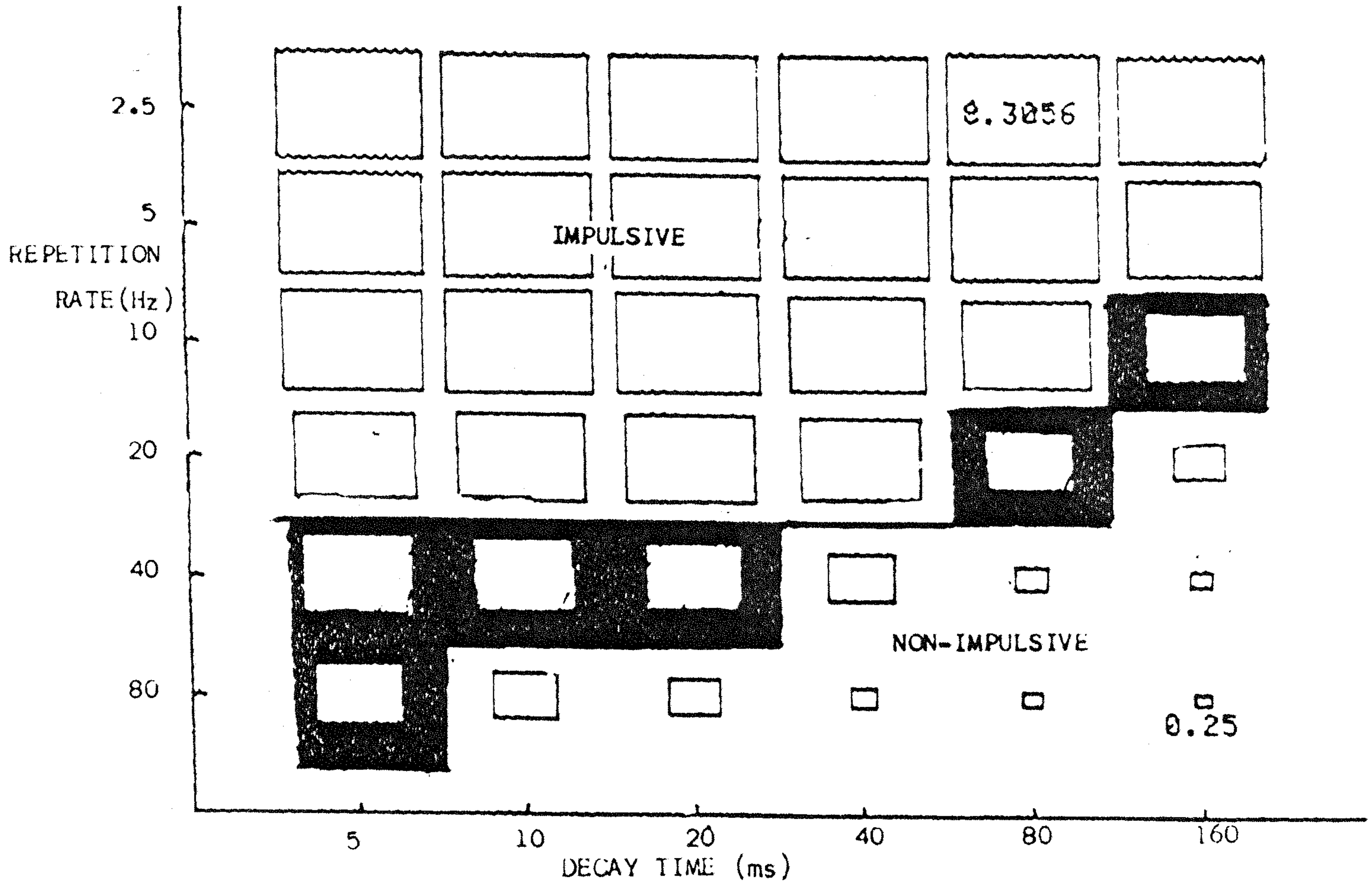

FIGURE 5.5 Rectangular plot of mean impulsivity SSVs for the synthetic sounds, illustrating the impulsive, non-impulsive, and 'grey' regions determined by the laboratory study results, at the 5% level of significance.

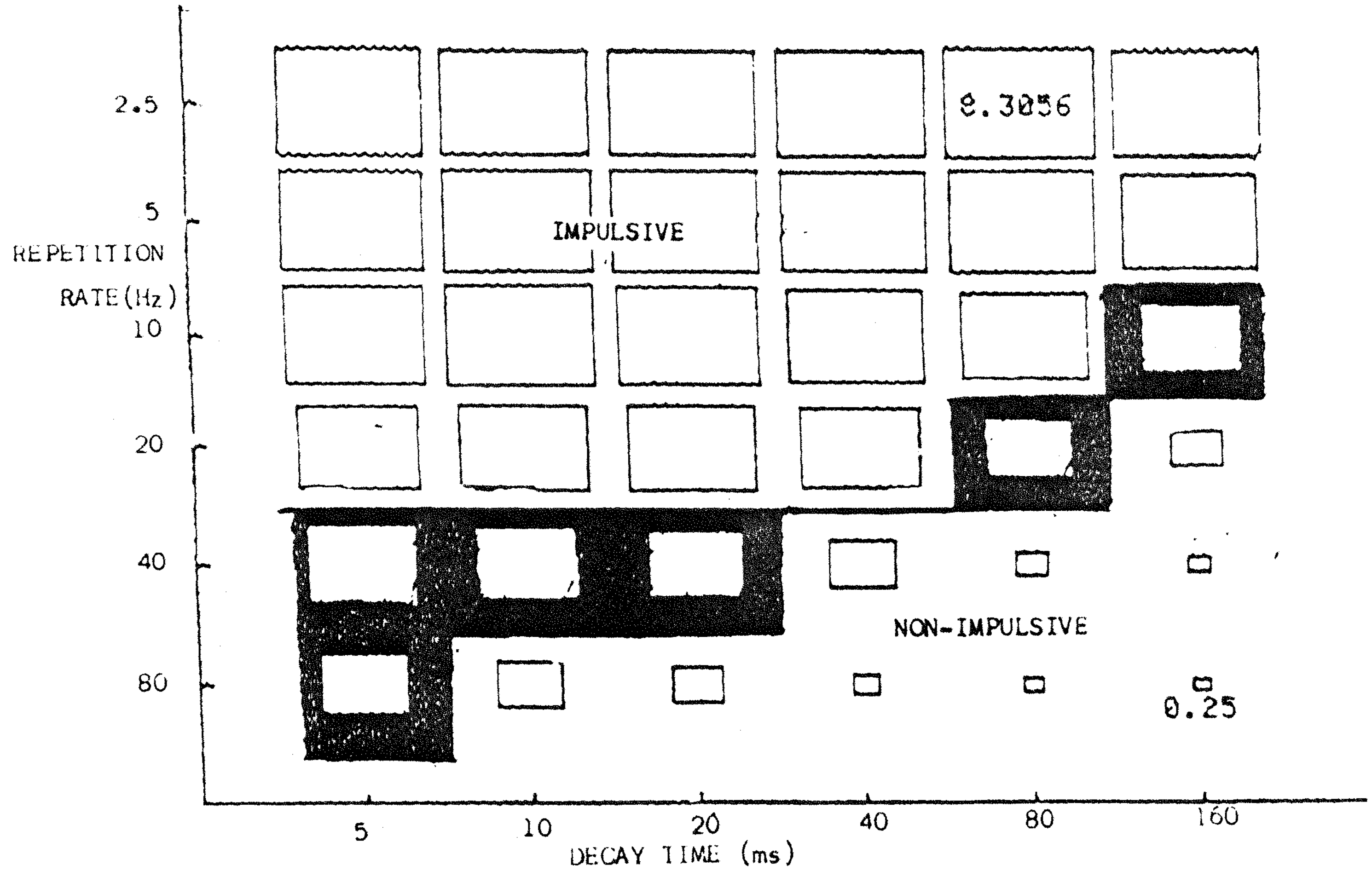

FIGURE 5.6 Rectangular plot of mean impulsivity SSVs for the synthetic sounds, illustrating the impulsive, non-impulsive, and 'grey' regions determined by the laboratory study results, at the 1% level of significance.

CHAPTER 6

COMPARATIVE ANALYSIS OF OBJECTIVE AND SUBJECTIVE STUDIES

6.1 Introduction

In this chapter, the objective measures for each of the impulsive noise descriptors modelled in the computer study are compared to the subjective judgements of sounds recorded in the laboratory. For each of the thirty-six sounds, the computed values of the objective descriptors obtained in Chapter 4 are listed in Table 6.1, together with the mean subjective score values (SSVs), from the experiment discussed in Chapter 5. The results of each descriptor are discussed separately in the next section. The effect of repetition rate and decay time on the objective measures is investigated, and comparisons are made between subjective and objective values for the sounds.

As discussed earlier in Chapter 2, one aim of the project is to obtain an objective method of defining whether or not a noise would subjectively be judged as impulsive. Therefore, what is required in addition to a good correlation between subjective and objective ratings, is ideally, some type of 'step' function, so that the objective descriptor clearly indicates a difference between sounds subjectively judged as impulsive and non-impulsive in character. This is illustrated in Figure 6.1. In practice this ideal case is unlikely to occur, as the results suggest that subjectively there exists a 'grey' region, and not a clear-cut boundary between impulsive and non-impulsive noise.

In order to investigate further the relationship between objective and subjective ratings, the spacing and ranking of sounds by these studies can be compared. The separation of sounds by each objective descriptor can be illustrated by forming significantly different groups using the measures. These groups are compared with those formed for the same sounds from subjective judgements which are given in Section 5.3.2. It is important that these groups rank in a similar order, rather than how the sounds rank within an individual group.

Table 6.1: Objective and subjective values for the synthetic sounds.

Rep. rate (Hz)	Decay time (ms)	Kurtosis (β)	Crest factor (dB(A))	NPL descriptor	Max Crest level dB(A) 10 ms	Max Crest level dB(A) 31.6 ms	K dB(A) 10 ms	K dB(A) 31.6 ms	SSV (mean)
2.5	5	291.17	36.62	20.48	22.66	20.50	41.31	34.96	8.138
	10	161.07	29.73	20.30	20.02	18.85	42.33	38.92	8.000
	20	82.52	21.03	18.76	23.13	19.00	45.97	41.03	8.000
	40	45.35	15.05	18.75	22.61	22.73	46.81	44.02	8.056
	80	22.83	11.18	16.15	15.24	18.21	41.37	40.02	8.306
	160	11.50	9.62	15.81	19.18	15.94	44.89	44.62	8.028
5	5	140.00	24.17	20.28	21.79	22.34	42.05	36.37	7.861
	10	78.03	20.17	17.80	22.37	20.44	44.81	38.36	8.111
	20	47.08	16.93	17.93	21.99	18.93	45.71	40.15	8.000
	40	22.94	11.62	17.13	21.34	19.69	44.08	40.99	7.890
	80	11.70	8.71	16.05	21.92	19.07	42.80	42.85	8.000
	160	5.91	7.20	15.13	22.10	18.43	43.96	30.37	7.278
10	5	73.33	17.51	16.79	18.15	22.39	40.49	34.41	7.750
	10	40.21	16.17	16.60	16.82	26.32	44.66	37.46	8.030
	20	21.37	11.79	16.85	23.37	20.09	44.86	41.38	7.750
	40	11.67	9.61	15.71	23.22	23.00	47.73	43.24	7.305
	80	5.88	7.07	15.04	21.62	21.84	40.82	16.28	6.722
	160	3.52	5.42	14.74	14.76	15.43	6.90	5.89	5.222
20	5	36.71	13.45	16.14	22.81	22.51	39.35	33.35	6.639
	10	19.80	12.08	15.76	23.19	26.41	40.73	32.29	6.889
	20	10.87	8.53	15.66	23.47	22.82	43.87	20.25	6.833
	40	5.63	6.35	14.89	20.95	17.92	26.39	6.97	6.333
	80	3.49	5.96	14.76	13.89	14.99	6.84	3.05	4.528
	160	3.09	4.85	14.64	12.41	13.67	4.14	2.18	2.389
40	5	17.81	11.19	15.05	23.25	20.10	38.90	6.48	5.889
	10	10.06	8.18	15.02	22.41	18.98	31.82	4.91	5.389
	20	5.39	5.95	14.76	17.98	16.80	13.66	3.80	5.028
	40	3.45	5.47	14.66	14.07	14.84	5.45	1.73	3.194
	80	3.09	4.96	14.63	13.09	13.56	3.75	1.71	1.139
	160	3.01	4.28	14.63	12.78	13.26	3.82	2.01	0.500
80	5	8.58	7.77	14.69	18.02	17.71	7.38	4.38	4.417
	10	4.85	6.01	14.63	14.94	15.86	5.09	2.88	3.083
	20	3.55	4.86	14.62	14.81	13.93	3.78	1.65	2.250
	40	3.04	4.60	14.63	13.16	13.25	4.92	1.65	0.778
	80	2.84	4.24	14.63	13.01	12.88	3.00	1.81	0.361
	160	2.98	4.60	14.64	12.84	13.20	2.63	1.59	0.250

6.2.1 A kurtosis measure

The objective measures of kurtosis given in Table 6.1 are plotted against repetition rate for each decay time in Figure 6.2. It can be seen that the decay time of the impulses is very influential on the kurtosis of the sounds with low repetition rates, but has little or no effect at higher repetition rates. This is confirmed by considering the analysis of variance of these objective results, given in Table 6.2.

Table 6.2: Analysis of variance for kurtosis measures

Due to	DoF	SS	MS = SS/DoF	F	Significance
Repetition rate	5	42436	8487	5.34	1% level
Decay time	5	35263	7053	4.44	1% level
Error	25	39719	1589		
TOTAL	35	117418			

The F test value must exceed $F_{5,25}(5\%) = 2.60$, for either factor to have a significant effect on the kurtosis measures at the 5% level of significance. The value must exceed $F_{5,25}(1\%) = 3.85$, for either factor to have a significant effect at the 1% level. Both the repetition rate and decay time of the impulses comprising the synthetic sounds have a significant effect at the 1% level. The significance of the interaction term between repetition rate and decay time cannot be quantified as this is contained within the residual term.

Figure 6.3 illustrates a scatter plot of the mean subjective values (SSV) against the kurtosis measures. Whilst the general trend is for a monotonic increase in subjective score within the range of objective values, the kurtosis measure makes no clear 'step' or boundary between impulsive and non-impulsive sounds. The criterion, given by Erdreich [34], of a kurtosis value of greater than 3.0 indicating a noise being impulsive, does not appear to be justified, as many sounds not judged impulsive in the laboratory study have values in excess of this. Indeed, pink (continuous) noise has a kurtosis value of 2.98, which is very close to this boundary.

From Table 6.2, the standard error of the differences of the means (SED) can be calculated to be 9.396. The significantly different groups for the 5% and 1% levels of significance are formed as in Section 5.3.2 and given in Tables 6.3 and 6.4 respectively. A sound in any one group is significantly different to the sounds in any other group.

Table 6.3: Significantly different groups for kurtosis measures of sounds at the 5% level of significance

		Decay time (ms)					
		5	10	20	40	80	160
Repetition rate (Hz)	2.5	A	B	D	E	E	E
	5	C	D	E	E	E	E
	10	D	E	E	E	E	E
	20	E	E	E	E	E	E
	40	E	E	E	E	E	E
	80	E	E	E	E	E	E

Table 6.4: Significantly different groups for kurtosis measures of sounds at the 1% level of significance

		Decay time (ms)					
		5	10	20	40	80	160
Repetition rate (Hz)	2.5	A	B	C	D	D	D
	5	B	C	D	D	D	D
	10	C	D	D	D	D	D
	20	D	D	D	D	D	D
	40	D	D	D	D	D	D
	80	D	D	D	D	D	D

The insensitivity of the kurtosis measures in highlighting the difference between sounds subjectively rated as impulsive or non-impulsive is illustrated by these tables. As can be seen, the measure can only separate sounds with very low repetition rates and short decay times into significantly different groups at either the 5% or 1% levels of significance. These groups do not correlate well with those formed in the subjective study, given in Tables 5.3 and 5.4.

It may be that some form of 'kurtosis-type' measure holds a solution to the problem of predicting the impulsivity of a noise. The method investigated in this project, however, must be dismissed as being too insensitive.

6.2.2 The NPL descriptor

The measures of an averaged value of the NPL impulsivity descriptor, I, given in Table 6.1, are plotted against repetition rate for each decay time in Figure 6.4. The analysis of variance for these objective values is shown in Table 6.5.

Table 6.5: Analysis of variance of NPL descriptor values

Due to	DoF	SS	MS = SS/DoF	F	Significance
Repetition rate	5	67.918	13.583	18.21	1% level
Decay time	5	23.518	4.704	6.31	1% level
Residual	25	18.642	0.746		
TOTAL	35	110.073			

Both the repetition rate and decay time of the impulses have a significant effect on the NPL descriptor measure at the 1% level of significance.

Figure 6.5 illustrates a scatter plot of the mean SSVs against the NPL measures, I. It can be seen that, whilst the subjective scores monotonically increase within the range of objective values, there is not a clear differentiation by the measure I, of those sounds subjectively judged impulsive and non-impulsive. This is emphasised if an attempt is made to separate the sounds into significantly different groups. From the analysis of variance the SED is computed to be 0.203. The groups for the 5% and 1% levels of significance are given in Tables 6.6 and 6.7, respectively.

Table 6.6: Significantly different groups for NPL descriptor measures of sounds at the 5% level of significance

		Decay time (ms)					
		5	10	20	40	80	160
Repetition rate (Hz)	2.5	A	A	B	B	E	E
	5	A	C	C	D	E	F
	10	D	D	D	E	F	F
	20	E	E	E	F	F	F
	40	F	F	F	F	F	F
	80	F	F	F	F	F	F

Table 6.7: Significantly different groups for NPL descriptor measures of sounds at the 1% level of significance

		Decay time (ms)					
		5	10	20	40	80	160
Repetition rate (Hz)	2.5	A	A	B	B	D	D
	5	A	C	C	D	D	D
	10	D	D	D	D	D	D
	20	D	D	D	D	D	D
	40	D	D	D	D	D	D
	80	D	D	D	D	D	D

These results show no clear distinction can be made between those sounds judged impulsive and those judged non-impulsive in the subjective study by grouping the sounds according to the NPL measures, at either level of significance. The groups formed do not correlate well with those calculated from the subjective scores and given in Tables 5.3 and 5.4.

6.2.3 A crest factor measure

The 10 second crest factor values of the synthetic sounds listed in Table 6.1 are plotted against repetition rate for each decay time in Figure 6.6. There is a clear resemblance between the plot of these values and that of the kurtosis measures, and indeed, Erdreich [34] indicates that a relationship may exist between these two descriptors.

The analysis of variance performed on the crest factor measures is given in Table 6.8 and shows that both the repetition rate and decay time have a significant effect on the objective values at the 1% level of significance.

Table 6.8: Analysis of variance of crest factor values

Due to	DoF	SS	MS = SS/DoF	F	Significance
Repetition rate	5	972.2	194.4	15.934	1% level
Decay time	5	723.9	144.8	11.869	1% level
Error	25	304.2	12.2		
TOTAL	35	2000.3			

The mean SSVs are plotted against the crest factors for the sounds in Figure 6.7. As in the two previous methods, the subjective scores monotonically increase within the range of objective values. However, there is no clear boundary between sounds subjectively judged as impulsive and non-impulsive. This objective measure appears to be too insensitive, and this can be illustrated further by analysis of the results using significantly different groups. The SED value is calculated from the analysis of variance to be 0.823, and from this the significantly different groups at the 5% and 1% levels can be calculated, and are given in Tables 6.9 and 6.10 respectively.

Table 6.9: Significantly different groups for the 10 second crest factor measures of sounds at the 5% level of significance

		Decay time (ms)					
		5	10	20	40	80	160
Repetition rate (Hz)	2.5	A	B	D	E	E	E
	5	C	D	E	E	E	E
	10	E	E	E	E	E	E
	20	E	E	E	E	E	E
	40	E	E	E	E	E	E
	80	E	E	E	E	E	E

Table 6.10: Significantly different groups for the 10 second crest factor measures of sounds at the 1% level of significance

		Decay time (ms)					
		5	10	20	40	80	160
Repetition rate (Hz)	2.5	A	B	D	E	E	E
	5	C	D	E	E	E	E
	10	E	E	E	E	E	E
	20	E	E	E	E	E	E
	40	E	E	E	E	E	E
	80	E	E	E	E	E	E

The groups formed at the 5% and 1% levels of significance are identical. Only a few of the sounds with low repetition rates and short decay times are separated from the majority, and the groupings provide no indication of any subjective boundary between impulsive and non-impulsive sounds. Consequently, these groups do not correlate well with those formed from the subjective study results, given in Tables 5.3 and 5.4.

6.2.4 Maximum Small Time Period Crest Levels

6.2.4.1 10 ms Time Period Measures

Somewhat confused relationships are produced if the maximum 10 ms crest levels are plotted against repetition rate for each decay time, illustrated in Figure 6.8. Although there is no easily visible trend, it is clear that both factors varied are influential on the objective measures. The analysis of variance, given in Table 6.11, shows that the repetition rate of the impulses has a significant effect on the maximum crest levels at the 1% level of significance. The decay time of the impulses has a significant effect at the 5% level.

Table 6.11: Analysis of variance of maximum 10 ms crest levels

Due to	DoF	SS	MS=SS/DoF	F	Significance
Repetition rate	5	208.93	41.79	4.99	1% level
Decay time	5	156.14	31.23	3.74	5% level
Residual	25	208.93	8.36		
TOTAL	35	573.99			

The mean SSVs are plotted against the maximum 10 ms crest levels in Figure 6.9. There is no clear distinction by this measure between those sounds subjectively judged as impulsive and non-impulsive. Indeed, some sounds subjectively judged as impulsive in the laboratory study are rated less impulsive by this descriptor than some subjectively judged as non-impulsive. From the analysis of variance, the SED value is 0.682. Tables 6.12 and 6.13 illustrate the significantly different groups at the 5% and 1% levels respectively.

Table 6.12: Significantly different groups for maximum 10 ms crest level measures of sounds at the 5% level of significance

		Decay time (ms)					
		5	10	20	40	80	160
Repetition rate (Hz)	2.5	A	A	A	A	B	A
	5	A	A	A	A	A	A
	10	A	A	A	A	A	A
	20	A	A	A	A	B	B
	40	A	A	A	B	B	B
	80	A	B	B	B	B	B

Table 6.13: Significantly different groups for maximum 10 ms crest level measures of sounds at the 1% level of significance

		Decay time (ms)					
		5	10	20	40	80	160
Repetition rate (Hz)	2.5	A	A	A	A	A	A
	5	A	A	A	A	A	A
	10	A	A	A	A	A	A
	20	A	A	A	A	A	A
	40	A	A	A	A	A	A
	80	A	A	A	A	A	A

The groups produced do not indicate any subjective boundary between impulsive and non-impulsive sounds, and the formation of all sounds into one group at the 1% level of significance illustrates the insensitivity of this measure. These groups do not correlate well with those for the subjective study results, given in Tables 5.3 and 5.4, at either level of significance.

6.2.4.2 31.6 ms Time Period Measures

Figure 6.10 is a graph of the maximum 31.6 ms crest levels against repetition rate for each decay time, and is similar to the plot obtained for the 10 ms values in Figure 6.8. The analysis of variance given in Table 6.14 indicates that both the repetition rate and decay time have a significant effect on the objective measure, at the 1% level of significance.

Table 6.14: Analysis of variance for maximum 31.6 ms crest levels

Due to	DoF	SS	MS	F	Significance
Repetition rate	5	204.29	40.86	8.86	1% level
Decay time	5	169.48	33.90	7.35	1% level
Residual	25	115.16	4.61		
TOTAL	35	488.93			

The mean SSVs are plotted against the max. 31.6 ms crest levels in Figure 6.11 and the scatter is similar to that obtained for the 10 ms crest levels illustrated in Figure 6.9. Again there is no clear distinction between those sounds subjectively judged as impulsive and non-impulsive. From the analysis of variance a value of SED of 0.506 can be obtained. The significantly different groups for the 5% and 1% levels of significance are illustrated in Tables 6.15 and 6.16 respectively.

Table 6.15: Significantly different groups for the maximum 31.6 ms crest level measures of sounds, at the 5% level of significance

		Decay Time (ms)					
		5	10	20	40	80	160
Repetition rate	2.5	C	C	C	B	C	C
(Hz)	5	B	C	C	C	C	C
	10	B	A	C	B	B	C
	20	B	A	B	C	C	C
	40	C	C	C	C	C	C
	80	C	C	C	C	C	C

Table 6.16: Significantly different groups for the maximum 31.6 ms crest level measures of sounds, at the 1% level of significance

		Decay Time (ms)					
		5	10	20	40	80	160
Repetition rate	2.5	B	B	B	B	B	B
(Hz)	5	B	B	B	B	B	B
	10	B	A	B	B	B	B
	20	B	A	B	B	B	B
	40	B	B	B	B	B	B
	80	B	B	B	B	B	B

The groups formed for the maximum 31.6 ms crest levels are similar to those for the 10 ms values, and do not illustrate the subjective difference between impulsive and non-impulsive sounds demonstrated in the laboratory studies. Hence, there is little correlation between the groups formed from this objective measure and those from the subjective study, given in Tables 5.3 and 5.4.

6.2.5 The K Descriptor

6.2.5.1 10 ms Time Period Measures

The values of $K_{10\ ms}$ for all the synthetic sounds are given in Table 6.1. In Figure 6.12 these are plotted against the repetition rate for each of the decay times. It is apparent that the majority of these objective measures lie within two relatively narrow ranges of values. This suggests that there may be some clear distinction between sounds, dependent on the repetition rate and decay time. The analysis of variance is given in Table 6.17 and shows that the repetition rate has a significant effect in the $K_{10\ ms}$ values at the 1% level of significance. The decay has a significant effect on the values at the 5% level.

Table 6.17: Analysis of variance for $K_{10\ ms}$ values

Due to	DoF	SS	MS	F	Significance
Repetition rate	5	7699.1	1539.8	15.52	1% level
Decay time	5	1485.0	297.0	2.994	5% level
Residual	25	2478.9	99.2		
TOTAL	35	11663.0			

The mean SSVs are plotted against the $K_{10\ ms}$ values in Figure 6.13. There is some indication of a 'step-like' division by the objective descriptor of the sounds into two principal clusters, denoting those sounds subjectively judged as impulsive and those subjectively judged as non-impulsive. From the analysis of variance of the measures, the SED value was calculated as 2.35. The significantly different groups for the 5% and 1% levels of significance are given in Tables 6.18 and 6.19, respectively.

Table 6.18: Significantly different groups for K_{10} ms measures of sounds at the 5% level of significance

		Decay Time (ms)					
		5	10	20	40	80	160
Repetition rate	2.5	A	A	A	A	A	A
(Hz)	5	A	A	A	A	A	A
	10	A	A	A	A	A	E
	20	A	A	A	C	E	E
	40	A	B	D	E	E	E
	80	E	E	E	E	E	E

Table 6.19: Significantly different groups for K_{10} ms measures of sounds at the 1% level of significance

		Decay Time (ms)					
		5	10	20	40	80	160
Repetition rate	2.5	A	A	A	A	A	A
(Hz)	5	A	A	A	A	A	A
	10	A	A	A	A	A	C
	20	A	A	A	B	C	C
	40	A	B	C	C	C	C
	80	C	C	C	C	C	C

At the 5% level of significance the groups of sounds formed correlate very well with those from the subjective study, described in Chapter 5. In the laboratory experiment, twenty-two sounds with the highest impulsivity scores form one significantly different group at the 5% level, denoted 'A' in Table 5.3. Of these sounds, twenty-one also form a significantly different group on the basis of the K_{10} ms measures, at the same level, denoted 'A' in Table 6.18. Only the synthetic sound comprising impulses with a decay time of 40 ms, occurring at a repetition rate of 20 Hz is excluded.

At the 1% level of significance, the groups from the subjective study given in Table 5.4 correlate well with those formed from the K_{10} ms values. However, only twenty-one of the twenty-seven sounds ranked in the highest group 'A' for impulsivity by the subjective study, form a significantly different group 'A' from analysis of the K_{10} ms measures.

6.2.5.2 31.6 ms Time Period Measures

The $K_{31.6}$ ms measures given in Table 6.1 are plotted against repetition rate for each decay time in Figure 6.14. As with the 10 ms values, the descriptor appears to separate the sounds into two narrow ranges of values. Decay time only has an influence on sounds with repetition rates between 10 Hz and 40 Hz, and this is reflected in the analysis of variance. Whilst the repetition rate has a significant effect on the measures at the 1% level of significance, Table 6.20 shows the decay time to have no significant effect at even the 20% level.

Table 6.20: Analysis of variance for $K_{31.6}$ ms values

Due to	DoF	SS	MS	F	Significance
Repetition rate	5	8587.5	1717.5	25.07	1% level
Decay time	5	647.8	129.6	1.892	
Residual	25	1712.0	68.5		
TOTAL	35	10947.3			

The mean SSVs are plotted against the $K_{31.6}$ ms measures in Figure 6.15, and illustrate how the descriptor differentiates between those sounds subjectively judged as impulsive and those judged non-impulsive. This is illustrated further by considering the significantly different groups formed. From the analysis of variance, the SED is found to be 1.95. Tables 6.21 and 6.22 show the significantly different groups for the $K_{31.6}$ ms measures of sound at the 5% and 1% levels of significance.

Table 6.21: Significantly different groups for $K_{31.6}$ ms measures of sounds at the 5% level of significance

		Decay Time (ms)					
		5	10	20	40	80	160
Repetition rate	2.5	A	A	A	A	A	A
(Hz)	5	A	A	A	A	A	A
	10	A	A	A	A	B	C
	20	A	A	B	C	C	C
	40	C	C	C	C	C	C
	80	C	C	C	C	C	C

Table 6.22: Significantly different groups for $K_{31.6\ ms}$ measures of sounds at the 1% level of significance

		Decay Time (ms)					
		5	10	20	40	80	160
Repetition rate	2.5	A	A	A	A	A	A
(Hz)	5	A	A	A	A	A	A
	10	A	A	A	A	B	C
	20	A	A	B	C	C	C
	40	C	C	C	C	C	C
	80	C	C	C	C	C	C

At the 5% level of significance, the groups correlate very well with those from the subjective study discussed in Chapter 5. Of the twenty-two sounds, with the highest impulsivity scores, which form one significantly different group in the subjective study, eighteen form an exclusive group, denoted 'A' from analysis of the $K_{31.6\ ms}$ measures.

At the 1% level of significance the groups from the subjective study correlate reasonably well with those for the $K_{31.6\ ms}$ measures given in Table 6.22, but only eighteen of the twenty-seven sounds classed in the group with the highest impulsivity scores in the subjective study are grouped together by analysis of the $K_{31.6\ ms}$ values.

6.3 Discussion

The previous section suggests the kurtosis, crest factor, crest level and NPL descriptor measures are all too insensitive and do not indicate the boundaries of impulsive and non-impulsive sounds, illustrated by the results of the subjective study. However, the $K_{10\ ms}$ and $K_{31.6\ ms}$ measures do give an indication of these subjective boundaries, and the significantly different groups formed from these objective measures correlate well with those from the laboratory study. More conservative boundaries were obtained in Section 5.4 by combining the significantly different groups and the analysis of the dichotomised subjective scores. Three regions were defined: impulsive sounds, non-impulsive sounds, and a grey region of uncertainty where sounds could not be clearly classified. Further analysis will now be performed by comparing these subjective classifications of the sounds to the objective measures of the K descriptors, in an attempt to obtain criteria for impulsivity.

Table 6.23 lists the sounds ranked in order of decreasing K_{10} ms values, together with the groups given in Tables 6.18 and 6.19 and the subjective classifications. All sounds with a K_{10} ms value of 39.35 or greater were rated impulsive (I) by the subjective study, at both the 5% and 1% levels of significance. These sounds are all rated in the same significantly different group (A) by the objective measure at either level. Only one sound of the twenty-one rated impulsive in the subjective study has a K_{10} ms value of less than 39.35. This is the synthetic sound (40 ms decay time, 20 Hz repetition rate) which has a value of 26.39. A value greater or equal to 26.3 is suggested as a criterion for objectively describing impulsive noise, twenty-three of the thirty-six sounds involved in the study will be classed as impulsive. These contain the twenty-one sounds rated as impulsive (I) in the subjective study, together with two sounds from the 'grey' region (-). This criterion is illustrated on the scatter plot in Figure 6.13.

Table 6.23 also shows that all these sounds subjectively ranked as non-impulsive (NI) in Chapter 5 have a K_{10} ms value of 5.45 or less, and are rated within the same significantly different group for the objective values, at the 5% and 1% levels of significance. A value of K_{10} ms ≤ 5.5 is suggested as a criterion for defining non-impulsive noise. This criterion is also illustrated on Figure 6.13.

Table 6.24 lists the sounds ranked in order of decreasing $K_{31.6}$ ms values, together with the significantly different groups for these objective measures, and the classifications from the subjective study. All those sounds with a $K_{31.6}$ ms value of 6.97 or greater are exclusively classed as impulsive by the subjective study. Of these twenty-one sounds, eighteen form one significantly different group (A), at both the 5% and 1% levels of significance. The results thus suggest a criterion for impulsive noise of a $K_{31.6}$ ms value of 6.9 or greater. This is illustrated on Figure 6.15.

All nine sounds classed as non-impulsive from the subjective study have $K_{31.6}$ ms values of 2.88 or less, and form the same significantly different groups for these objective measures at both the 5% and 1% levels of significance. The suggested criterion of a $K_{31.6}$ ms value of less than or equal to 2.9 indicating a non-impulsive noise, is illustrated on Figure 6.15.

Table 6.23 Comparison between subjective and $K_{10\ ms}$ measures

Repetition rate (Hz)	Decay time (ms)	Subjective Groupings 5% level	Subjective Groupings 1% level	K_{10} ms	Objective Groupings 5% level	Objective Groupings 1% level
10	40	I	I	47.73	A	A
2.5	40	I	I	46.81	A	A
2.5	20	I	I	45.97	A	A
5	20	I	I	45.71	A	A
2.5	160	I	I	44.89	A	A
10	20	I	I	44.86	A	A
5	10	I	I	44.81	A	A
10	10	I	I	44.66	A	A
5	40	I	I	44.08	A	A
5	160	I	I	43.96	A	A
20	20	I	I	43.87	A	A
5	80	I	I	42.80	A	A
2.5	10	I	I	42.33	A	A
5	5	I	I	42.05	A	A
2.5	80	I	I	41.37	A	A
2.5	5	I	I	41.31	A	A
10	80	I	I	40.82	A	A
20	10	I	I	40.73	A	A
10	5	I	I	40.99	A	A
20	5	I	I	39.35	A	A
40	5	–	–	38.90	A	A
40	10	–	–	31.82	B	B
20	40	I	I	26.39	C	B
40	20	–	–	13.66	D	C
80	5	–	–	7.38	E	C
10	160	–	–	6.90	E	C
20	80	–	–	6.84	E	C
40	40	NI	NI	5.45	E	C
80	10	NI	NI	5.09	E	C
80	40	NI	NI	4.92	E	C
20	160	NI	NI	4.14	E	C
40	160	NI	NI	3.82	E	C
80	20	NI	NI	3.78	E	C
40	80	NI	NI	3.75	E	C
80	80	NI	NI	3.00	E	C
80	160	NI	NI	2.63	E	C

Table 6.24 Comparison between subjective and $K_{31.6}$ ms measures

Repetition rate (Hz)	Decay time (ms)	Subjective Groupings 5% level	Subjective Groupings 1% level	$K_{31.6}$ ms	Objective Groupings 5% level	Objective Groupings 1% level
2.5	160	I	I	44.62	A	A
2.5	40	I	I	44.02	A	A
10	40	I	I	43.24	A	A
5	80	I	I	42.85	A	A
10	20	I	I	41.38	A	A
2.5	20	I	I	41.03	A	A
5	40	I	I	40.99	A	A
5	20	I	I	40.15	A	A
2.5	80	I	I	40.02	A	A
2.5	10	I	I	38.92	A	A
5	10	I	I	38.36	A	A
10	10	I	I	37.46	A	A
5	5	I	I	36.37	A	A
2.5	5	I	I	34.96	A	A
10	5	I	I	34.41	A	A
20	5	I	I	33.35	A	A
20	10	I	I	32.29	A	A
5	160	I	I	30.37	A	A
20	20	I	I	20.25	B	B
10	80	I	I	16.28	B	B
20	40	I	I	6.97	C	C
40	5	–	–	6.48	C	C
10	160	–	–	5.89	C	C
40	10	–	–	4.91	C	C
80	5	–	–	4.38	C	C
40	20	–	–	3.80	C	C
20	80	–	–	3.05	C	C
80	10	NI	NI	2.88	C	C
20	160	NI	NI	2.18	C	C
40	160	NI	NI	2.01	C	C
80	80	NI	NI	1.81	C	C
40	40	NI	NI	1.73	C	C
40	80	NI	NI	1.71	C	C
80	20	NI	NI	1.65	C	C
80	40	NI	NI	1.65	C	C
80	160	NI	NI	1.59	C	C

Between these objective boundaries for impulsive and non-impulsive noise lay those sounds which are subjectively judged to be in the grey region discussed in Chapter 5. It would appear that the larger the K value over which this grey region extends, the clearer the distinction beween the criteria for impulsive and non-impulsive sound. For the K_{10} ms measure this grey region extends over 20 dB, whereas for the $K_{31.6}$ ms measure the value is under 5 dB. It must be noted that these proposed boundaries may have to be altered to incorporate the results of any further analysis of synthetic or real-life sounds.

From the respective analysis of variance and significantly different groups, it is interesting to note that the size of the time period used to calculate the K measure appears to influence the effect that the decay time of a synthetic sound has on this objective descriptor.

6.4 Conclusions

The main conclusions of this comparative analysis are as follows:

(i) The K descriptor measured over either the 10 ms or 31.6 ms time period provides the best indication of the subjective evaluation of the impulsivity of a noise.

(ii) The best correlation between objective and subjective groupings of sounds is provided by the K_{10} measure at both the 5% and 1% levels of significance. Of the twenty-two sounds classed as impulsive (I) by the subjective study, twenty-one are within the significantly different group (A) formed for the highest value of K_{10} ms objective measures at either level of significance.

(iii) For the K_{10} ms measure the following criteria can be defined:

K_{10} ms $\geqslant$ 26.3 – constitutes an impulsive sound

26.3 $>K_{10}$ ms $>$5.5 – constitutes the 'grey' region, where sounds cannot be clearly classified by this study

K_{10} ms $\leqslant$ 5.5 – constitutes a non-impulsive sound

(iv) For the $K_{31.6\,ms}$ measure the following criteria can be defined:

$K_{31.6\,ms} \geq 6.9$ – constitutes an impulsive sound

$6.9 > K_{31.6\,ms} > 2.9$ – constitutes the 'grey' region, where sounds cannot be clearly classified by this study

$K_{31.6\,ms} \leq 2.9$ – constitutes a non-impulsive sound

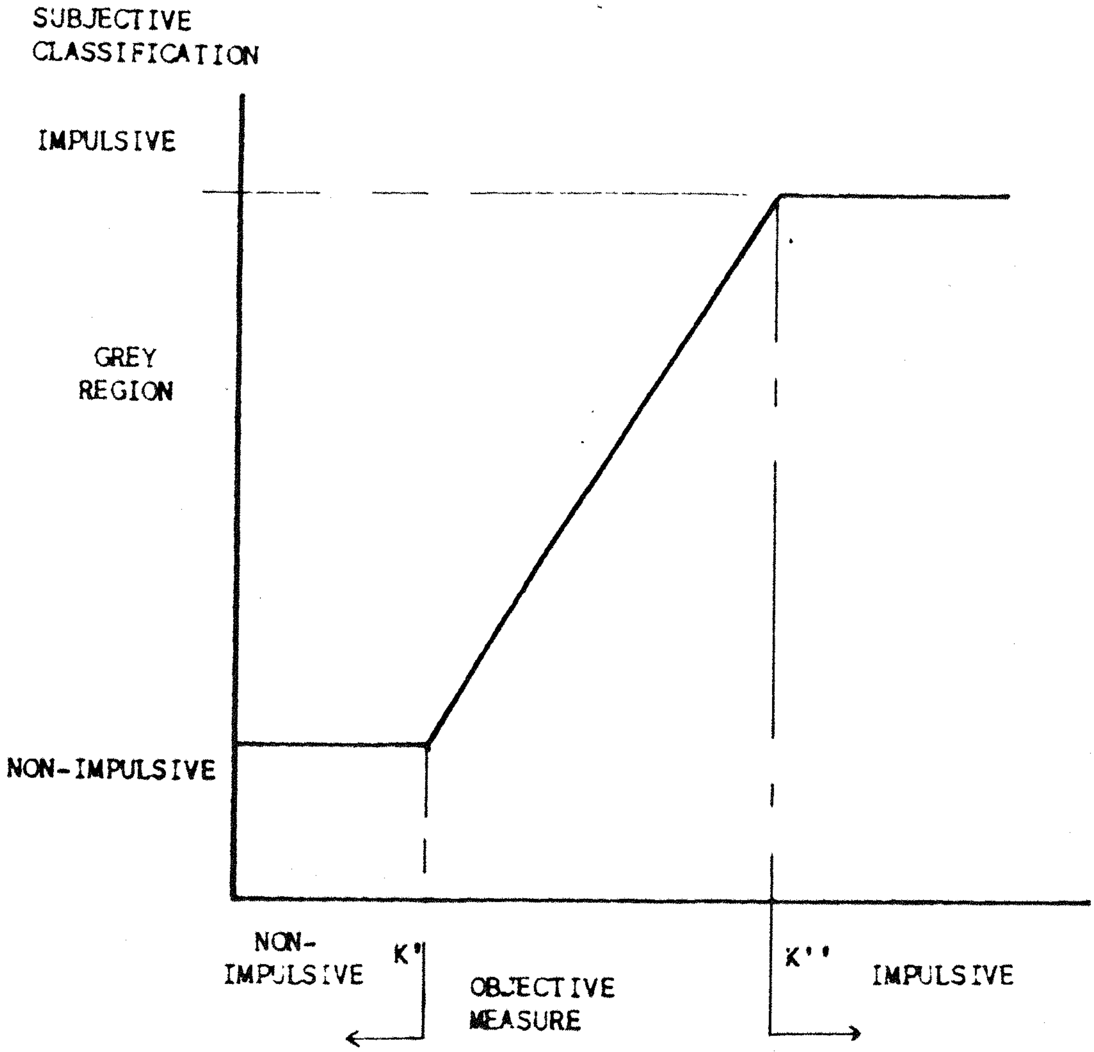

FIGURE 6.1. Subjective impulsivity classifications against objective measures, for an ideal impulsivity descriptor.

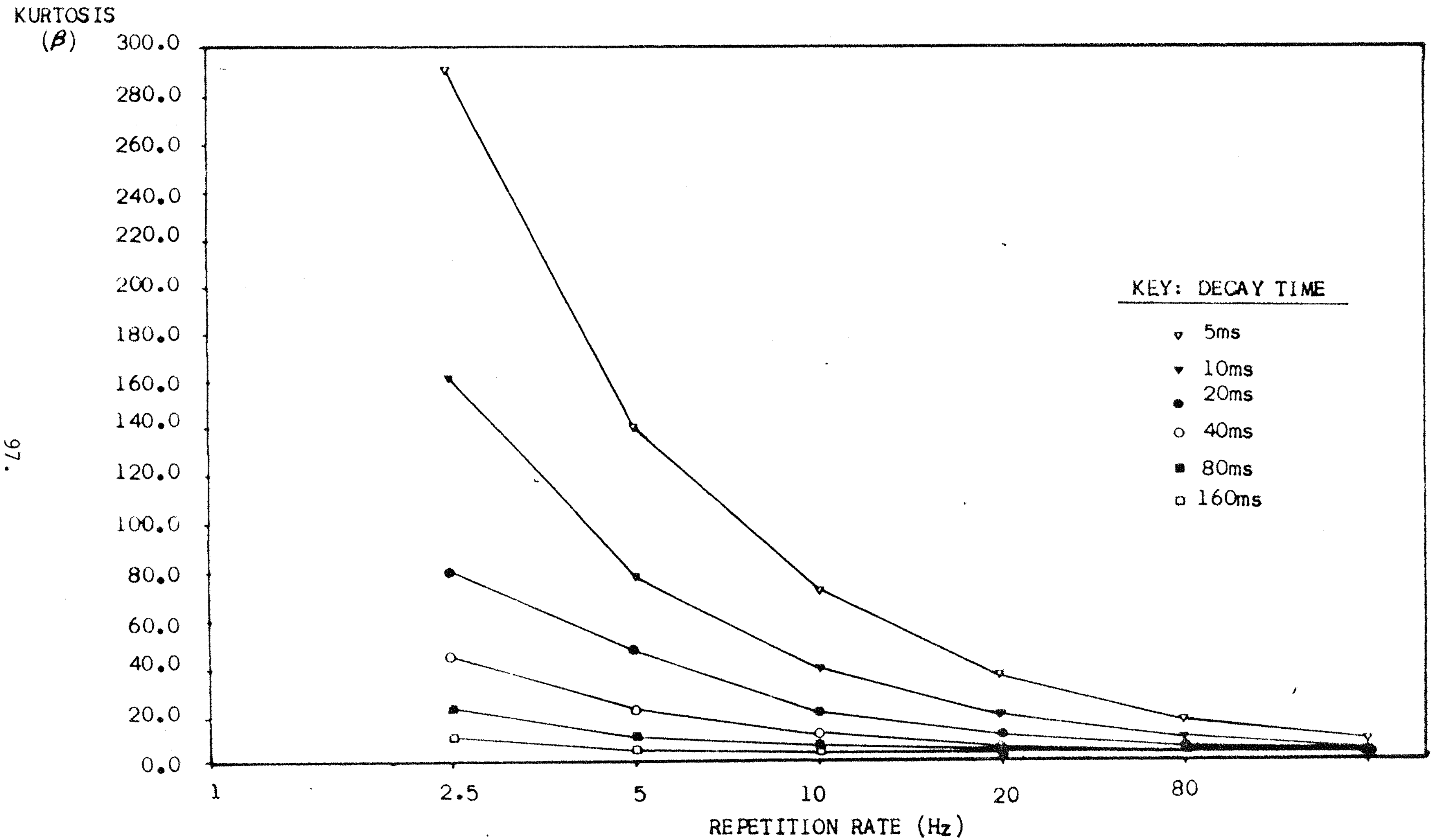

FIGURE 6.2. Graph of NPL Descriptor measures against repetition rate, for all decay times.

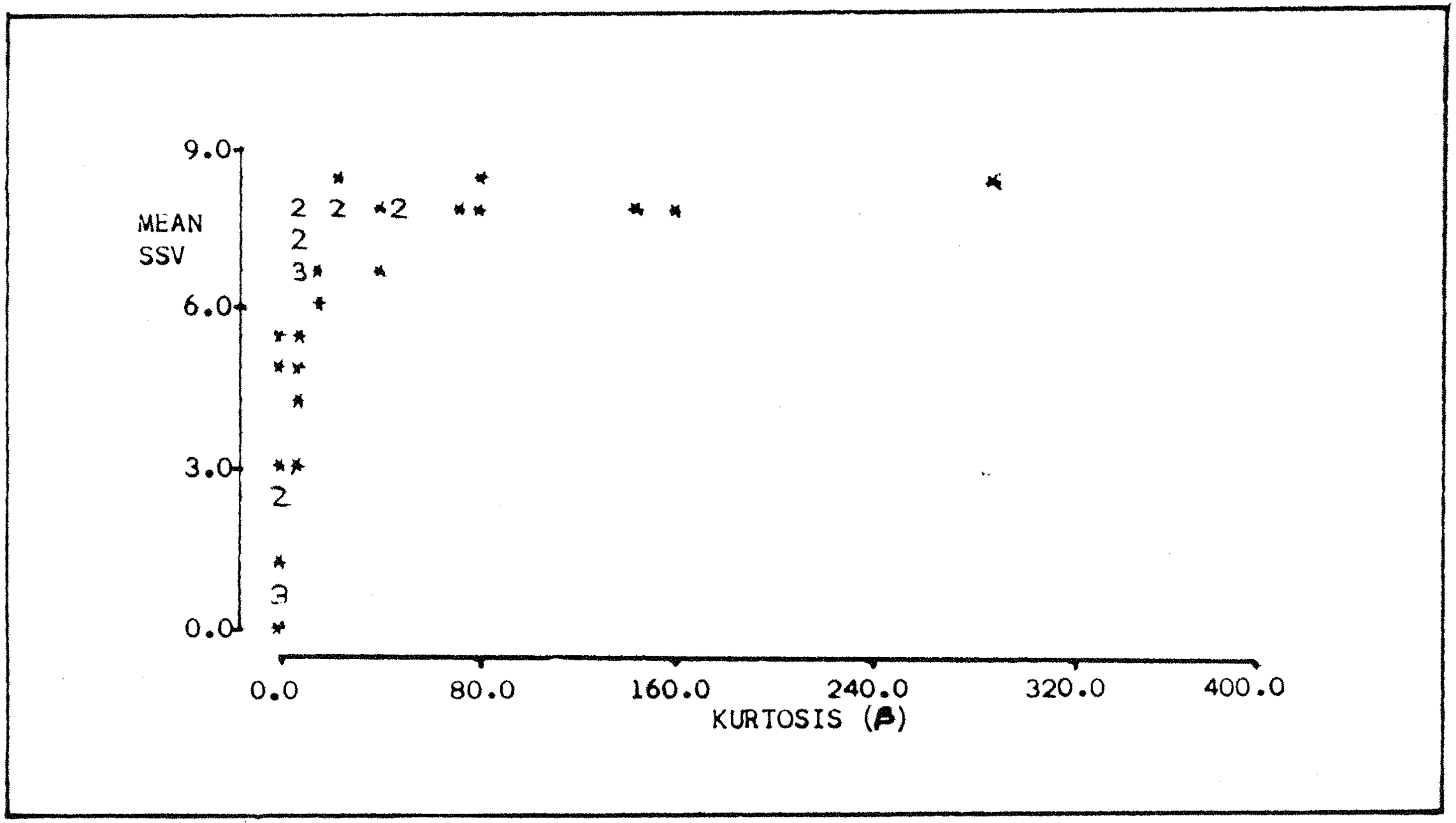

FIGURE 6.3. Scatter plot of mean impulsivity SSVs against Kurtosis measures.

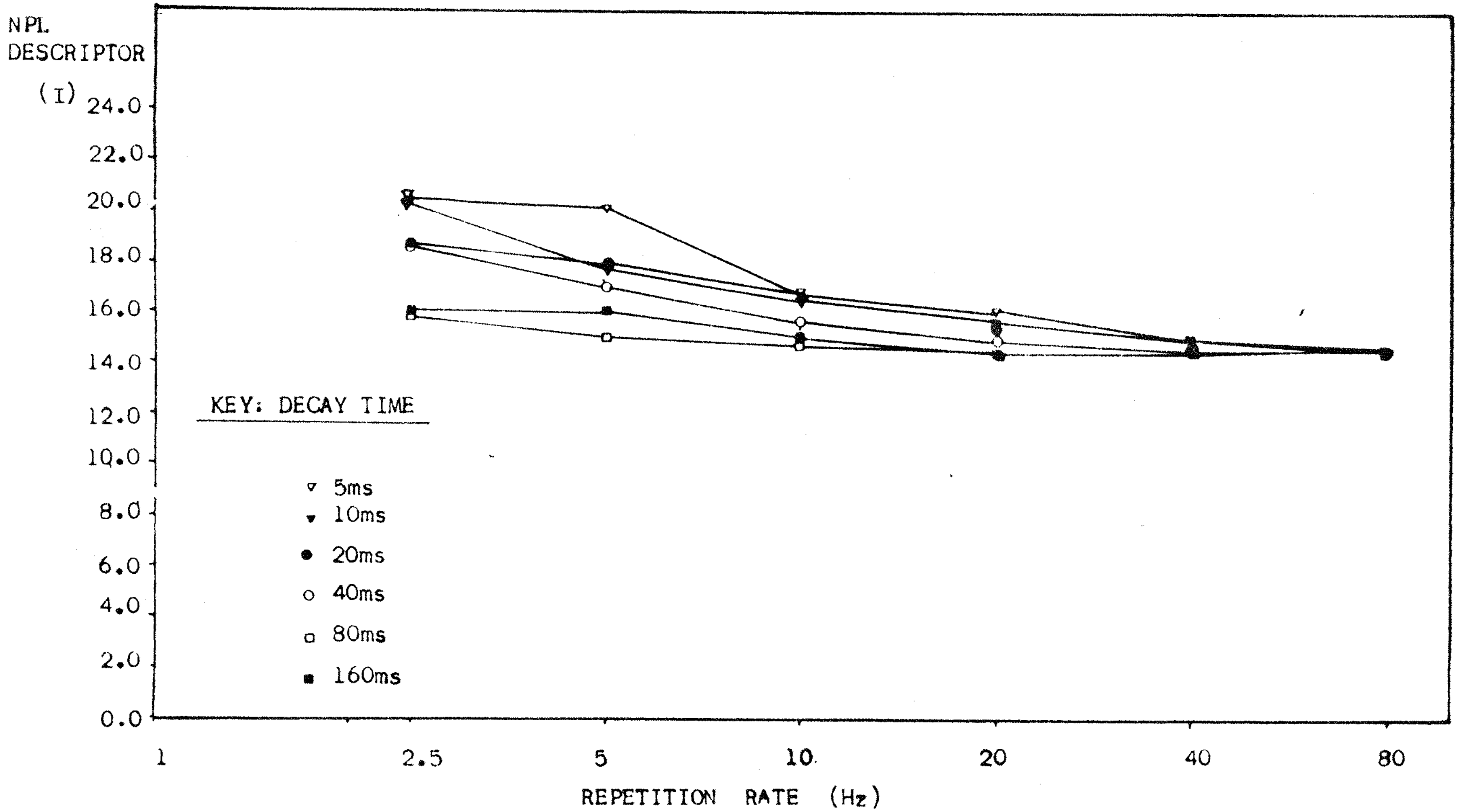

FIGURE 6.4. Graph of NPL Descriptor measures against repetition rate, for all decay times.

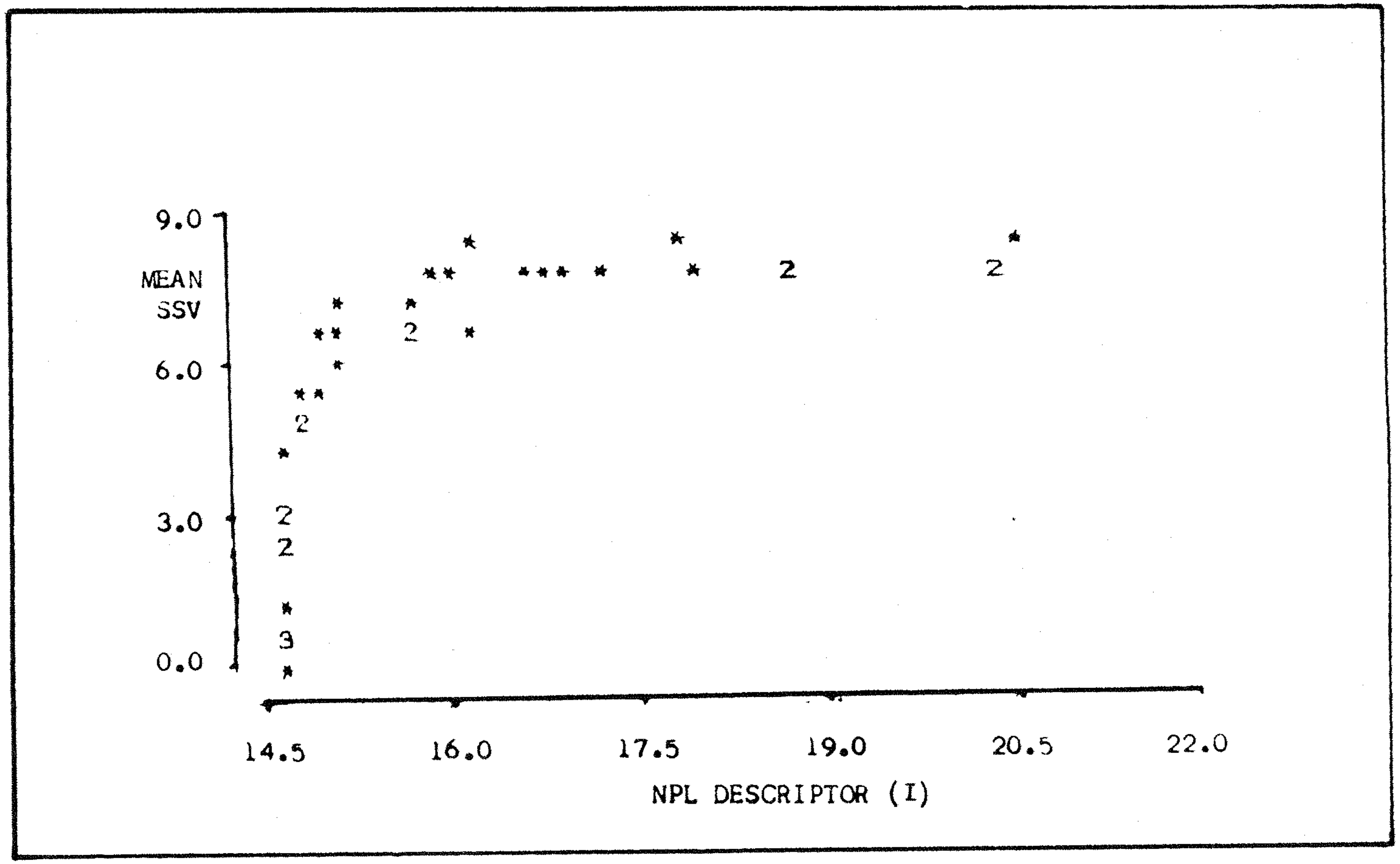

FIGURE 6.5 Scatter plot of mean impulsivity SSVs against NPL descriptor measures.

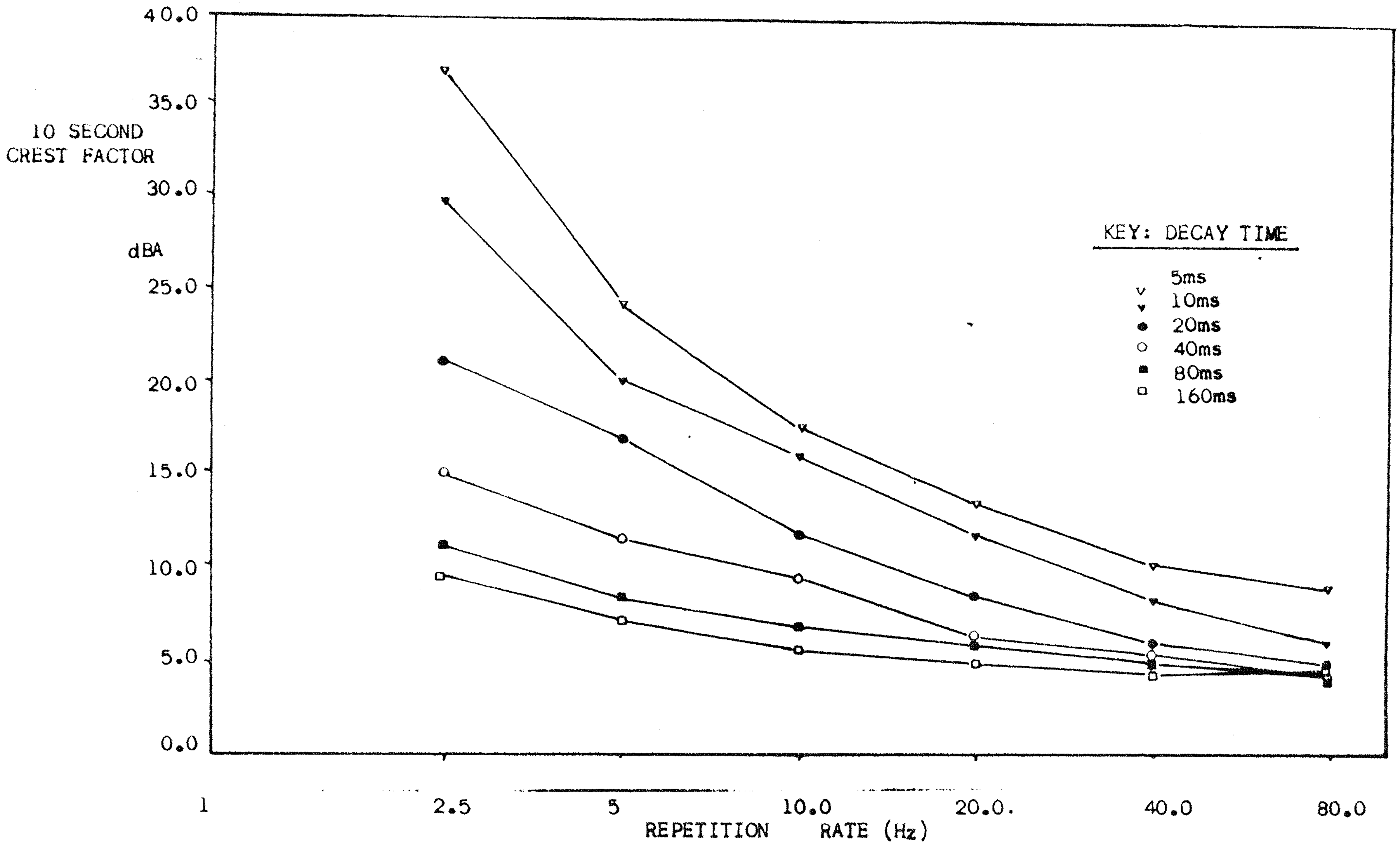

FIGURE 6.6. Graph of 10 second Crest Factor measures against repetition rate, for each decay time.

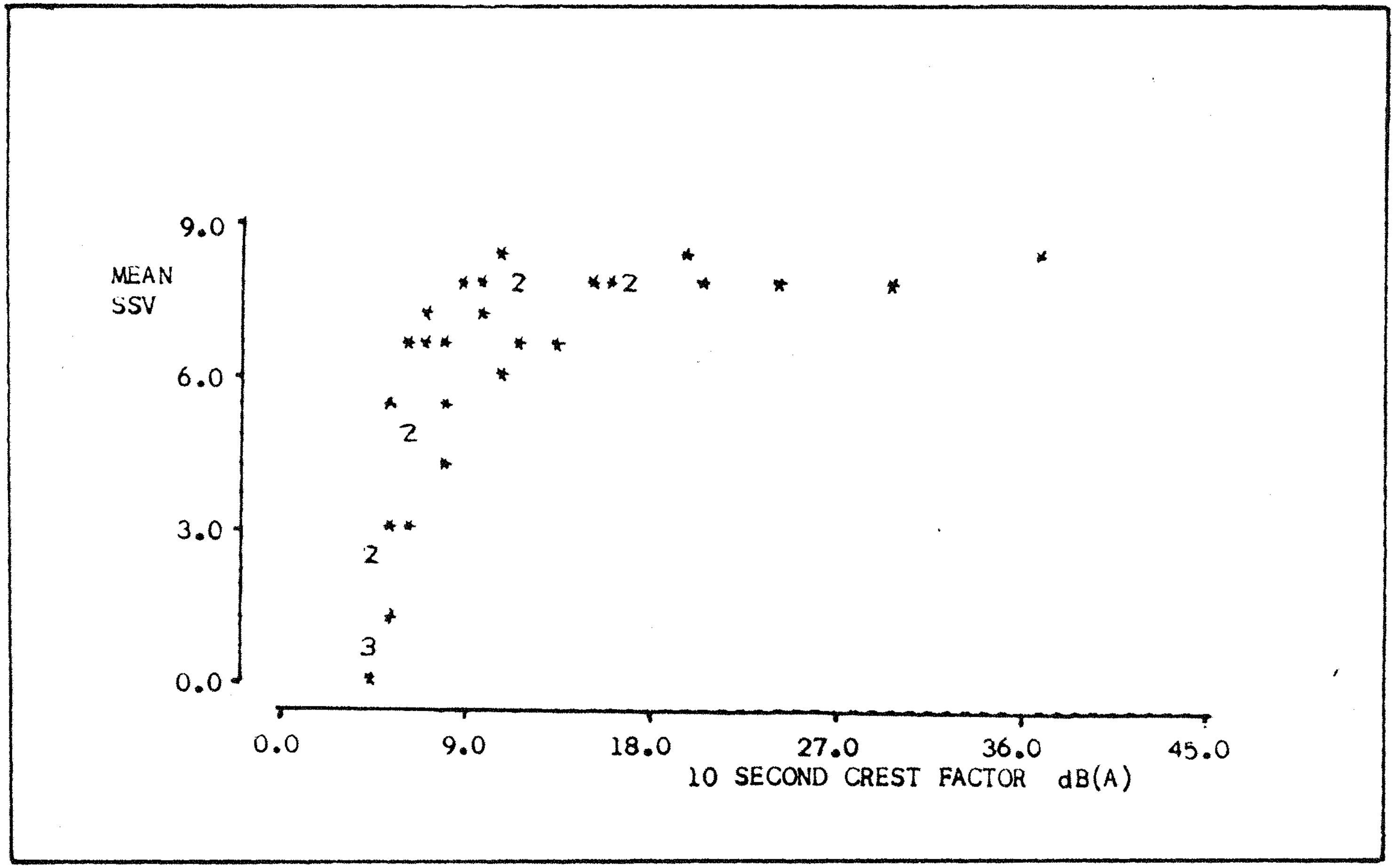

FIGURE 6.7. Scatter plot of mean impulsivity SSVs against 10 second crest factors.

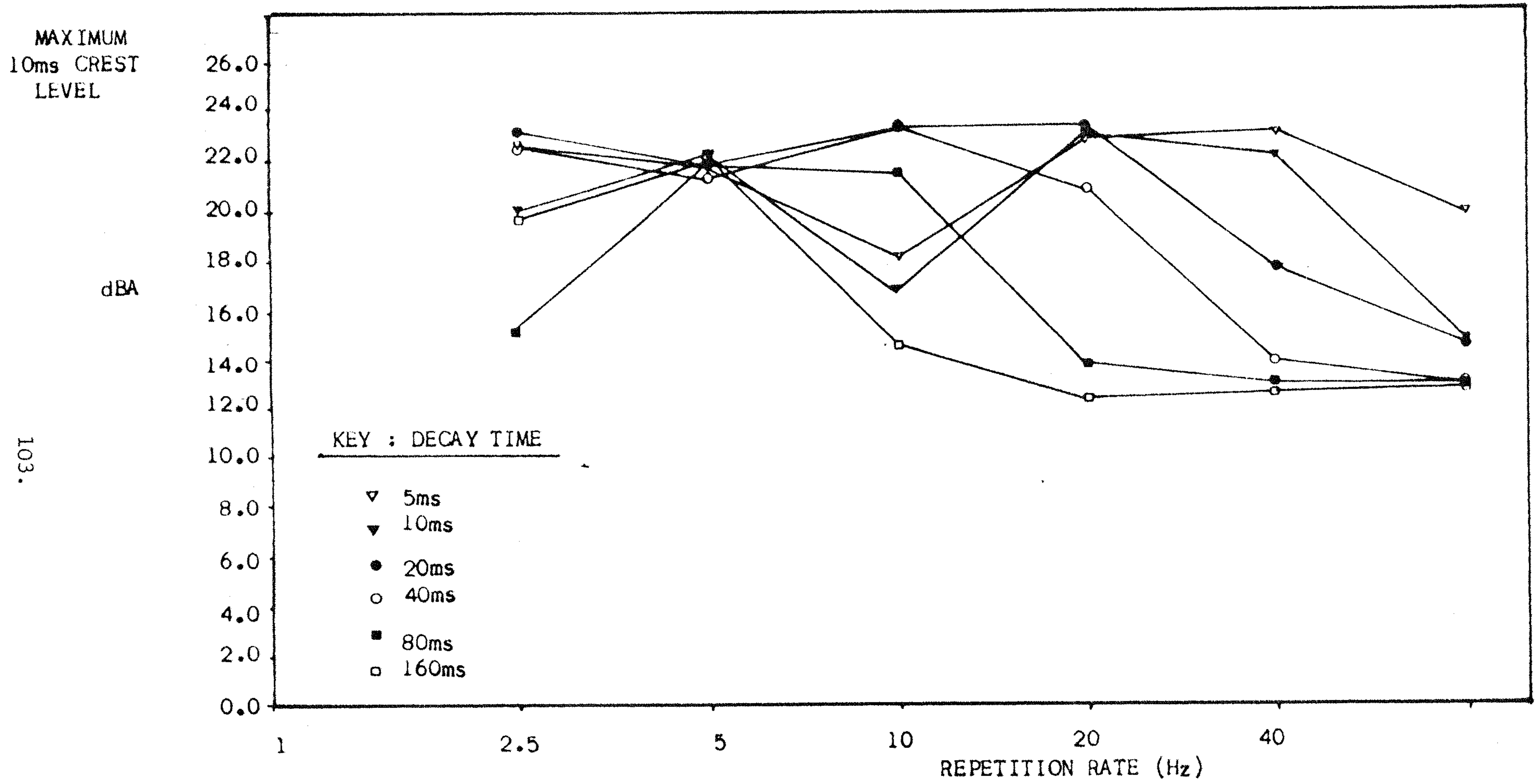

FIGURE 6.8. Graph of maximum 10ms Crest Levels against repetition rate, for all decay times.

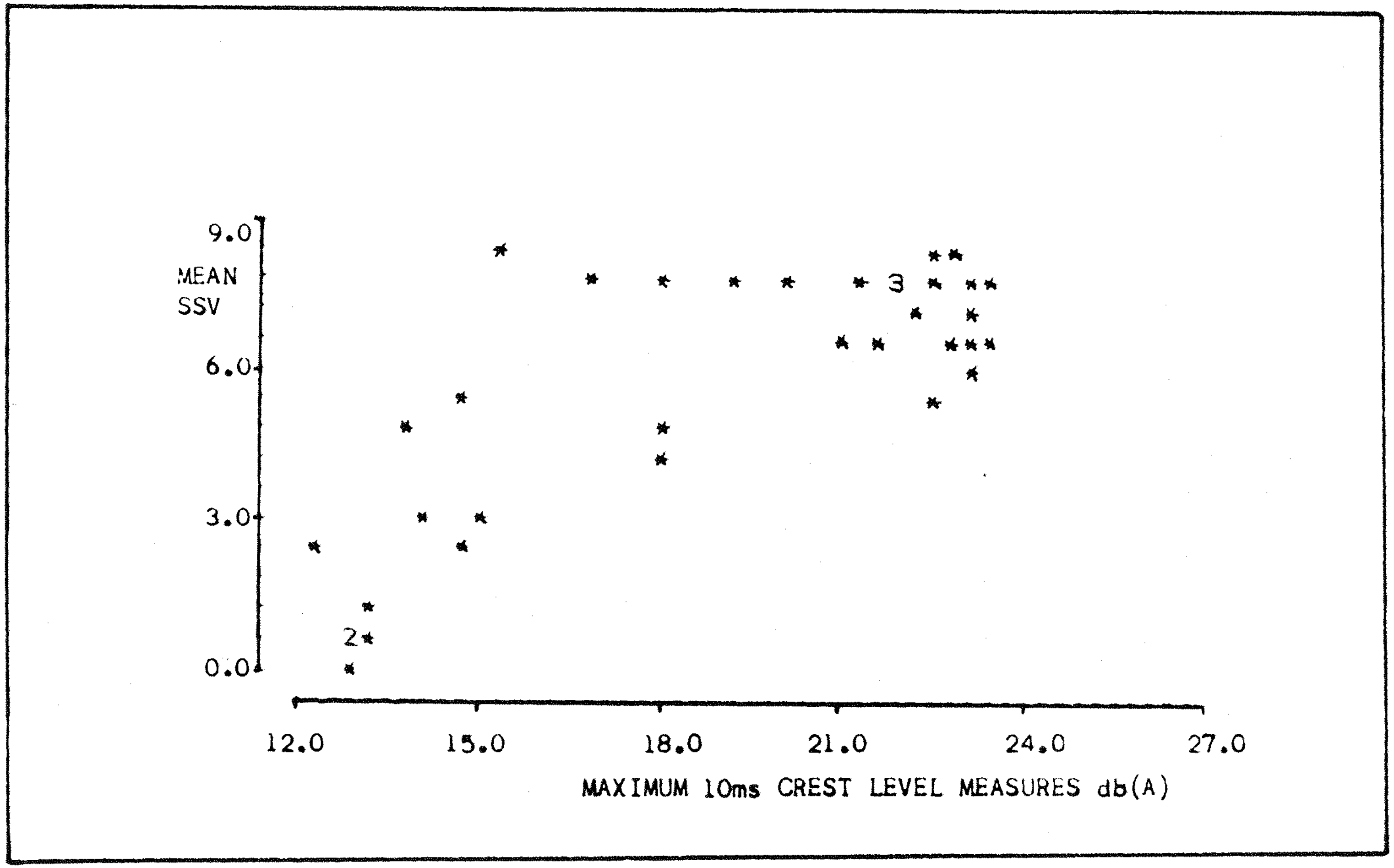

FIGURE 6.9 Scatter plot of mean impulsivity SSVs against maximum 10 ms crest level measures.

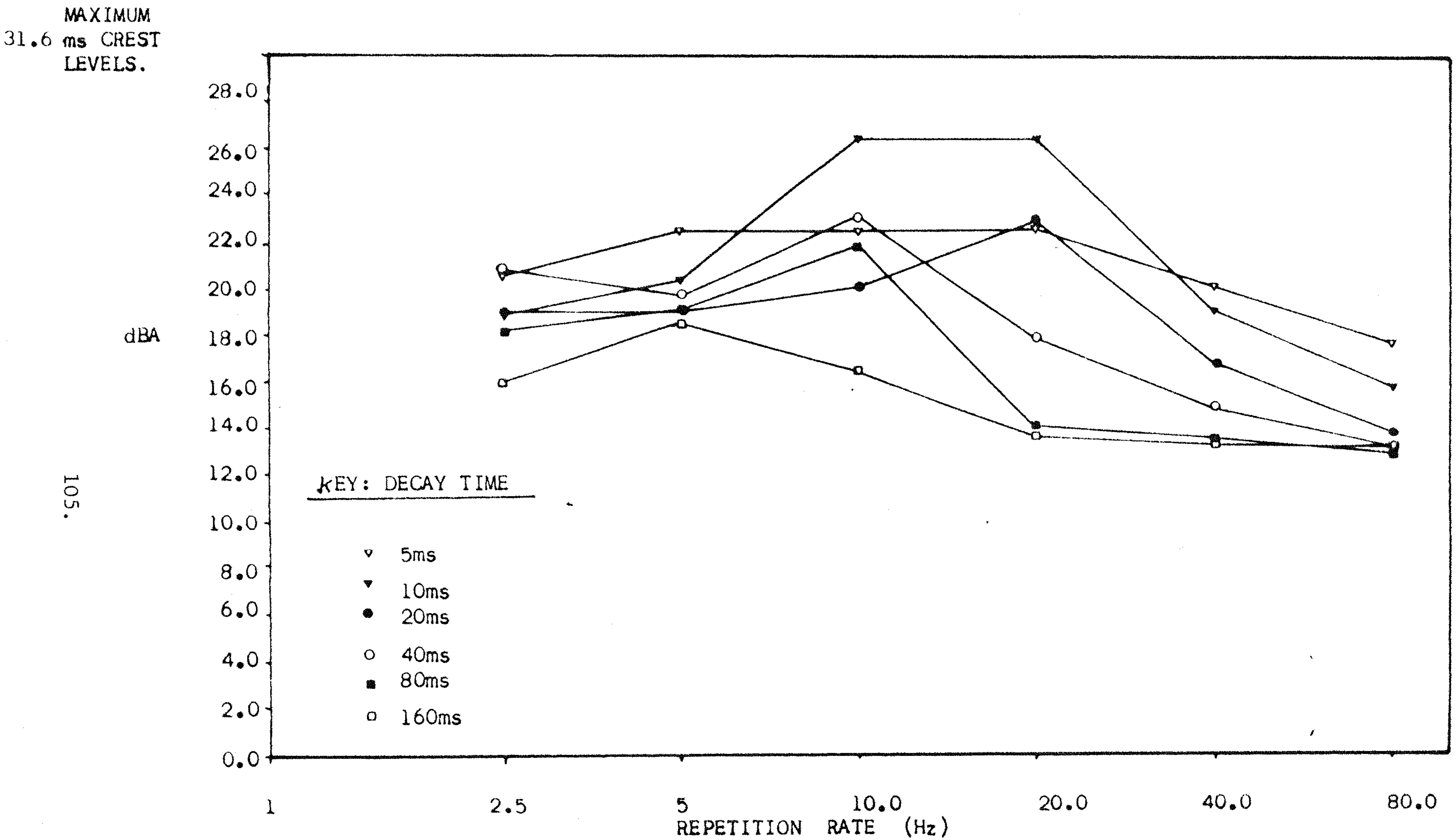

FIGURE 6.10. Graph of maximum 31.6ms Crest Level measures against repetition rate, for all decay times.

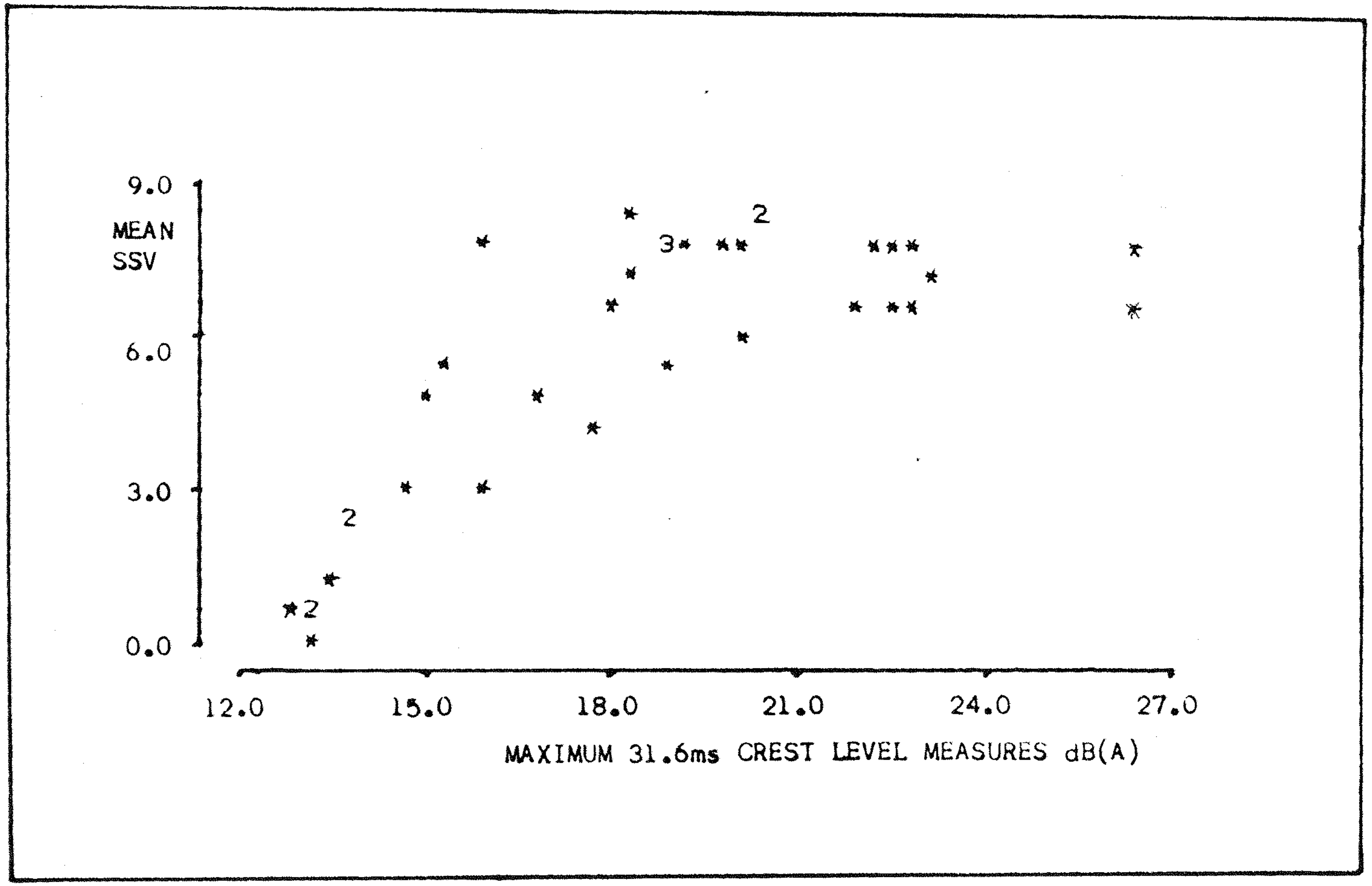

FIGURE 6.11 Scatter plot of mean impulsivity SSVs against maximum 31.6 ms crest level measures

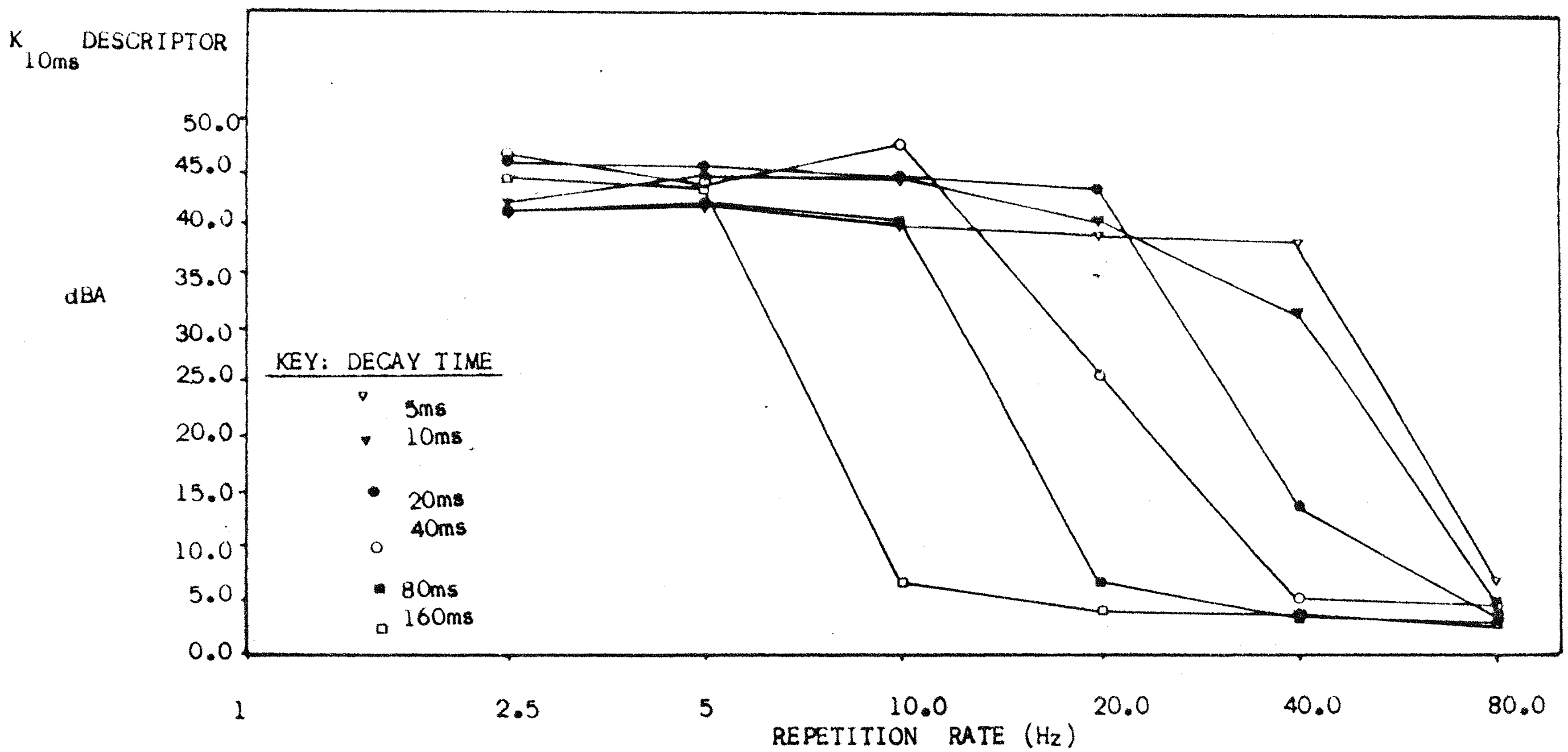

FIGURE 6.12. Graph of K_{10ms} measures against repetition rate, for each decay time.

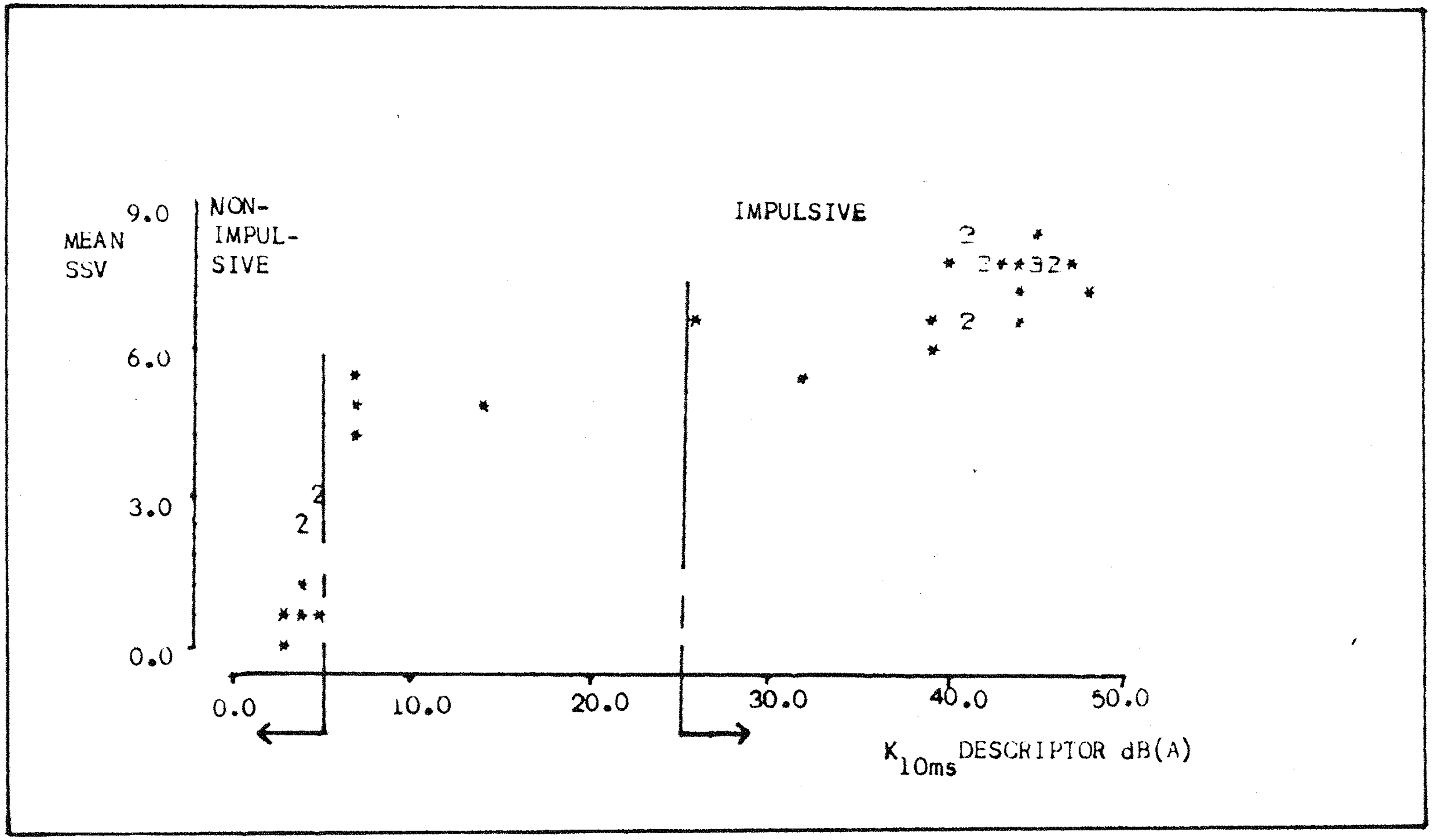

FIGURE 6.13 Scatter plot of mean impulsivity SSVs against $K_{10\ ms}$ measures

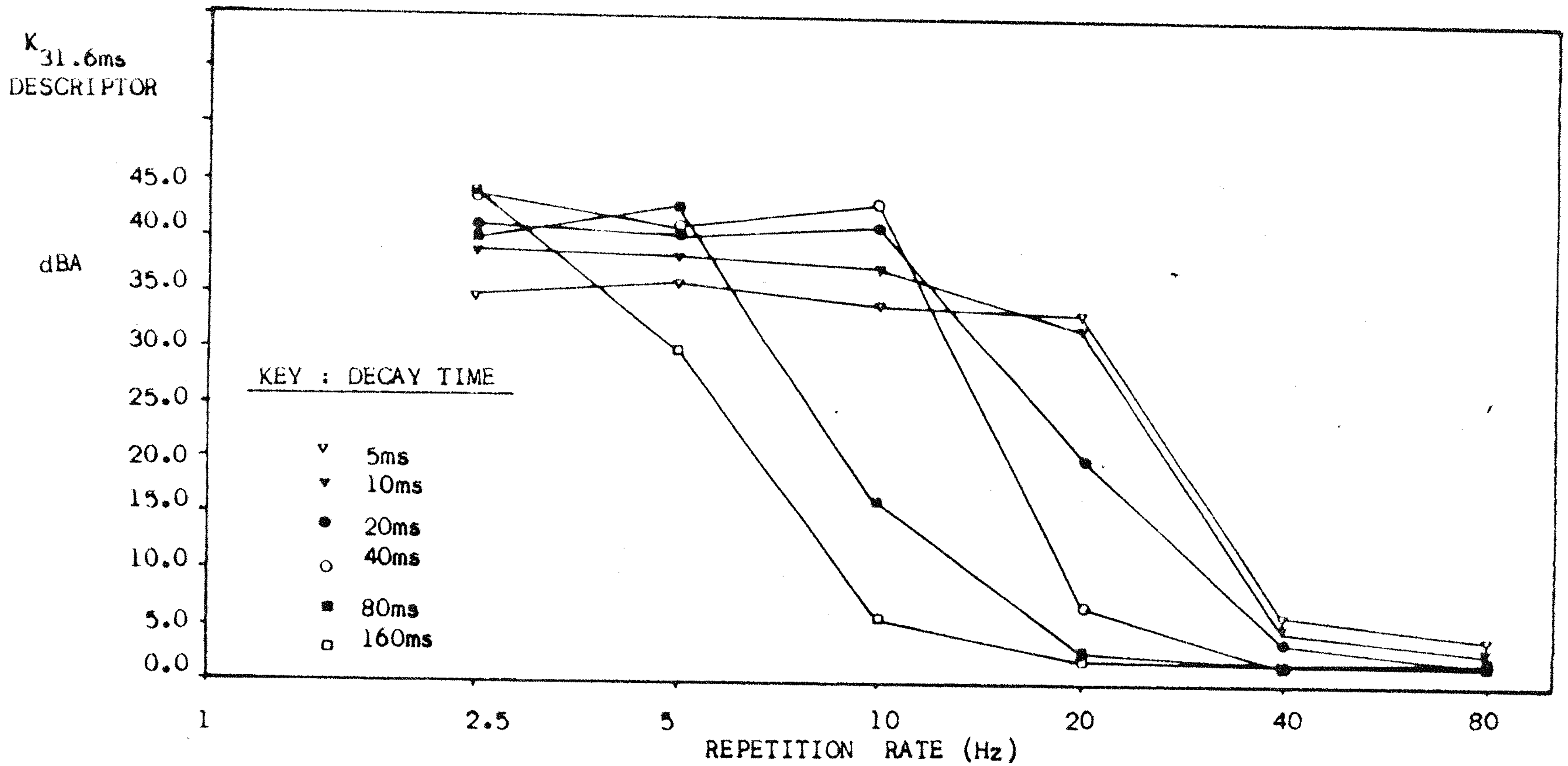

FIGURE 6.14. Graph of $K_{31.6ms}$ measures against repetition rate, for all decay times.

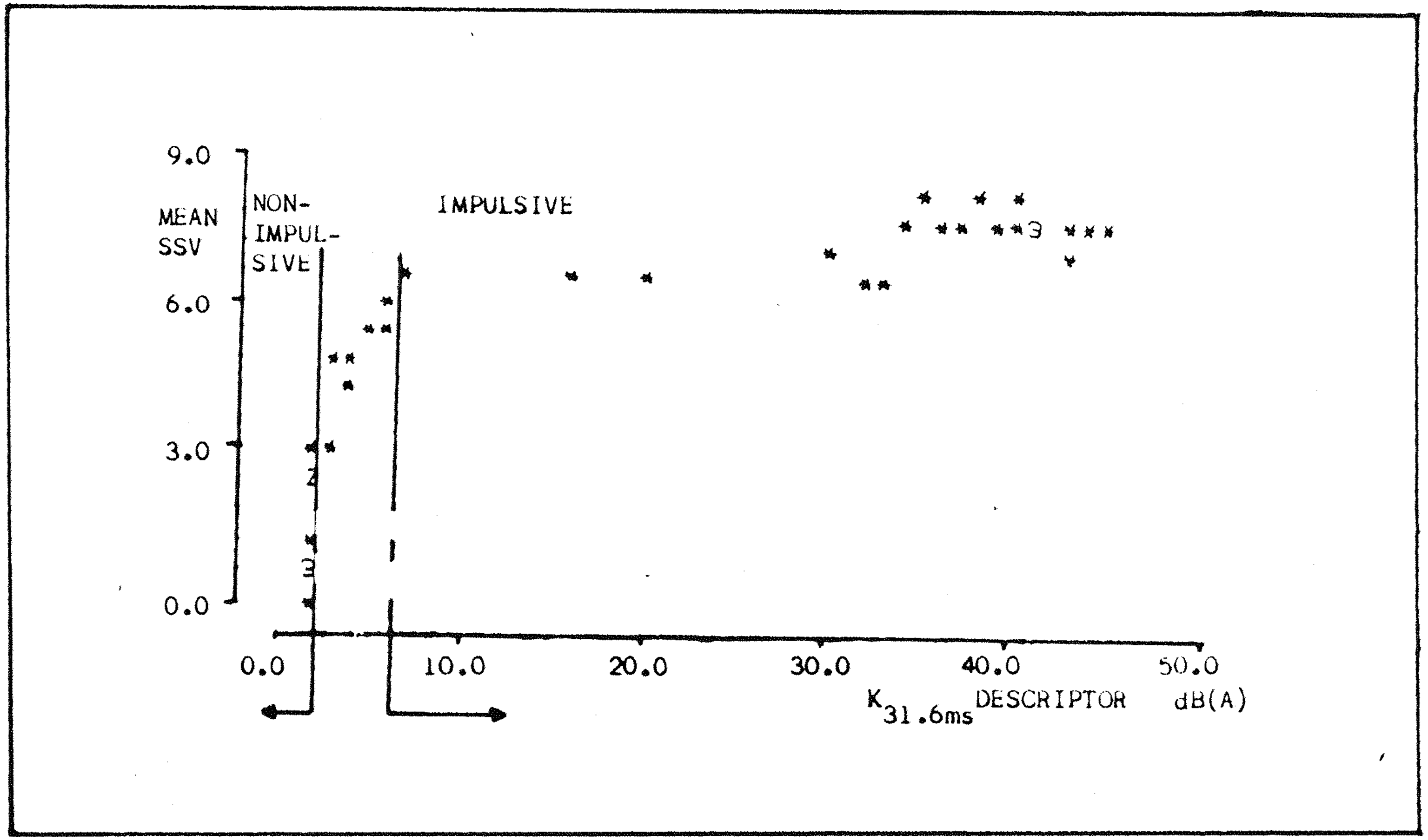

FIGURE 6.15 Scatter plot of mean impulsivity SSVs against $K_{31.6\ ms}$ measures.

CHAPTER 7

RECOMMENDED WORK TOWARDS AN OBJECTIVE METHOD OF IMPULSIVE NOISE DETECTION

7.1 Introduction

The effectiveness of the objective descriptors, modelled on the computer system in rating impulsive noise, is evaluated in Chapter 6. For the most suitable measure, the K descriptor, criteria have been defined so that for any raw signal input to the system, a rating can be obtained of whether or not the noise would be subjectively judged as impulsive. The eventual aim is to develop a 'black-box' type instrument, suitable for field use by engineers, noise consultants, Local Government Officers, and the like, in much the same way as a sound level meter (SLM). The actual design of such an instrument is only possible once a viable and consistent objective measure can be modelled in a software package on the computer system. This chapter provides recommendations for further work necessary to reach this goal.

7.2 The Influence of the Time Period on K Measures

It was suggested in Section 3.4, that the small time period over which the L_{Aeq} measures were evaluated has an effect on the value of the K descriptor obtained. This is substantiated by the comparative analysis undertaken in Chapter 6, which showed that whilst both the decay time and repetition rate of the synthetic impulses have a significant effect on the $K_{10\ ms}$ measures, only the repetition rate has a significant effect on the $K_{31.6\ ms}$ measures. Hence, although the majority of those sounds subjectively rated as impulsive are classed the same by either of the K measures, the boundaries of the classifications differ in the vicinity of the 'grey' region.

From the definition given in Section 3.4, it is clear that the decay time has no effect on the K measure for either time period at low repetition rates, unless consecutive impulses overlap. Indeed, the decay time of the impulses only appears to have a significant effect on the $K_{31.6\ ms}$ measure over the range of repetition rates from 10 Hz to 40 Hz inclusive. From theory it is not possible for this measure to rate any sound as impulsive if it has a repetition rate in excess of 40 Hz. As Figure 7.1(a) shows, the reason for this is that the signal is averaged over discrete 31.6 ms time periods, and so consecutive impulses with a separation time τ_{sep} (as defined in Section 3.1) of greater than this may be contained within a single L_{Aeq} measure. Thus, all that is obtained is an estimate of the energy contained within one or more impulses, illustrated in Figure 7.1(b).

Initial experimental analysis by the author, outlined in Section 3.3, suggested that a suitable time period for the K measure lay within the range of 8-50 ms. For the main objective study outlined in this project, 10 ms and 31.6 ms were chosen as representative values within this range. If L_{Aeq} measures of 10 ms or less are used the output time series obtained closely resembles the raw signal, and the averaging process does not provide a good approximation to the time constant of the hearing mechanism of the human ear, whereas the time series generated from the discrete 31.6 ms L_{Aeq} measures may not adequately model the interaction between the decay time and repetition rate of impulses, present in the subjective study described in Chapter 5.

Thus, the 10 ms measure is too selective and the 31.6 ms measure is not selective enough to model the human perception of impulsivity over the array of sounds studied. It is therefore recommended that further objective analysis is undertaken using K descriptors measured over time periods within the range of those already studied, for instance 16 ms or 25 ms.

7.3 Criticisms of the K Descriptor

Whilst Chapter 6 showed the K descriptor, measured over either a 10 ms or 31.6 ms time period, to be the best of the objective methods studied at indicating the subjective boundaries of impulsive noise, there are still some criticisms regarding the discrimination of this measure. These relate to the possibility of sounds being wrongly classified as impulsive. The K descriptor detects the onset of an impulse by use of a measure of level change, ΔL, over a stated time period (described in Section 3.4), which gives no indication of the 'on-time' of an impulse. Consequently, it is possible that some synthetically generated signals consisting of individual components other than impulses, will be rated as impulsive by this measure.

An example of one such signal is the simple voltage step illustrated in Figure 7.2(a). This will be converted to a small time period L_{Aeq} series, given in Figure 7.2(b). If the step is of sufficient amplitude, then it is possible that the criteria for impulsive noise will be met, for either K measure. As a progression from the simple step, it can be seen that a train of rectangular pulses of sufficient amplitude, illustrated in Figure 7.2(c), may also be rated as impulsive by the criteria for either time period, as Figure 7.2(d) suggests. Whether or not these raw noise signals would be subjectively judged as impulsive is uncertain as no data is at present available, but several Japanese studies discuss the loudness and noisiness implications of sounds with such temporal characteristics. Clearly any further subjective studies should include examples of these types of synthetic sounds.

It is possible that a pure sinusoidal signal, of a sufficiently low repetition rate may also be rated as impulsive by the K_{10} ms and $K_{31.6}$ ms descriptors. Whether the L_{Aeq} measures met the criteria for either K descriptor is dependent on the time period over which the L_{Aeq} is measured and the period, T, of the sinusoidal.

As mentioned previously these criticisms result from the inability of the K descriptor in accounting for the 'on-time' of a single impulse. An alternative method is discussed in the next section which attempts to relate both the decay time and repetition rate of impulses directly to the impulsivity of a sound.

7.4 An Alternative Method

The results of the subjective study, discussed in Chapter 5, are presented in a different format in Figure 7.3. The graph illustrates a linear plot of the repetition rate and decay time for each of the thirty-six synthetic sounds investigated. The subjective boundaries for impulsive and non-impulsive classifications are illustrated, and are separated by the 'grey' region of uncertainty. As mentioned in Section 5.5, these boundaries are only estimates, and it is possible that an absolute cut-off between impulsive and non-impulsive signals may exist within this region of uncertainty. By expressing the sounds in the graphical format Figure 7.3, it is clear that any relationship between repetition rate (y-variate) and decay time (x-variate) must produce a boundary within this region.

An initial suggestion is illustrated for a criterion of $yx < 1.0$ to define a sound as impulsive. This is a crude measure of the degree of overlap of consecutive impulses; defining a sound as being impulsive if the decay time is less than the separation time, τ_{sep}, between consecutive impulses. However, this criterion does not fully describe the subjective classifications of impulsive noise at repetition rates above 40 Hz; although the results of the subjective study indicate that all sounds with repetition rates exceeding this may be classed as non-impulsive. Indeed, Moore [43] suggests that the human auditory mechanism cannot distinguish between two complex sounds separated by 40 ms or less, which would imply that sounds with impulses repeating at a rate of 25 Hz or greater would be perceived as continuous. This figure appears to be substantiated by a paper by Powell [46] describing early investigations into the effect of the repetition rate on human response to simulated impulsive sounds. If a cut-off of 25 Hz for the repetition rate [Y] is used, a linear plot of $Y=-0.1X + 25$ satisfies the conditions of a criterion for the thirty-six sounds, and is illustrated in Figure 7.3. Further experimental studies may well produce a relationship between repetition rate and decay time which satisfies the subjective classifications for psychological and physiological reasons.

It would be necessary, therefore, to obtain an estimate of the decay time and repetition rate of the impulsive content of a sound. For the synthetic sounds used in the subjective study comprising ideal impulses, this can be performed using the small time period L_{Aeq} values, generated by the software package described in Chapter 4. The $[L_{Aeq}(i) - L_{Aeq}(i-1)]$ values provide an indication of the onset of an impulse, and hence an estimate of the repetition rate can be obtained. Using the L_{Aeq} values an estimate of the decay time can be taken as being either the time for the level to drop by a predetermined amount, or the time elapsed until the $[L_{Aeq}(i) - L_{Aeq}(i-1)]$ values become positive again. Initial investigations by the author suggest that whilst these methods produce good estimates of the repetition rates and decay times of some synthetic sounds used in the subjective study, they may be difficult to implement on sounds around the boundaries of the 'grey' region. Work by Commins [36,37,38] has shown that it is possible to obtain values of the decay time and number of impulses from noise signals by use of small time period L_{Aeq} series analysis. However, the alternative method proposed in this section relies on a relationship beween two factors obtained from ideal synthetic impulses, and may therefore not be applicable to more complex irregular sounds.

7.5 Sounds in Combination

In the laboratory study, discussed in Chapter 5, only a selection of simple synthetic sounds were considered. However, any viable method for objectively describing impulsive noise must be applicable in a complex noise environment, in which, typically, an impulsive noise is heard in combination with a background noise of a non-impulsive character. Previous laboratory studies [17,33] investigating the influence of ambient noise level on the annoyance response to impulsive noise are outlined in Chapter 2. In Section 3.1, the effect of background noise on the impulsive character of a noise is investigated, and accounted for in the proposed K descriptor, developed in Section 3.4.

Further objective analysis has now been performed on the combinations of gunfire and traffic sounds used in in the study described by Rice [17]. A comparison between the results of this objective analysis and the laboratory study is given in Appendix 7.1. This suggests that if a condition has a value of $K_{31.6ms} \geqslant 6.9$ it will be subjectively judged as impulsive, and hence be subjectively judged as more annoying than non -impulsive noise. The values of the K_{10ms} descriptor obtained for the noise conditions indicate that the criteria proposed in Chapter 6 for this measure may be too conservative, and should perhaps include some of the sounds rated in the 'grey' region of uncertainty. However, further experimentation, not outlined in this thesis, would be necessary to define more accurate criteria for this measure.

7.6 Frequency Composition of Sounds

As stated in Section 3.1, this project has concentrated on investigating some of the temporal parameters which may determine the impulsive character of a sound. However, the frequency composition of a sound influences the way in whih it is perceived, and should be investigated in further studies.

The transient nature associated with impulsive sounds is predominantly related to their high frequency content. It is the higher frequencies that describe the 'sharp' onset or decay which characterises such sounds. However, in practice, most environmental impulsive sounds also possess a significant low frequency content. Low frequencies propagate further in a free field situation, so that, for example, heavy artillery noise reaching a listener a quarter of a mile from the noise source will consist principally of frequency components below about 100 Hz. With the attenuation of high frequencies in this situation, the sound no longer has a sharp definition, but may still be perceived as an impulsive 'bang'.

It is therefore difficult to formulate a precise hypothesis as to the effect of frequency composition on the subjective perception of impulsivity of a sound. To resolve this a subjective study is proposed using the synthetic sounds, rated in the laboratory study described in Chapter 5. The frequency characteristics of these sounds can be altered by the use of high and low pass filters. The impulsivity ratings of the modified sounds can then be compared to those for the original sounds used in the previous study, to determine the effect of the frequency spectrum of a sound on its impulsive character.

The filtered sounds can also be analysed using the software package described in Chapter 4, to obtain values of the objective impulsivity descriptor K. These values can be compared to those obtained for the unfiltered synthetic sounds, which are given in Chapter 6. The effectiveness of the K descriptor in modelling subjective judgements of impulsivity for sounds of differing frequency spectra can then be evaluated. Any dependence of the values of discrete small time period L_{Aeq} (on which the K descriptor is based) on the frequency composition of the analysed sound can also be ascertained.

7.7 Conclusions

Further research is recommended using a K descriptor measured over a small time period of beween 10 ms and 31.6 ms, to analyse the thirty-six synthetic sounds used in the subjective study. Values of 16 ms and 25 ms are suggested for the time period. Comparative analysis, similar to that performed in Chapter 6 will then indicate over which time period this descriptor best satisfies the requirements of an objective method of impulsive noise description, stipulated by the subjective study.

Further subjective and objective studies are then required to investigate the impulsivity of a wider range of noises than the synthetic sounds discussed in this project. These must include more complex synthetic sounds, such as steps and rectangular pulses, and also 'real-life' environmental noises which contain both impulsive and non-impulsive sounds in combination. An investigation into the effect of frequency composition on the impulsivity of a sound should also be included in these studies.

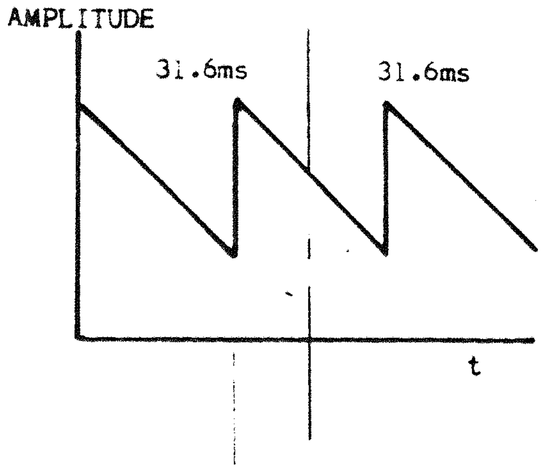

FIGURE 7.1(a). An idealised train of impulses with a seperation time, $_{sep}$ 31.6ms.

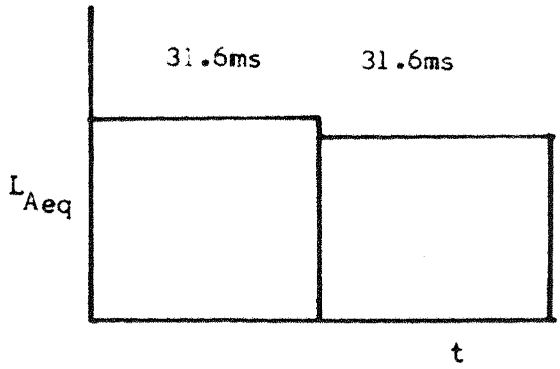

FIGURE 7.1(b). Small time series L_{Aeq} for FIGURE 7.1(a).

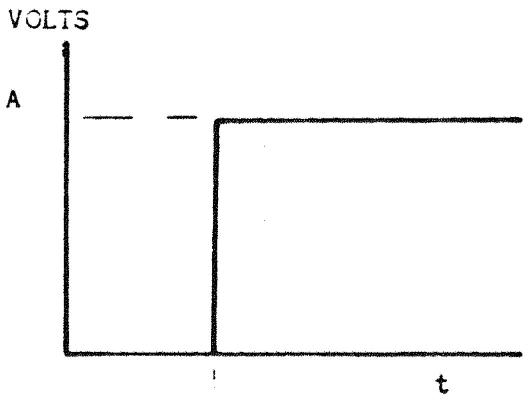

FIGURE 7.2(a). A simple voltage step input.

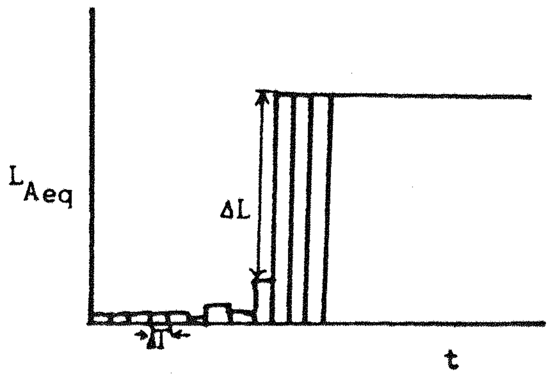

FIGURE 7.2(b). Small time series L_{Aeq} for FIGURE 7.2(a).

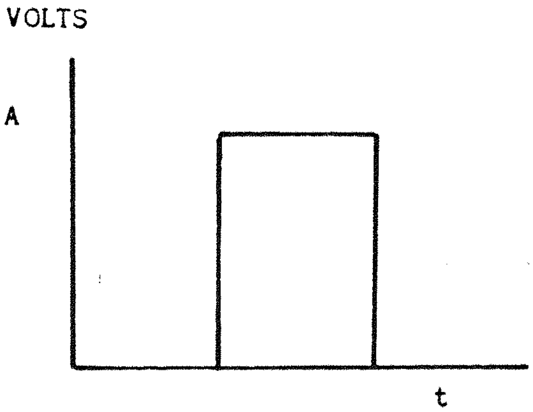

FIGURE 7.2(c). A pulse train of rectangular pulses.

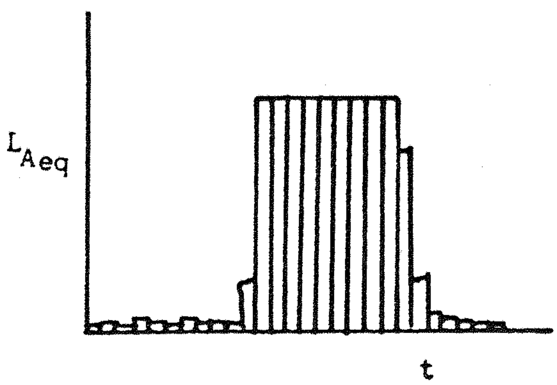

FIGURE 7.2(d). Small time series L_{Aeq} for FIGURE 7.2(c).

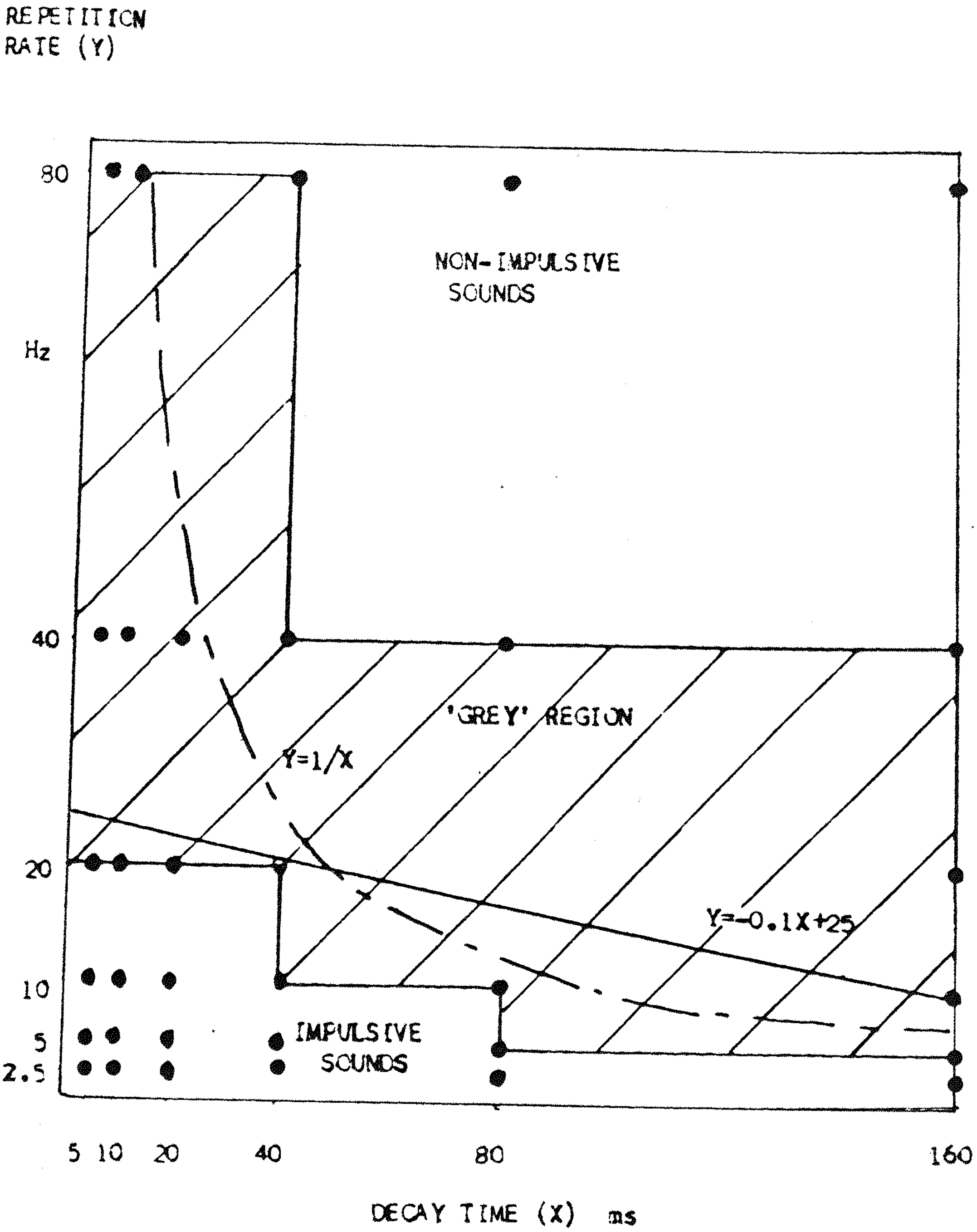

FIGURE 7.3 Plot of repetition rate against decay time, for all synthetic sounds.

CHAPTER 8

CONCLUSIONS

Of the objective measures investigated in this thesis, the K descriptor using either 10 ms or 31.6 ms consecutive L_{eq} values provides the best indication of the subjective evaluation of the impulsivity of a sound. The software package developed performs analysis on a finite section of signal, which should be chosen to be representative of exposure to immisions of possible impulsive nature. From comparative analysis of objective and subjective studies, an initial criterion is proposed, suggesting a sound with a value of $K_{10\ ms} \geqslant 26.3$ or $K_{31.6\ ms} \geqslant 6.9$ would be subjectively judged as impulsive.

Laboratory studies performed agree with the inference of recent EEC research, indicating that all sounds perceived as impulsive may be represented by a single dose-response relationship, being significantly more annoying than traffic (continuous) noise. By comparing the dose-response relationships obtained for both impulsive and continuous noise, and observing the points at which annoyance responses are equal, it is possible to regard the difference in equivalent noise levels as a penalty for impulsive noise compared to traffic. The results of laboratory studies discussed in this thesis suggest a level dependent correction varying between 5 and 10 dB over the range of 70-35 dB L_{Aeq} should be applied to sounds objectively classed as impulsive by the K descriptor.

Whilst the K descriptor was developed to incorporate the effect of background noise level on the impulsive character of a noise, only sounds in isolation were considered in the objective analysis. However, further research suggests that the criteria proposed for the $K_{31.6ms}$ descriptor may be applicable to combinations of impulsive and continuous noise.

The K descriptor does not model the impulsive 'turn-off' of sounds, but it would be possible to include this in the measure by considering the maximum negative difference between consecutive L_{Aeq} values.

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APPENDIX 2.1

The Equivalent Continuous Sound Level, L_{eq}

The equivalent continuous sound level, L_{eq}, has been adopted in a number of countries as a means of measuring and assessing noise. Mean energy level, equivalent energy level and equivalent sound level are all other titles sometimes used to refer to the equivalent continuous sound level.

A report, published by the Noise Advisory Council [A1] provides a guide to the measurement and prediction of L_{eq} for differing environmental noise situations.

L_{eq} is a noise scale itself, being the level of notional steady sound having the same A-weighted acoustic energy as the fluctuating noise at a given position and over a defined period.

The mathematical definition of L_{eq} over an interval from time T_1 to T_2 is given as:

$$L_{eq} = 10\log_{10} \left| \frac{1}{T_2-T_1} \int_{T_1}^{T_2} \frac{P_A^2(t)}{P_{ref}^2} dt \right| \text{dB} \qquad 1.1$$

where P_A is the 'A' weighted sound pressure as a function of time and P_{ref} is the reference pressure taken as 20 micropascals.

A more convenient definition of L_{eq} is an approximation to the exact expression equation (1.1) and this alternative formula is:

$$L_{eq} = 10\log_{10} \left| \frac{1}{T_2-T_1} \right| \int_{T_1}^{T_2} 10^{\frac{L_A(t)}{10}} dt \qquad (1.2)$$

in which L_A is the 'A' weighted sound pressure level, defined as:

$$L_A = 10\log_{10} \frac{\overline{p_A^2}}{p_{ref}^2} \text{ dB} \qquad (1.3)$$

L_A is the immediate subjective impression of the strength of a noise, known as a measure of the auditory magnitude of that noise. This takes into account such factors as sound pressure and frequency content which affect the perception of sound.

If the time interval T_2-T_1 is large compared to the time period over which the mean of p_A^2 is obtained the equations (1.1) and (1.2) are equivalent.

The equivalent continuous sound level is sometimes calculated using sound pressure levels which are not A-weighted for environmental purposes. For this reason the suffix A can be used to denote the A-weighted equivalent continuous level, L_{Aeq}.

L_{eq} can be measured directly using a sound level meter set to slow if the noise is steady. Steady noise is defined as noise which has maximum fluctuations of ± 4dB.

When the fluctuations are greater than this, visual averaging form a sound level meter can no longer be used to obtain an accurate measurement of L_{eq}. The L_{Aeq} is instead calculated from the formula

$$L_{Aeq} = 10\log_{10} \left| \frac{1}{100} \Sigma f_i \, 10^{\frac{L_{Ai}}{10}} \right| \qquad (1.4)$$

where L_{Aeq} is the 'A' weighted equivalent continuous sound level.

L_{Ai} is the 'A' weighted sound pressure level, corresponding to the class midpoint of the i^{th} class.

f_i is the time interval as expressed as a percentage of the relevant time period for which the sound pressure level is within the limits of class i.

Thus effectively, L_{eq} indicates the total energy and represents the equivalent steady level in terms of energy over the period concerned.

The International Organisation for Standardisation recommends the use of equivalent continuous sound level in its document ISO R 1996-1971(E) "Assessment of Noise with Respect to Community Response". The time period over which the sound level is obtained is prescribed by the specifications of the noise type to be measured.

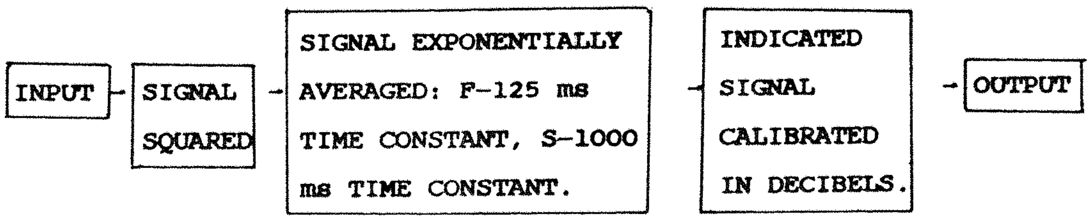
REFERENCE

A1 THE NOISE ADVISORY COUNCIL 1978. 'A Guide to Measurement and Prediction of the Equivalent Continuous Sound Level L_{eq}.' Report by a Working Party for the Technical Sub-committee. HMSO London.

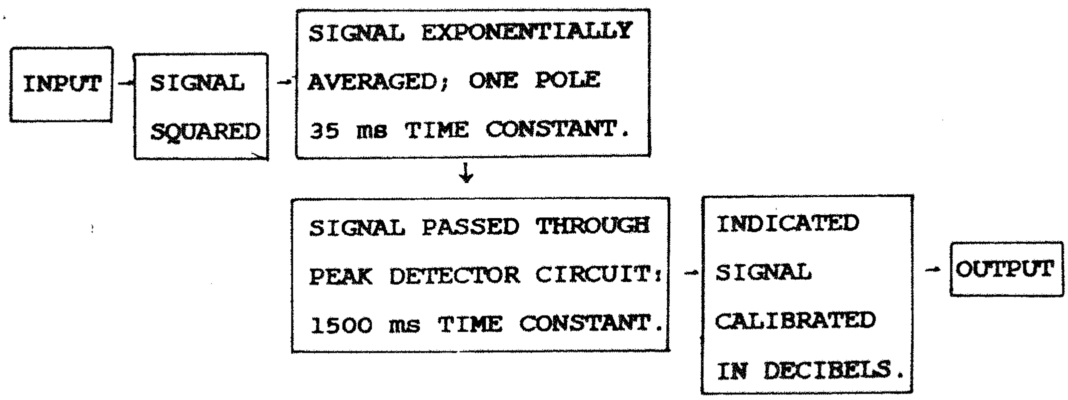
APPENDIX 2.2 TIME WEIGHTING CHARACTERISTICS FOR SOUND LEVEL METERS

The British Standard for specification of sound level meters [A2], states a sound level meter with either the fast (F) or slow (S) detector-indicator characteristic in operation, will produce an indication of the r.m.s. value of the signal, the averaging time being specified differently for either time weighting. A sound level meter with the impulse (I) detector-indicator characteristic in operation will produce an indication related to the maximum of the short-time r.m.s. value of the signal, achieved by means of an r.m.s. detector with a short averaging time, and a peak detector with a long decay time.

In an instrument containing either F or S detector-indicator characteristics, the signal passes through a network given in simplified form in the diagram below:



In an instrument containing impulse (I) detector-indicator characteristics, the signal passes through a similar network, except a peak detector is introduced. This is outlined in simplified form in the block diagram given below:



The time constant of the exponential averaging circuit is equal for both charge and discharge. The peak detector has the effect of storing the voltage fed to it for a sufficient time to allow it to be displayed by the indicator.

Tests for r.m.s. accuracy and time weighting characteristics are specified by the relevant standard [A2].

Reference

A2. BRITISH STANDARDS INSTITUTION 1981 'Specification for sound level meters'. BS 5969 (IEC 651: 1979).

Appendix 4.1:

Listing of Fortran program.

```
C      ****** PROGRAM TO MODEL OBJECTIVE IMPULSIVITY DESCRIPTORS ****
C      ****** by J.N.FAIRFAX , completed on 10/5/86 ****
C      ****** AUDIOLOGY & HUMAN EFFECTS GROUP, ISVR ****
C      ****** UNIVERSITY OF SOUTHAMPTON           ****

C      **** SUBROUTINE TO HANDLE INPUT & OUTPUT FILES ,TO DEFINE PARAMETERS ***

C
C      **** DIMENSION ARRAYS ,SET UP CONTROL BLOCK, DEFINE INTEGERS ****
C
       INTEGER*4 I,N,K5,K,J,L,M,I1,J3,J4,K1,K2,K6
       DIMENSION A(300),CB(128),V(50000),W(50000)
       DIMENSION B(50000),C(50000),D(50000),F(300)
       DIMENSION Q(50000),O(50000),CB1(128)
       EQUIVALENCE (A(11),M)
       DIMENSION G(300),H(300)
       CALL TYPE('&JIM1.FOR')
C
C      **** DEFINE INPUT AND OUTPUT FILES ****
C
       CALL ASKPN(A,'&SIGNAL INPUT FILE =')
       CALL ASKPN(F,'&OUTPUT FILE TO STORE SMALL TIME PERIOD LEQS=')
       CALL ASKPN(H,'&OUTPUT FILE TO STORE SMALL TIME PERIOD CREST LEVELS=')

       CALL ASKPN(G,'&OUTPUT FILE TO STORE [Leq(i)-Leq(i-1)] VALUES=')
       CALL INPUT(A,CB,M)
       CALL INS(A,0,0,0)
C
C      **** INPUT TIME PERIODS FOR ANALYSIS ****
C
       CALL ASKPR(U3,'&ENTER TOTAL TIME DURATION OF SIGNAL TO BE ANALYSED;')
       CALL ASKPR(S,'&ENTER LARGE LEQ TIME WINDOW(NOT LESS THAN 2E-5 SECS);')
       CALL ASKPR(T,'&ENTER SMALL LEQ TIME WINDOW(NOT LESS THAN 2E-5 SECS);')
C
C      **** LABEL SIGNAL OUTPUT ****
C
       CALL ASKPR(U1,'&WHAT IS SIGNAL REPETITION RATE ?')
       CALL ASKPR(U2,'&WHAT IS SIGNAL DECAY TIME ?')
C
C      **** OPEN OUTPUT FILE ('OUT.DAT') & DATA OUTPUT FILES F,G,H ****
C
       OPEN(UNIT=99,NAME='OUT.DAT',STATUS='UNKNOWN',FORM='FORMATTED')
       CALL OUTPUT(F)
       CALL OUTPUT(G)
       CALL OUTPUT(H)
C
C      **** SET COUNTERS FOR DO LOOPS ****
C
       N=INT(T*25000.0)
       J=INT(S/T)
       J3=INT(U3/S)
       J4=J3*J
C
```

```
C     **** SET VARIABLES AND CONSTANTS TO ZERO ****
C
      PEAK=0.0
      AN=0.0
      AS=0.0
      AT=0.0
      CP=0.0
      RAT=0.0
      DUM=0.0
C
C
C
C     **** SUBROUTINE TO CALCULATE SMALL PERIOD LEQS , PEAK-LEQS ,****
C     **** AND OTHER VALUES FROM INPUT SIGNAL ****
C
C     **** DO LOOP FOR TOTAL PERIOD ****
C
      DO 17 K1=1,J3
C
C     **** DO LOOP FOR CALCULATING LARGE TIME PERIOD  VALUES ****
C
      DO 10 K2=1,J
      K6=K6+1
      K=K2+J*((K1)-1)
C
C     **** DO LOOP FOR CALCULATING SMALL TIME PERIOD  VALUES ****
C
      DO 5 I=1,N
      CALL IN (A,X)
      K5=K5+1
      IF (X.EQ.0.0) GOTO 5
      IF (X.LT.CP) GOTO 1
      CP=X
1     AN=AN+(X**2)
      AL=AL+(X**2)
      AS=AS+(X**4)
      VAL=(X*1000000)**2
      O(K2)=O(K2)+(X**2)/FLOAT(N)
      SPL=10*ALOG10(VAL)
      IF (SPL.LT.PEAK) GOTO 2
      PEAK=SPL
2     SUM=SUM+(VAL/FLOAT(N))
5     CONTINUE
C
C
C
      VAR=VAR+O((K2))/FLOAT(J)
      SUMTOT=SUMTOT+SUM
      ALEQ=10*ALOG10(SUM)
      RU=(AL/FLOAT(N))**0.5
      B(K)=20*ALOG10(RU*1000000)
      AL=0.0
      W(K6)=PEAK
      V(K6)=ALEQ
      PEAK=0.0
10    SUM=0.0
C
C
```

```
C
      COT=0.0
      DO 13 K2=1,J
13    COT=COT+((O(K2)-VAR)/VAR)**2
      Q(K1)=COT
C
C
17     SUMTOT=0.0
      CALL INEND(A)
C
C
C      **** SUBROUTINES TO PERFORM CALCULATIONS ON VALUES OBTAINED ****
C      **** FROM THE INPUT SIGNAL ****
C
C      **** CREST FACTOR & KURTOSIS ****
C
      AKUR=(AS/K5)/((AN/K5)**2)
      CRET=CP/((AN/K5)**0.5)
C
C      **** NPL DESCRIPTOR ****

C
      DO 67 K1=1,J3
67     GUT=GUT+Q(K1)
      APL=10*ALOG10(GUT/FLOAT(J3))

C      *** SUBROUTINE TO COMPUTE [Leq(i)-Leq(i-1)] VALUES & CREST LEVELS ****
      TOTAL=0.0
      COUNT=0.0
      V(0)=V(1)
C
      DO 11 M=1,K6
      DUM=DUM+10**(V(M)/10)
      D(M)=V(M)-V(M-1)
      C(M)=W(M)-B(M)
      IF (C(M).LT.COUNT) GOTO 3
      COUNT=C(M)
3     IF (D(M).LT.TOTAL) GOTO 14
      TOTAL=D(M)
14     CONTINUE
C
C      **** SEND SMALL TIME SERIES VALUES TO OUTPUT DATA FILES ****
C
      DO 20 I1=1,N
      CALL OUT(H,C(M))
      CALL OUT(F,V(M))
20     CALL OUT(G,D(M))
11     CONTINUE
C
C
C      **** OVERALL LEQ OF 10 SECOND SIGNAL ****
      RAT=10*ALOG10(DUM/K6)
C
C
C
C      **** SUBROUTINE TO SEND RESULTS TO SCREEN (6) ****
C      **** AND OUTPUT FILE ('OUT.DAT' 99)          ****
C
```

```
      WRITE(6,77)U1
      WRITE(99,77)U1
77     FORMAT('&REPETITION RATE OF SIGNAL(Hz)=',F6.2)
      WRITE(6,78)U2
      WRITE(99,78)U2
78     FORMAT('&DECAY TIME OF SIGNAL(ms)=',F6.2)
      WRITE(99,80)
      WRITE(6,80)
80     FORMAT('&CONSECUTIVE VALUES FOR SMALLER TIME WINDOWS(dB re 10E-6V)')
      WRITE(99,81)
      WRITE(6,81)
81     FORMAT('& TIME PERIOD  LEQ    PEAK    RMS     CREST LEVEL dLeq/dt')
      DO 15 L=1,K6
      P=T*L
     WRITE(99,90)(P,V(L),W(L),B(L),C(L),D(L))
90       FORMAT('/',F8.3,2X,F8,2,2X,F8.2,2X,F8.2,2X,F8.2,2X,F8.2)
     WRITE(6,90)(P,V(L),W(L),B(L),C(L),D(L))
15     CONTINUE
C
      WRITE(6,31)AKUR
      WRITE(99,31)AKUR
31     FORMAT('&KURTOSIS MEASURE FOR NOISE(REF TO 10E-6V)=',F6.2)
      WRITE(99,72)CRET
      WRITE(6,72)CRET
72     FORMAT('&CREST FACTOR FOR TOTAL DURATION OF SIGNAL=',F6.2)
      WRITE(99,73)TOTAL
      WRITE(6,73)TOTAL
73    FORMAT('&MAX VALUE OF [Leq(i)-Leq(i-1)]=',F6.2)
      WRITE(99,74)COUNT
      WRITE(6,74)COUNT
74     FORMAT('&MAX VALUE OF SMALL TIME PERIOD CREST LEVEL=',F6.2)
      WRITE(6,62)APL
      WRITE(99,62)APL
62     FORMAT('&VALUE OF NPL IMPULSIVITY DETECTOR =',F6.2)
      WRITE(99,36)RAT
36     FORMAT('& TOTAL 10 SECOND LEQ =',F6.2)
C
      CLOSE(UNIT=99)
     CALL TYPE('&TOTAL LEQ OVER LARGER TIME PERIOD (dB re 10E-6V)=')
      CALL TYPER(RAT)
     CB1(2)=CB(2)
     CB1(4)=CB(4)
C
C     **** CLOSE OUTPUT DATA FILES ****
C
      CALL OUTEND(F,CB1,-1)
      CALL OUTEND(G,CB1,-1)
      CALL OUTEND(H,CB1,-1)
      CALL ANLEND

      END
```

APPENDIX 4.2. Sample Printout of OUT.DAT File.

REPETITION RATE OF SIGNAL(Hz)= 20.00
DECAY TIME OF SIGNAL(ms)= 40.00
CONSECUTIVE VALUES FOR SMALLER TIME WINDOWS (dB re 10E-6V)

TIME PERIOD	LEQ	PEAK	RMS	CREST LEVEL	dLeq/dt
0.010	116.36	129.66	116.36	13.30	0.00
0.020	115.62	126.36	115.62	10.74	-0.74
0.030	115.62	125.51	115.62	9.89	0.00
0.040	110.22	117.90	110.22	7.67	-5.40
0.050	104.34	114.78	104.34	10.44	-5.89
0.060	114.14	127.93	114.14	13.79	9.80
0.070	117.14	126.73	117.14	9.59	3.00
0.080	113.28	122.25	113.28	8.97	-3.86
0.090	110.03	118.73	110.03	8.70	-3.25
0.100	104.22	113.80	104.22	9.58	-5.82
0.110	111.83	125.18	111.83	13.34	7.62
0.120	116.62	126.84	116.62	10.22	4.78
0.130	113.45	122.63	113.45	9.18	-3.17
0.140	110.54	121.57	110.54	11.03	-2.91
0.150	102.53	114.89	102.53	12.36	-8.01
0.160	114.64	127.25	114.64	12.60	12.12
0.170	116.68	124.86	116.68	8.17	2.04
0.180	114.61	123.83	114.61	9.22	-2.08
0.190	111.18	121.11	111.18	9.93	-3.42
0.200	103.56	115.04	103.56	11.49	-7.62
0.210	112.94	125.11	112.94	12.17	9.38
0.220	117.08	124.54	117.08	7.46	4.14
0.230	113.11	122.82	113.11	9.71	-3.97
0.240	111.41	122.15	111.41	10.74	-1.70
0.250	104.82	114.93	104.82	10.11	-6.59
0.260	113.79	128.62	113.79	14.82	8.97
0.270	115.90	123.98	115.90	8.08	2.10
0.280	113.19	121.46	113.19	8.27	-2.71
0.290	111.71	120.79	111.71	9.08	-1.48
0.300	104.38	114.34	104.38	9.96	-7.33
0.310	112.17	124.43	112.17	12.27	7.78
0.320	116.60	125.64	116.60	9.04	4.44
0.330	113.70	123.41	113.70	9.71	-2.90
0.340	111.14	120.08	111.14	8.94	-2.56
0.350	103.85	115.97	103.85	12.12	-7.30
0.360	112.10	124.76	112.10	12.66	8.26
0.370	116.69	125.94	116.69	9.25	4.59
0.380	114.31	123.94	114.31	9.63	-2.38
0.390	109.84	119.36	109.84	9.52	-4.47
0.400	103.08	113.17	103.08	10.09	-6.76
0.410	115.22	127.30	115.22	12.08	12.14
0.420	117.13	128.46	117.13	11.32	1.92
0.430	113.81	122.55	113.81	8.74	-3.33
0.440	111.29	120.88	111.29	9.60	-2.52
0.450	103.09	112.10	103.09	9.01	-8.20
0.460	113.01	124.62	113.01	11.60	9.92
0.470	116.83	126.35	116.83	9.52	3.81
0.480	114.94	123.29	114.94	8.36	-1.89
0.490	110.00	120.67	110.00	10.67	-4.94
0.500	104.21	115.30	104.21	11.10	-5.79
0.510	113.66	127.01	113.66	13.35	9.46
0.520	116.40	125.28	116.40	8.88	2.74
0.530	113.46	123.34	113.46	9.88	-2.94
0.540	110.54	119.65	110.54	9.12	-2.92
0.550	103.96	115.08	103.96	11.12	-6.58
0.560	115.08	127.75	115.08	12.66	11.13
0.570	117.63	125.60	117.63	7.97	2.54
0.580	113.77	123.68	113.77	9.91	-3.86
0.590	110.23	119.93	110.23	9.70	-3.54
0.600	104.30	115.36	104.30	11.06	-5.93
0.610	115.82	127.49	115.82	11.68	11.52
0.620	117.40	126.66	117.40	9.26	1.58
0.630	115.12	123.13	115.12	8.01	-2.28
0.640	111.21	121.78	111.21	10.57	-3.91
0.650	104.89	114.22	104.89	9.33	-6.32
0.660	114.47	127.23	114.47	12.75	9.58
0.670	118.34	128.29	118.34	9.95	3.87
0.680	114.27	124.35	114.27	10.08	-4.07
0.690	110.33	120.31	110.33	9.98	-3.94
0.700	101.97	111.59	101.97	9.62	-8.36
0.710	114.26	126.77	114.26	12.51	12.30
0.720	116.90	126.48	116.90	9.57	2.64
0.730	114.31	123.55	114.31	9.24	-2.59
0.740	109.55	118.29	109.55	8.74	-4.76
0.750	102.87	112.31	102.87	9.44	-6.68
0.760	113.01	125.23	113.01	12.22	10.14
0.770	116.64	126.57	116.64	9.93	3.64
0.780	114.02	121.60	114.02	7.58	-2.63
0.790	111.37	121.96	111.37	10.60	-2.65
0.800	104.28	114.93	104.28	10.65	-7.08
0.810	113.41	126.00	113.41	12.60	9.13
0.820	116.54	129.01	116.54	12.47	3.13
0.830	114.93	125.49	114.93	10.56	-1.61
0.840	110.70	120.46.	110.70	9.76	-4.23
0.850	103.86	114.42	103.86	10.56	-6.84
0.860	114.24	126.71	114.24	12.47	10.38
0.870	116.45	125.48	116.45	9.03	2.21
0.880	112.87	123.54	112.87	10.67	-3.58
0.890	110.42	120.81	110.42	10.39	-2.46
0.900	102.80	113.49	102.80	10.69	-7.62
0.910	114.20	126.72	114.20	12.52	11.40
0.920	116.90	125.58	116.90	8.67	2.71
0.930	115.00	122.94	115.00	7.94	-1.90
0.940	109.76	118.57	109.76	8.81	-5.24
0.950	104.33	114.82	104.33	10.48	-5.43
0.960	114.86	127.05	114.86	12.19	10.52
0.970	116.23	124.47	116.23	8.24	1.37
0.980	114.93	123.10	114.93	8.18	-1.30
0.990	111.75	120.41	111.75	8.66	-3.17
1.000	102.28	115.62	102.28	13.34	-9.47
1.010	114.85	126.41	114.85	11.56	12.56
1.020	116.90	128.09	116.90	11.18	2.06
1.030	113.44	121.64	113.44	8.20	-3.47
1.040	110.94	121.62	110.94	10.68	-2.50
1.050	103.40	112.18	103.40	8.78	-7.54
1.060	113.91	125.07	113.91	11.16	10.51

1.070	115.57	125.43	115.57	9.87	1.66	1.700	102.92	113.49	102.92	10.57	-8.20
1.080	113.56	124.33	113.56	10.78	-2.01	1.710	113.46	127.02	113.46	13.56	10.54
1.090	110.34	121.58	110.34	11.24	-3.21	1.720	115.99	124.89	115.99	8.91	2.52
1.100	103.33	116.14	103.33	12.80	-7.01	1.730	113.20	123.47	113.20	10.27	-2.79
1.110	112.78	125.08	112.78	12.31	9.45	1.740	110.79	122.39	110.79	11.60	-2.41
1.120	116.45	127.38	116.45	10.93	3.68	1.750	103.99	114.70	103.99	10.71	-6.80
1.130	114.30	124.25	114.30	9.96	-2.16	1.760	113.73	125.84	113.73	12.11	9.74
1.140	109.98	118.14	109.98	8.16	-4.32	1.770	116.91	127.86	116.91	10.95	3.18
1.150	103.25	116.83	103.25	13.58	-6.73	1.780	113.69	122.94	113.69	9.25	-3.22
1.160	115.69	127.54	115.69	11.85	12.43	1.790	109.40	120.02	109.40	10.62	-4.29
1.170	116.47	126.89	116.47	10.42	0.79	1.800	102.63	113.88	102.63	11.26	-6.77
1.180	114.18	124.41	114.18	10.23	-2.29	1.810	114.79	126.89	114.79	12.10	12.17
1.190	109.92	119.78	109.92	9.87	-4.26	1.820	116.49	128.92	116.49	12.43	1.69
1.200	102.43	113.66	102.43	11.23	-7.49	1.830	113.88	124.24	113.88	10.36	-2.60
1.210	112.80	124.74	112.80	11.94	10.37	1.840	110.32	119.89	110.32	9.58	-3.57
1.220	117.66	127.56	117.66	9.90	4.87	1.850	102.83	115.01	102.83	12.18	-7.49
1.230	113.33	123.95	113.33	10.62	-4.33	1.860	115.63	128.89	115.63	13.26	12.80
1.240	109.63	119.08	109.63	9.45	-3.70	1.870	116.58	127.98	116.58	11.40	0.96
1.250	103.05	113.53	103.05	10.48	-6.58	1.880	113.44	125.95	113.44	12.51	-3.14
1.260	114.09	127.20	114.09	13.11	11.05	1.890	109.53	119.01	109.53	9.48	-3.90
1.270	116.62	126.13	116.62	9.51	2.53	1.900	101.75	115.87	101.75	14.12	-7.79
1.280	114.95	122.06	114.95	7.11	-1.67	1.910	114.18	126.51	114.18	12.33	12.43
1.290	109.51	120.25	109.51	10.74	-5.44	1.920	116.57	125.40	116.57	8.83	2.39
1.300	103.74	114.05	103.74	10.31	-5.77	1.930	112.89	124.04	112.89	11.15	-3.67
1.310	114.40	126.96	114.40	12.56	10.66	1.940	110.25	118.60	110.25	8.35	-2.65
1.320	117.12	127.10	117.12	9.98	2.72	1.950	100.83	111.53	100.83	10.70	-9.42
1.330	114.58	123.40	114.58	8.81	-2.53	1.960	117.28	128.83	117.28	11.55	16.45
1.340	109.82	120.92	109.82	11.10	-4.76	1.970	117.64	128.06	117.64	10.42	0.36
1.350	103.05	115.19	103.05	12.15	-6.77	1.980	114.16	123.19	114.16	9.04	-3.49
1.360	112.48	123.19	112.48	10.71	9.43	1.990	111.01	123.54	111.01	12.52	-3.14
1.370	116.49	126.23	116.49	9.75	4.01	2.000	101.57	110.33	101.57	8.75	-9.44
1.380	113.35	121.95	113.35	8.59	-3.14	2.010	113.64	126.31	113.64	12.66	12.07
1.390	110.54	120.49	110.54	9.95	-2.81	2.020	116.38	124.55	116.38	8.17	2.74
1.400	103.52	116.80	103.52	13.28	-7.02	2.030	114.30	124.29	114.30	10.00	-2.09
1.410	113.79	124.72	113.79	10.93	10.27	2.040	109.69	118.37	109.69	8.68	-4.61
1.420	116.01	127.00	116.01	10.99	2.22	2.050	103.12	115.23	103.12	12.11	-6.56
1.430	113.87	123.09	113.87	9.21	-2.13	2.060	115.67	126.38	115.67	10.70	12.55
1.440	109.17	118.24	109.17	9.07	-4.70	2.070	116.54	125.33	116.54	8.79	0.87
1.450	102.28	111.75	102.28	9.47	-6.89	2.080	114.18	123.29	114.18	9.11	-2.36
1.460	114.07	127.76	114.07	13.69	11.79	2.090	109.19	119.89	109.19	10.70	-4.99
1.470	116.60	125.59	116.60	8.99	2.53	2.100	100.49	110.20	100.49	9.70	-8.70
1.480	114.36	123.59	114.36	9.23	-2.23	2.110	114.42	125.39	114.42	10.97	13.93
1.490	110.19	120.33	110.19	10.14	-4.17	2.120	116.28	126.62	116.28	10.34	1.86
1.500	102.53	115.83	102.53	13.30	-7.66	2.130	113.76	124.11	113.76	10.35	-2.52
1.510	113.35	128.47	113.35	15.12	10.82	2.140	108.86	118.32	108.86	9.46	-4.91
1.520	116.40	125.11	116.40	8.71	3.05	2.150	101.27	113.80	101.27	12.52	-7.58
1.530	113.12	122.88	113.12	9.76	-3.28	2.160	114.60	125.98	114.60	11.38	13.33
1.540	111.49	120.85	111.49	9.36	-1.63	2.170	116.33	125.80	116.33	9.47	1.72
1.550	103.38	114.38	103.38	11.00	-8.11	2.180	113.16	124.15	113.16	10.99	-3.17
1.560	114.90	126.12	114.90	11.21	11.53	2.190	109.74	120.37	109.74	10.64	-3.42
1.570	117.53	128.42	117.53	10.89	2.62	2.200	103.10	113.30	103.10	10.20	-6.63
1.580	113.98	123.13	113.98	9.16	-3.55	2.210	113.57	123.69	113.57	10.12	10.46
1.590	109.03	117.22	109.03	8.19	-4.94	2.220	116.05	125.11	116.05	9.06	2.48
1.600	102.66	112.23	102.66	9.58	-6.38	2.230	113.35	120.96	113.35	7.61	-2.70
1.610	113.34	125.01	113.34	11.68	10.68	2.240	110.17	120.61	110.17	10.44	-3.18
1.620	116.26	126.39	116.26	10.13	2.92	2.250	103.79	117.42	103.79	13.63	-6.38
1.630	113.32	122.89	113.32	9.57	-2.94	2.260	114.30	127.07	114.30	12.77	10.51
1.640	110.06	118.75	110.06	8.69	-3.27	2.270	117.04	125.73	117.04	8.70	2.73
1.650	102.86	114.50	102.86	11.64	-7.20	2.280	113.74	123.38	113.74	9.64	-3.29
1.660	114.36	125.75	114.36	11.40	11.50	2.290	109.95	118.77	109.95	8.82	-3.79
1.670	116.38	126.03	116.38	9.66	2.02	2.300	102.67	112.18	102.67	9.51	-7.28
1.680	112.29	124.36	112.29	12.06	-4.08	2.310	115.46	126.61	115.46	11.15	12.79
1.690	111.12	120.31	111.12	9.19	-1.17	2.320	114.95	125.25	114.95	10.29	-0.50

2.330	113.79	122.65	113.79	8.86	-1.16
2.340	110.77	120.61	110.77	9.84	-3.02
2.350	102.33	114.38	102.33	12.05	-8.44
2.360	114.13	126.52	114.13	12.39	11.80
2.370	117.81	127.73	117.81	9.92	3.67
2.380	113.81	121.76	113.81	7.94	-3.99
2.390	110.28	120.08	110.28	9.80	-3.53
2.400	102.95	114.18	102.95	11.22	-7.33
2.410	114.03	126.23	114.03	12.20	11.08
2.420	116.33	126.40	116.33	10.07	2.30
2.430	113.06	122.69	113.06	9.63	-3.27
2.440	109.88	119.03	109.88	9.16	-3.18
2.450	101.26	112.64	101.26	11.38	-8.62
2.460	115.29	126.33	115.29	11.04	14.03
2.470	116.60	125.08	116.60	8.49	1.31
2.480	113.31	123.87	113.31	10.56	-3.29
2.490	110.85	120.88	110.85	10.04	-2.46
2.500	102.75	118.27	102.75	15.52	-8.10
2.510	114.80	128.53	114.80	13.73	12.05
2.520	116.55	126.66	116.55	10.10	1.75
2.530	113.75	122.94	113.75	9.19	-2.80
2.540	109.83	120.79	109.83	10.96	-3.92
2.550	103.58	115.04	103.58	11.46	-6.25
2.560	115.05	128.39	115.05	13.34	11.46
2.570	117.18	129.90	117.18	12.72	2.13
2.580	113.02	121.48	113.02	8.46	-4.16
2.590	109.32	118.87	109.32	9.55	-3.70
2.600	102.26	113.03	102.26	10.76	-7.06
2.610	114.03	125.50	114.03	11.47	11.77
2.620	116.52	125.36	116.52	8.84	2.49
2.630	112.92	122.77	112.92	9.85	-3.61
2.640	109.96	119.45	109.96	9.49	-2.96
2.650	102.84	115.12	102.84	12.28	-7.12
2.660	113.51	126.12	113.51	12.61	10.67
2.670	117.30	125.33	117.30	8.03	3.79
2.680	112.97	122.11	112.97	9.14	-4.33
2.690	111.19	121.78	111.19	10.58	-1.78
2.700	101.83	113.40	101.83	11.57	-9.36
2.710	114.90	126.02	114.90	11.13	13.06
2.720	115.20	123.25	115.20	8.05	0.31
2.730	114.07	123.16	114.07	9.09	-1.13
2.740	110.20	120.92	110.20	10.73	-3.87
2.750	101.83	113.40	101.83	11.57	-8.37
2.760	114.01	124.35	114.01	10.34	12.19
2.770	116.64	127.56	116.64	10.92	2.62
2.780	113.83	122.63	113.83	8.80	-2.81
2.790	108.90	119.76	108.90	10.86	-4.93
2.800	101.10	111.59	101.10	10.49	-7.81
2.810	113.65	125.17	113.65	11.52	12.55
2.820	115.33	126.01	115.33	10.68	1.69
2.830	113.53	122.83	113.53	9.30	-1.80
2.840	109.02	119.85	109.02	10.83	-4.51
2.850	103.43	115.97	103.43	12.53	-5.58
2.860	114.41	125.51	114.41	11.10	10.98
2.870	116.19	126.53	116.19	10.33	1.78
2.880	113.89	124.20	113.89	10.31	-2.30
2.890	109.65	119.34	109.65	9.69	-4.24
2.900	101.63	113.12	101.63	11.49	-8.02
2.910	117.15	128.57	117.15	11.42	15.52
2.920	116.61	126.52	116.61	9.91	-0.54
2.930	112.53	122.60	112.53	10.07	-4.08
2.940	110.27	119.31	110.27	9.05	-2.26
2.950	101.35	114.80	101.35	13.45	-8.92
2.960	115.05	124.94	115.05	9.90	13.70
2.970	116.64	126.81	116.64	10.17	1.60
2.980	113.72	124.52	113.72	10.80	-2.92
2.990	110.89	119.20	110.89	8.30	-2.83
3.000	102.03	115.93	102.03	13.90	-8.86
3.010	115.25	125.46	115.25	10.21	13.22
3.020	115.28	124.00	115.28	8.73	0.03
3.030	113.53	123.28	113.53	9.75	-1.75
3.040	109.98	119.91	109.98	9.93	-3.55
3.050	102.28	112.83	102.28	10.55	-7.70
3.060	114.13	126.24	114.13	12.11	11.85
3.070	117.95	127.16	117.95	9.20	3.82
3.080	114.73	124.88	114.73	10.15	-3.22
3.090	109.62	117.62	109.62	8.00	-5.11
3.100	101.08	113.66	101.08	12.59	-8.54
3.110	115.15	128.13	115.15	12.98	14.08
3.120	117.17	128.43	117.17	11.25	2.02
3.130	113.68	124.00	113.68	10.32	-3.49
3.140	108.76	118.45	108.76	9.69	-4.92
3.150	101.05	114.46	101.05	13.41	-7.71
3.160	114.50	125.45	114.50	10.95	13.45
3.170	116.52	125.21	116.52	8.70	2.01
3.180	113.30	124.97	113.30	11.66	-3.21
3.190	110.13	118.87	110.13	8.73	-3.17
3.200	101.69	117.54	101.69	15.85	-8.45
3.210	116.43	126.72	116.43	10.29	14.74
3.220	116.60	126.02	116.60	9.42	0.17
3.230	113.69	122.81	113.69	9.12	-2.91
3.240	109.52	119.87	109.52	10.35	-4.17
3.250	101.75	114.09	101.75	12.34	-7.77
3.260	113.80	127.47	113.80	13.66	12.05
3.270	116.35	126.06	116.35	9.71	2.54
3.280	113.27	122.89	113.27	9.62	-3.08
3.290	110.27	119.83	110.27	9.56	-3.00
3.300	101.59	113.97	101.59	12.37	-8.68
3.310	115.30	126.76	115.30	11.46	13.71
3.320	116.11	125.51	116.11	9.40	0.81
3.330	113.91	123.34	113.91	9.43	-2.20
3.340	108.76	116.77	108.76	8.01	-5.15
3.350	101.42	111.36	101.42	9.94	-7.34
3.360	115.50	126.23	115.50	10.73	14.08
3.370	116.31	126.34	116.31	10.02	0.81
3.380	114.12	122.62	114.12	8.50	-2.20
3.390	110.19	122.46	110.19	12.27	-3.93
3.400	103.31	114.66	103.31	11.35	-6.88
3.410	114.55	127.28	114.55	12.73	11.24
3.420	116.13	125.73	116.13	9.60	1.58
3.430	113.56	122.63	113.56	9.07	-2.57
3.440	107.98	118.67	107.98	10.69	-5.58
3.450	102.16	112.28	102.16	10.13	-5.82
3.460	116.12	127.92	116.12	11.80	13.96
3.470	117.56	125.79	117.56	8.23	1.44
3.480	113.04	123.45	113.04	10.41	-4.51
3.490	108.82	118.84	108.82	10.02	-4.23
3.500	103.09	115.97	103.09	12.88	-5.73
3.510	114.11	125.86	114.11	11.75	11.02
3.520	116.79	125.61	116.79	8.83	2.67
3.530	113.17	123.35	113.17	10.18	-3.62
3.540	109.67	117.45	109.67	7.78	-3.49
3.550	102.40	117.05	102.40	14.65	-7.28
3.560	115.63	126.77	115.63	11.15	13.23
3.570	115.00	123.99	115.00	8.99	-0.63
3.580	113.62	122.30	113.62	8.68	-1.38

3.590	108.74	117.71	108.74	8.96	-4.87
3.600	99.11	111.07	99.11	11.96	-9.63
3.610	115.24	126.57	115.24	11.33	16.13
3.620	116.63	125.84	116.63	9.21	1.39
3.630	113.50	123.82	113.50	10.31	-3.12
3.640	109.23	118.62	109.23	9.39	-4.27
3.650	99.33	110.89	99.33	11.56	-9.90
3.660	114.90	125.48	114.90	10.58	15.57
3.670	115.61	123.57	115.61	7.95	0.72
3.680	113.02	121.26	113.02	8.24	-2.59
3.690	109.56	117.84	109.56	8.28	-3.46
3.700	100.92	111.92	100.92	10.99	-8.64
3.710	115.86	127.68	115.86	11.83	14.93
3.720	116.21	125.39	116.21	9.18	0.36
3.730	113.00	121.33	113.00	8.33	-3.21
3.740	107.85	118.11	107.85	10.26	-5.15
3.750	101.36	112.39	101.36	11.02	-6.48
3.760	115.85	129.75	115.85	13.90	14.49
3.770	117.28	126.20	117.28	8.93	1.43
3.780	113.05	123.65	113.05	10.60	-4.22
3.790	109.00	117.62	109.00	8.63	-4.06
3.800	101.40	114.66	101.40	13.26	-7.60
3.810	115.53	128.67	115.53	13.14	14.13
3.820	115.95	125.53	115.95	9.58	0.42
3.830	113.72	122.79	113.72	9.07	-2.23
3.840	108.80	117.25	108.80	8.45	-4.92
3.850	100.97	110.77	100.97	9.79	-7.83
3.860	114.94	126.23	114.94	11.29	13.97
3.870	115.65	123.66	115.65	8.02	0.71
3.880	113.58	123.83	113.58	10.25	-2.07
3.890	108.54	120.10	108.54	11.56	-5.04
3.900	100.79	112.93	100.79	12.14	-7.75
3.910	114.43	125.08	114.43	10.66	13.64
3.920	116.67	126.28	116.67	9.62	2.24
3.930	114.68	123.88	114.68	9.20	-1.99
3.940	109.18	120.79	109.18	11.61	-5.50
3.950	101.49	114.78	101.49	13.29	-7.69
3.960	117.45	128.21	117.45	10.76	15.96
3.970	115.95	125.23	115.95	9.28	-1.50
3.980	112.59	120.39	112.59	7.80	-3.36
3.990	108.69	120.04	108.69	11.35	-3.89
4.000	101.24	113.80	101.24	12.56	-7.45
4.010	115.28	125.81	115.28	10.52	14.05
4.020	116.82	125.77	116.82	8.95	1.53
4.030	113.66	122.38	113.66	8.72	-3.16
4.040	109.24	118.72	109.24	9.48	-4.42
4.050	101.72	113.58	101.72	11.86	-7.52
4.060	114.86	124.83	114.86	9.97	13.14
4.070	117.36	128.32	117.36	10.96	2.50
4.080	114.48	126.68	114.48	12.20	-2.88
4.090	109.43	118.16	109.43	8.73	-5.05
4.100	101.06	111.75	101.06	10.69	-8.37
4.110	115.86	127.37	115.86	11.51	14.79
4.120	116.22	123.79	116.22	7.57	0.36
4.130	113.34	121.98	113.34	8.64	-2.88
4.140	109.97	119.74	109.97	9.77	-3.38
4.150	101.61	113.03	101.61	11.42	-8.36
4.160	117.09	127.25	117.09	10.16	15.48
4.170	115.74	125.49	115.74	9.75	-1.35
4.180	113.49	122.88	113.49	9.39	-2.25
4.190	108.16	117.48	108.16	9.32	-5.33
4.200	99.20	112.44	99.20	13.24	-8.96
4.210	115.69	127.78	115.69	12.09	16.49

4.220	116.51	125.78	116.51	9.27	0.82
4.230	114.26	121.48	114.26	7.22	-2.25
4.240	108.78	119.85	108.78	11.07	-5.48
4.250	99.89	110.26	99.89	10.37	-8.88
4.260	115.64	126.38	115.64	10.73	15.75
4.270	115.23	126.18	115.23	10.95	-0.41
4.280	113.46	124.33	113.46	10.87	-1.77
4.290	109.56	119.50	109.56	9.93	-3.90
4.300	99.41	111.64	99.41	12.23	-10.15
4.310	114.87	126.25	114.87	11.38	15.46
4.320	116.35	124.49	116.35	8.14	1.48
4.330	112.38	121.39	112.38	9.01	-3.97
4.340	108.76	120.96	108.76	12.20	-3.62
4.350	100.89	111.97	100.89	11.08	-7.88
4.360	116.21	127.32	116.21	11.11	15.32
4.370	115.66	125.35	115.66	9.69	-0.54
4.380	113.20	122.20	113.20	8.99	-2.46
4.390	109.67	117.98	109.67	8.31	-3.54
4.400	99.57	110.89	99.57	11.32	-10.10
4.410	114.56	126.48	114.56	11.92	14.99
4.420	115.19	124.94	115.19	9.75	0.63
4.430	113.42	122.23	113.42	8.81	-1.78
4.440	109.70	119.72	109.70	10.01	-3.71
4.450	99.27	110.26	99.27	10.99	-10.43
4.460	116.20	127.16	116.20	10.96	16.93
4.470	117.14	126.58	117.14	9.43	0.94
4.480	114.30	123.75	114.30	9.45	-2.84
4.490	108.66	119.01	108.66	10.35	-5.64
4.500	101.18	111.64	101.18	10.46	-7.48
4.510	114.80	125.10	114.80	10.30	13.62
4.520	117.03	127.92	117.03	10.89	2.23
4.530	112.46	122.08	112.46	9.62	-4.57
4.540	109.10	117.84	109.10	8.75	-3.36
4.550	100.10	111.59	100.10	11.48	-8.99
4.560	114.85	128.04	114.85	13.19	14.75
4.570	116.06	125.05	116.06	8.99	1.21
4.580	114.29	126.48	114.29	12.19	-1.77
4.590	108.07	119.11	108.07	11.03	-6.22
4.600	99.74	114.42	99.74	14.68	-8.33
4.610	115.48	124.15	115.48	8.67	15.74
4.620	115.92	125.45	115.92	9.54	0.44
4.630	113.64	124.67	113.64	11.03	-2.28
4.640	108.54	119.67	108.54	11.13	-5.10
4.650	100.20	112.49	100.20	12.29	-8.34
4.660	116.60	128.78	116.60	12.18	16.40
4.670	117.55	125.93	117.55	8.38	0.95
4.680	113.45	122.58	113.45	9.13	-4.09
4.690	109.85	119.15	109.85	9.30	-3.60
4.700	99.63	110.00	99.63	10.36	-10.22
4.710	115.81	127.53	115.81	11.72	16.17
4.720	116.69	124.78	116.69	8.09	0.89
4.730	112.84	121.13	112.84	8.29	-3.85
4.740	107.76	118.47	107.76	10.71	-5.09
4.750	99.49	112.74	99.49	13.24	-8.27
4.760	116.81	127.53	116.81	10.72	17.32
4.770	117.22	126.23	117.22	9.02	0.41
4.780	112.77	122.01	112.77	9.24	-4.45
4.790	108.77	118.82	108.77	10.05	-4.00
4.800	99.07	109.52	99.07	10.45	-9.70

4.810	116.80	128.30	116.80	11.50	17.73	5.390	108.77	117.00	108.77	8.23	-4.66
4.820	116.76	125.62	116.76	8.86	-0.04	5.400	99.00	113.49	99.00	14.48	-9.77
4.830	112.53	121.13	112.53	8.60	-4.23	5.410	114.36	124.59	114.36	10.23	15.35
4.840	109.71	124.31	109.71	14.59	-2.82	5.420	115.17	123.96	115.17	8.80	0.81
4.850	100.70	113.49	100.70	12.79	-9.02	5.430	111.98	123.12	111.98	11.14	-3.18
4.860	115.38	125.45	115.38	10.08	14.68	5.440	108.14	118.72	108.14	10.58	-3.85
4.870	116.64	126.54	116.64	9.89	1.27	5.450	100.02	112.08	100.02	12.06	-8.12
4.880	113.20	121.17	113.20	7.97	-3.44	5.460	115.72	125.77	115.72	10.04	15.71
4.890	108.55	117.19	108.55	8.65	-4.65	5.470	116.39	124.59	116.39	8.20	0.66
4.900	98.66	111.86	98.66	13.20	-9.88	5.480	113.46	124.50	113.46	11.04	-2.93
4.910	116.51	127.70	116.51	11.19	17.85	5.490	109.76	119.42	109.76	9.65	-3.70
4.920	115.86	124.65	115.86	8.78	-0.65	5.500	99.28	112.64	99.28	13.36	-10.48
4.930	112.72	122.63	112.72	9.91	-3.15	5.510	114.79	125.25	114.79	10.46	15.51
4.940	108.86	119.06	108.86	10.20	-3.86	5.520	116.15	126.14	116.15	9.99	1.36
4.950	99.99	114.54	99.99	14.56	-8.87	5.530	113.52	123.75	113.52	10.22	-2.63
4.960	116.52	125.56	116.52	9.03	16.54	5.540	108.39	121.79	108.39	13.40	-5.13
4.970	115.47	124.86	115.47	9.39	-1.06	5.550	100.50	112.83	100.50	12.34	-7.89
4.980	112.80	121.40	112.80	8.60	-2.67	5.560	116.62	129.38	116.62	12.76	16.12
4.990	109.14	118.50	109.14	9.36	-3.66	5.570	115.18	124.83	115.18	9.66	-1.44
5.000	99.94	111.01	99.94	11.07	-9.20	5.580	113.28	124.23	113.28	10.95	-1.89
5.010	115.78	126.80	115.78	11.02	15.84	5.590	106.48	117.45	106.48	10.97	-6.80
5.020	116.44	125.43	116.44	8.99	0.66	5.600	98.63	109.66	98.63	11.03	-7.86
5.030	113.50	123.57	113.50	10.06	-2.94	5.610	116.09	127.51	116.09	11.42	17.46
5.040	109.21	119.38	109.21	10.17	-4.29	5.620	118.01	126.40	118.01	8.39	1.92
5.050	101.27	112.88	101.27	11.61	-7.94	5.630	113.30	124.37	113.30	11.07	-4.71
5.060	114.77	126.21	114.77	11.45	13.50	5.640	108.90	117.95	108.90	9.06	-4.40
5.070	116.34	125.29	116.34	8.95	1.57	5.650	98.58	110.52	98.58	11.94	-10.32
5.080	113.42	121.00	113.42	7.58	-2.92	5.660	116.20	125.99	116.20	9.79	17.62
5.090	108.94	118.40	108.94	9.46	-4.48	5.670	114.46	126.61	114.46	12.14	-1.74
5.100	99.39	109.52	99.39	10.12	-9.55	5.680	113.41	123.90	113.41	10.49	-1.05
5.110	115.86	125.42	115.86	9.56	16.47	5.690	109.03	117.90	109.03	8.86	-4.38
5.120	114.62	122.86	114.62	8.24	-1.24	5.700	100.34	113.26	100.34	12.92	-8.69
5.130	114.65	125.19	114.65	10.54	0.03	5.710	116.81	128.27	116.81	11.46	16.47
5.140	109.42	118.77	109.42	9.35	-5.23	5.720	115.11	124.88	115.11	9.78	-1.70
5.150	98.60	108.30	98.60	9.70	-10.82	5.730	113.38	124.12	113.38	10.75	-1.73
5.160	115.78	127.70	115.78	11.93	17.18	5.740	108.15	118.50	108.15	10.35	-5.22
5.170	115.65	125.56	115.65	9.90	-0.12	5.750	99.05	110.71	99.05	11.65	-9.10
5.180	113.17	122.00	113.17	8.82	-2.48	5.760	117.80	128.58	117.80	10.78	18.75
5.190	110.03	120.67	110.03	10.64	-3.14	5.770	116.03	124.36	116.03	8.33	-1.77
5.200	99.93	111.75	99.93	11.83	-10.11	5.780	114.26	126.28	114.26	12.03	-1.77
5.210	116.99	128.10	116.99	11.11	17.06	5.790	110.54	120.98	110.54	10.44	-3.72
5.220	115.92	124.28	115.92	8.36	-1.06	5.800	97.96	110.52	97.96	12.55	-12.58
5.230	113.29	124.35	113.29	11.06	-2.63	5.810	115.71	126.51	115.71	10.80	17.75
5.240	110.37	119.93	110.37	9.57	-2.92	5.820	116.20	128.07	116.20	11.87	0.49
5.250	99.79	113.53	99.79	13.74	-10.57	5.830	111.73	121.15	111.73	9.42	-4.47
5.260	115.74	126.16	115.74	10.42	15.95	5.840	108.91	118.24	108.91	9.34	-2.83
5.270	114.94	124.22	114.94	9.28	-0.80	5.850	98.95	111.59	98.95	12.64	-9.96
5.280	114.08	123.71	114.08	9.63	-0.86	5.860	117.98	131.48	117.98	13.50	19.03
5.290	108.84	120.08	108.84	11.24	-5.23	5.870	115.52	123.55	115.52	8.03	-2.46
5.300	100.39	115.90	100.39	15.51	-8.46	5.880	112.88	121.58	112.88	8.70	-2.64
5.310	116.11	127.58	116.11	11.48	15.72	5.890	108.52	120.83	108.52	12.30	-4.36
5.320	116.05	125.84	116.05	9.79	-0.06	5.900	96.69	107.62	96.69	10.93	-11.83
5.330	113.59	123.87	113.59	10.28	-2.46	5.910	116.52	127.65	116.52	11.13	19.83
5.340	108.62	119.06	108.62	10.44	-4.98	5.920	116.55	124.95	116.55	8.40	0.03
5.350	99.99	111.59	99.99	11.60	-8.62	5.930	113.14	122.42	113.14	9.29	-3.41
5.360	115.56	126.10	115.56	10.54	15.57	5.940	108.70	118.88	108.70	10.18	-4.44
5.370	115.04	123.41	115.04	8.37	-0.52	5.950	97.85	110.95	97.85	13.10	-10.85
5.380	113.43	122.30	113.43	8.87	-1.61	5.960	114.55	124.54	114.55	9.98	16.71

5.970	116.75	125.36	116.75	8.61	2.20
5.980	111.41	122.57	111.41	11.16	-5.34
5.990	108.85	117.71	108.85	8.86	-2.57
6.000	99.86	111.07	99.86	11.21	-8.99
6.010	116.49	127.53	116.49	11.03	16.64
6.020	115.42	123.19	115.42	7.77	-1.07
6.030	112.19	121.09	112.19	8.90	-3.23
6.040	109.91	119.87	109.91	9.96	-2.28
6.050	100.51	114.34	100.51	13.83	-9.40
6.060	116.01	127.30	116.01	11.30	15.50
6.070	115.59	124.12	115.59	8.53	-0.42
6.080	111.88	120.63	111.88	8.75	-3.71
6.090	107.23	116.36	107.23	9.13	-4.65
6.100	99.68	111.42	99.68	11.74	-7.56
6.110	116.69	126.91	116.69	10.22	17.01
6.120	116.27	125.52	116.27	9.25	-0.42
6.130	112.75	122.79	112.75	10.03	-3.51
6.140	108.74	120.35	108.74	11.61	-4.01
6.150	99.57	112.79	99.57	13.22	-9.17
6.160	115.32	126.20	115.32	10.88	15.75
6.170	115.75	124.12	115.75	8.37	0.43
6.180	112.76	122.25	112.76	9.48	-2.99
6.190	107.45	116.86	107.45	9.42	-5.32
6.200	97.72	108.30	97.72	10.58	-9.72
6.210	116.38	126.27	116.38	9.89	18.66
6.220	116.28	126.16	116.28	9.87	-0.10
6.230	113.13	122.00	113.13	8.87	-3.15
6.240	109.19	119.74	109.19	10.55	-3.94
6.250	99.11	111.92	99.11	12.81	-10.08
6.260	117.52	127.56	117.52	10.03	18.42
6.270	116.00	124.51	116.00	8.51	-1.53
6.280	113.22	121.76	113.22	8.54	-2.78
6.290	108.57	119.18	108.57	10.60	-4.65
6.300	99.13	110.46	99.13	11.33	-9.45
6.310	116.16	126.20	116.16	10.04	17.04
6.320	115.67	125.86	115.67	10.19	-0.49
6.330	112.08	121.57	112.08	9.49	-3.59
6.340	108.20	118.40	108.20	10.20	-3.88
6.350	99.99	113.05	99.99	13.06	-8.21
6.360	116.90	127.44	116.90	10.53	16.92
6.370	114.52	125.00	114.52	10.49	-2.39
6.380	113.03	122.91	113.03	9.88	-1.48
6.390	108.72	119.41	108.72	10.68	-4.31
6.400	96.88	110.00	96.88	13.12	-11.84
6.410	115.64	127.91	115.64	12.27	18.76
6.420	116.45	125.06	116.45	8.61	0.81
6.430	113.58	122.94	113.58	9.36	-2.87
6.440	109.84	119.56	109.84	9.72	-3.74
6.450	98.66	109.93	98.66	11.27	-11.18
6.460	115.70	127.02	115.70	11.32	17.04
6.470	115.23	124.45	115.23	9.22	-0.48
6.480	112.76	121.26	112.76	8.50	-2.47
6.490	107.49	118.52	107.49	11.03	-5.27
6.500	98.07	110.13	98.07	12.06	-9.42
6.510	115.99	127.91	115.99	11.92	17.92
6.520	115.65	126.74	115.65	11.09	-0.34
6.530	112.91	121.58	112.91	8.67	-2.74
6.540	109.02	118.37	109.02	9.35	-3.89

6.550	97.22	107.97	97.22	10.75	-11.81
6.560	117.22	127.29	117.22	10.07	20.00
6.570	116.85	126.96	116.85	10.11	-0.37
6.580	111.10	118.50	111.10	7.40	-5.75
6.590	109.02	117.84	109.02	8.83	-2.08
6.600	96.14	107.71	96.14	11.57	-12.88
6.610	115.53	126.15	115.53	10.62	19.39
6.620	114.85	123.49	114.85	8.65	-0.68
6.630	113.28	124.16	113.28	10.88	-1.56
6.640	108.70	119.41	108.70	10.71	-4.58
6.650	97.14	107.35	97.14	10.21	-11.56
6.660	115.99	126.18	115.99	10.19	18.85
6.670	115.36	123.12	115.36	7.76	-0.63
6.680	115.05	124.97	115.05	9.91	-0.31
6.690	107.52	116.90	107.52	9.37	-7.53
6.700	98.51	110.20	98.51	11.69	-9.02
6.710	116.70	125.27	116.70	8.57	18.20
6.720	115.65	126.76	115.65	11.11	-1.05
6.730	112.53	121.33	112.53	8.80	-3.12
6.740	107.87	116.74	107.87	8.87	-4.66
6.750	97.88	111.59	97.88	13.70	-9.98
6.760	116.58	126.01	116.58	9.44	18.69
6.770	116.17	125.59	116.17	9.42	-0.41
6.780	112.43	121.11	112.43	8.68	-3.74
6.790	109.09	119.25	109.09	10.15	-3.34
6.800	98.21	110.95	98.21	12.74	-10.88
6.810	116.47	127.07	116.47	10.60	18.26
6.820	116.76	126.35	116.76	9.58	0.29
6.830	112.74	123.79	112.74	11.05	-4.02
6.840	108.82	118.75	108.82	9.92	-3.92
6.850	95.61	105.76	95.61	10.15	-13.22
6.860	117.50	127.31	117.50	9.81	21.89
6.870	115.49	124.94	115.49	9.46	-2.01
6.880	114.04	123.55	114.04	9.51	-1.44
6.890	108.07	117.57	108.07	9.50	-5.98
6.900	96.84	107.80	96.84	10.95	-11.22
6.910	115.64	126.30	115.64	10.66	18.79
6.920	115.52	123.88	115.52	8.36	-0.11
6.930	112.26	120.57	112.26	8.32	-3.27
6.940	108.54	118.71	108.54	10.17	-3.72
6.950	98.11	110.07	98.11	11.95	-10.42
6.960	117.18	126.52	117.18	9.34	19.06
6.970	115.52	125.10	115.52	9.57	-1.65
6.980	112.38	120.75	112.38	8.37	-3.15
6.990	109.35	119.56	109.35	10.21	-3.03
7.000	97.72	108.93	97.72	11.21	-11.63
7.010	116.97	125.73	116.97	8.76	19.25
7.020	116.53	125.54	116.53	9.01	-0.44
7.030	112.32	121.42	112.32	9.11	-4.21
7.040	107.88	116.96	107.88	9.08	-4.44
7.050	96.64	107.71	96.64	11.07	-11.24
7.060	116.75	127.00	116.75	10.24	20.11
7.070	117.22	125.50	117.22	8.28	0.46
7.080	112.53	122.01	112.53	9.48	-4.68
7.090	108.64	119.27	108.64	10.63	-3.89
7.100	95.95	110.00	95.95	14.05	-12.69
7.110	115.29	125.23	115.29	9.94	19.33
7.120	116.53	124.00	116.53	7.47	1.25

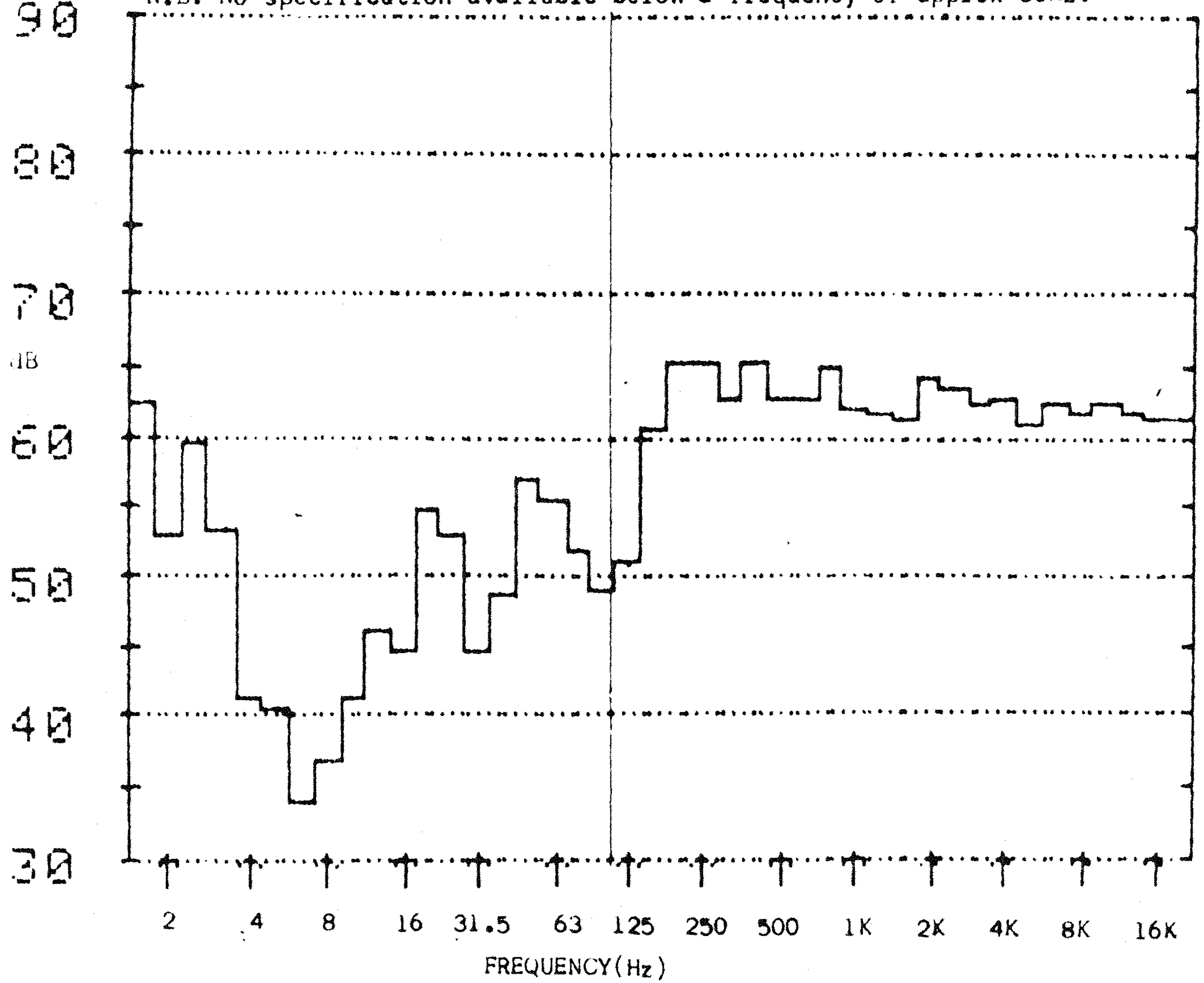
7.130	111.71	123.45	111.71	11.74	-4.82
7.140	108.14	118.03	108.14	9.89	-3.57
7.150	96.41	110.95	96.41	14.54	-11.73
7.160	117.31	127.47	117.31	10.17	20.90
7.170	116.50	126.56	116.50	10.06	-0.81
7.180	112.01	120.90	112.01	8.90	-4.49
7.190	107.62	118.94	107.62	11.32	-4.39
7.200	98.42	111.70	98.42	13.28	-9.20
7.210	116.42	127.11	116.42	10.69	18.00
7.220	115.70	123.83	115.70	8.13	-0.72
7.230	113.01	121.74	113.01	8.73	-2.69
7.240	108.28	118.55	108.28	10.27	-4.73
7.250	96.78	109.00	96.78	12.23	-11.51
7.260	116.26	125.63	116.26	9.38	19.48
7.270	115.97	126.83	115.97	10.86	-0.29
7.280	110.62	121.81	110.62	11.19	-5.34
7.290	107.67	118.57	107.67	10.90	-2.95
7.300	98.45	112.13	98.45	13.68	-9.22
7.310	115.89	126.95	115.89	11.05	17.44
7.320	115.90	125.58	115.90	9.68	0.01
7.330	112.79	122.86	112.79	10.07	-3.11
7.340	109.42	118.65	109.42	9.23	-3.38
7.350	97.26	108.85	97.26	11.59	-12.15
7.360	115.65	128.64	115.65	12.99	18.38
7.370	114.49	124.03	114.49	9.54	-1.15
7.380	113.04	121.78	113.04	8.74	-1.46
7.390	107.93	119.06	107.93	11.13	-5.10
7.400	97.10	108.05	97.10	10.95	-10.83
7.410	116.74	129.61	116.74	12.87	19.63
7.420	116.22	124.29	116.22	8.07	-0.52
7.430	111.43	121.26	111.43	9.83	-4.79
7.440	108.62	120.06	108.62	11.44	-2.81
7.450	96.54	108.78	96.54	12.23	-12.08
7.460	116.83	125.81	116.83	8.98	20.29
7.470	115.79	124.23	115.79	8.44	-1.04
7.480	112.52	122.31	112.52	9.79	-3.27
7.490	108.36	120.45	108.36	12.09	-4.17
7.500	97.89	110.00	97.89	12.11	-10.47
7.510	117.15	126.99	117.15	9.84	19.26
7.520	117.69	127.05	117.69	9.36	0.55
7.530	112.23	122.03	112.23	9.80	-5.47
7.540	107.79	119.27	107.79	11.47	-4.43
7.550	97.90	112.98	97.90	15.07	-9.89
7.560	117.08	127.13	117.08	10.04	19.18
7.570	115.79	126.37	115.79	10.58	-1.30
7.580	112.78	121.26	112.78	8.48	-3.01
7.590	107.79	118.84	107.79	11.05	-4.99
7.600	96.49	107.49	96.49	11.00	-11.30
7.610	116.58	125.77	116.58	9.18	20.09
7.620	115.90	125.53	115.90	9.64	-0.69
7.630	113.79	123.59	113.79	9.80	-2.11
7.640	108.47	118.84	108.47	10.38	-5.32
7.650	97.37	109.15	97.37	11.78	-11.09
7.660	116.35	126.79	116.35	10.44	18.97
7.670	116.88	127.83	116.88	10.94	0.54
7.680	112.02	120.49	112.02	8.48	-4.87
7.690	108.81	119.20	108.81	10.38	-3.20
7.700	96.43	108.46	96.43	12.03	-12.38
7.710	115.56	126.15	115.56	10.59	19.13
7.720	116.22	127.05	116.22	10.84	0.66
7.730	111.93	124.45	111.93	12.51	-4.28
7.740	108.23	118.21	108.23	9.99	-3.70
7.750	96.31	109.73	96.31	13.42	-11.92
7.760	116.60	126.25	116.60	9.65	20.29
7.770	117.32	125.79	117.32	8.47	0.72
7.780	112.52	123.51	112.52	10.98	-4.80
7.790	108.46	118.03	108.46	9.57	-4.06
7.800	96.12	109.59	96.12	13.46	-12.34
7.810	117.02	125.96	117.02	8.94	20.90
7.820	115.94	124.80	115.94	8.86	-1.09
7.830	112.52	121.22	112.52	8.71	-3.42
7.840	107.40	117.54	107.40	10.14	-5.11
7.850	94.96	107.71	94.96	12.75	-12.44
7.860	117.13	125.82	117.13	8.69	22.17
7.870	114.85	123.92	114.85	9.08	-2.28
7.880	110.84	120.59	110.84	9.76	-4.01
7.890	107.44	116.56	107.44	9.11	-3.39
7.900	94.63	105.76	94.63	11.13	-12.82
7.910	117.43	128.62	117.43	11.20	22.80
7.920	116.03	124.65	116.03	8.62	-1.39
7.930	112.19	123.82	112.19	11.62	-3.84
7.940	107.22	116.62	107.22	9.40	-4.98
7.950	94.74	106.89	94.74	12.15	-12.48
7.960	116.90	127.27	116.90	10.37	22.16
7.970	114.92	123.06	114.92	8.14	-1.98
7.980	111.97	121.53	111.97	9.56	-2.95
7.990	108.43	120.48	108.43	12.05	-3.54
8.000	96.36	106.69	96.36	10.34	-12.08
8.010	117.80	125.97	117.80	8.17	21.45
8.020	115.57	125.46	115.57	9.89	-2.24
8.030	112.27	122.33	112.27	10.06	-3.30
8.040	107.51	117.71	107.51	10.20	-4.76
8.050	96.42	107.62	96.42	11.20	-11.08
8.060	117.44	128.64	117.44	11.20	21.02
8.070	114.97	126.95	114.97	11.98	-2.48
8.080	111.56	121.65	111.56	10.09	-3.40
8.090	106.88	116.23	106.88	9.35	-4.68
8.100	96.52	107.08	96.52	10.56	-10.37
8.110	117.16	126.28	117.16	9.13	20.64
8.120	115.19	124.66	115.19	9.47	-1.97
8.130	112.80	121.98	112.80	9.18	-2.39
8.140	107.31	119.00	107.31	11.69	-5.49
8.150	95.92	108.93	95.92	13.01	-11.39
8.160	117.81	129.78	117.81	11.98	21.89
8.170	115.75	126.92	115.75	11.17	-2.06
8.180	113.12	121.28	113.12	8.16	-2.63
8.190	108.43	119.13	108.43	10.70	-4.69
8.200	95.47	108.62	95.47	13.15	-12.96
8.210	117.05	125.79	117.05	8.74	21.58
8.220	114.92	125.57	114.92	10.65	-2.13
8.230	112.40	119.86	112.40	7.46	-2.52
8.240	108.14	118.27	108.14	10.13	-4.26
8.250	96.88	110.26	96.88	13.38	-11.25
8.260	116.05	124.94	116.05	8.89	19.17
8.270	114.80	125.04	114.80	10.24	-1.26
8.280	111.92	122.65	111.92	10.73	-2.88

8.290	105.94	114.38	105.94	8.44	-5.98
8.300	97.74	109.79	97.74	12.05	-8.20
8.310	117.14	128.59	117.14	11.45	19.40
8.320	114.33	124.07	114.33	9.74	-2.81
8.330	112.72	121.46	112.72	8.74	-1.61
8.340	107.83	119.47	107.83	11.65	-4.89
8.350	94.05	105.20	94.05	11.14	-13.77
8.360	116.88	125.28	116.88	8.40	22.83
8.370	117.13	127.40	117.13	10.28	0.24
8.380	113.32	124.51	113.32	11.20	-3.81
8.390	107.74	117.59	107.74	9.86	-5.58
8.400	96.07	106.39	96.07	10.32	-11.67
8.410	117.07	126.75	117.07	9.68	21.00
8.420	116.07	124.97	116.07	8.91	-1.00
8.430	112.64	121.46	112.64	8.82	-3.43
8.440	107.93	119.43	107.93	11.50	-4.70
8.450	94.11	105.31	94.11	11.20	-13.82
8.460	116.58	125.10	116.58	8.51	22.47
8.470	116.07	125.00	116.07	8.93	-0.51
8.480	112.68	122.16	112.68	9.48	-3.39
8.490	108.30	118.14	108.30	9.84	-4.38
8.500	96.52	106.89	96.52	10.37	-11.78
8.510	117.38	127.04	117.38	9.67	20.86
8.520	116.54	126.57	116.54	10.02	-0.83
8.530	112.41	120.90	112.41	8.50	-4.14
8.540	106.61	116.52	106.61	9.91	-5.79
8.550	93.76	104.47	93.76	10.70	-12.85
8.560	116.94	125.60	116.94	8.66	23.18
8.570	116.41	124.89	116.41	8.49	-0.53
8.580	112.20	121.07	112.20	8.87	-4.21
8.590	108.33	118.03	108.33	9.70	-3.87
8.600	95.56	109.08	95.56	13.52	-12.77
8.610	116.37	123.73	116.37	7.36	20.81
8.620	115.52	125.73	115.52	10.22	-0.85
8.630	112.11	120.92	112.11	8.81	-3.40
8.640	108.34	117.98	108.34	9.63	-3.77
8.650	93.07	103.53	93.07	10.46	-15.27
8.660	117.05	127.17	117.05	10.13	23.97
8.670	116.26	127.19	116.26	10.93	-0.79
8.680	111.93	122.82	111.93	10.89	-4.33
8.690	107.48	117.76	107.48	10.28	-4.44
8.700	96.80	110.39	96.80	13.60	-10.69
8.710	116.00	125.99	116.00	9.98	19.21
8.720	114.27	123.55	114.27	9.28	-1.73
8.730	113.43	122.69	113.43	9.26	-0.84
8.740	106.31	116.07	106.31	9.76	-7.12
8.750	93.33	107.35	93.33	14.03	-12.99
8.760	118.25	126.89	118.25	8.64	24.92
8.770	115.64	125.98	115.64	10.34	-2.61
8.780	111.13	120.45	111.13	9.32	-4.51
8.790	107.48	116.23	107.48	8.76	-3.65
8.800	94.77	106.69	94.77	11.92	-12.70
8.810	116.53	127.10	116.53	10.57	21.76
8.820	115.78	125.96	115.78	10.18	-0.75
8.830	111.76	121.06	111.76	9.29	-4.02
8.840	107.61	118.52	107.61	10.91	-4.15
8.850	94.47	107.80	94.47	13.33	-13.14
8.860	117.64	126.66	117.64	9.01	23.18
8.870	114.30	125.73	114.30	11.43	-3.34
8.880	112.09	124.38	112.09	12.29	-2.21
8.890	106.97	116.65	106.97	9.68	-5.12
8.900	95.88	108.05	95.88	12.17	-11.09
8.910	117.23	127.04	117.23	9.82	21.35
8.920	115.48	125.25	115.48	9.76	-1.74
8.930	112.95	121.94	112.95	8.99	-2.53
8.940	106.36	116.14	106.36	9.78	-6.59
8.950	94.43	105.20	94.43	10.76	-11.93
8.960	117.18	126.04	117.18	8.87	22.75
8.970	114.36	127.36	114.36	12.99	-2.81
8.980	111.80	120.33	111.80	8.53	-2.56
8.990	106.98	115.52	106.98	8.54	-4.82
9.000	95.93	108.93	95.93	12.99	-11.04
9.010	116.74	125.54	116.74	8.80	20.81
9.020	115.51	123.34	115.51	7.83	-1.23
9.030	112.82	121.88	112.82	9.05	-2.68
9.040	106.15	116.00	106.15	9.85	-6.67
9.050	94.27	104.65	94.27	10.38	-11.88
9.060	115.90	125.05	115.90	9.15	21.63
9.070	114.20	124.20	114.20	10.00	-1.69
9.080	112.23	121.31	112.23	9.09	-1.97
9.090	107.91	120.45	107.91	12.55	-4.32
9.100	95.27	107.17	95.27	11.90	-12.63
9.110	117.64	126.86	117.64	9.22	22.37
9.120	115.22	124.20	115.22	8.98	-2.41
9.130	112.49	122.57	112.49	10.07	-2.73
9.140	108.63	119.13	108.63	10.50	-3.86
9.150	94.07	104.59	94.07	10.52	-14.56
9.160	116.74	128.21	116.74	11.47	22.67
9.170	116.53	126.00	116.53	9.47	-0.21
9.180	112.62	122.16	112.62	9.54	-3.91
9.190	106.55	117.19	106.55	10.65	-6.07
9.200	95.03	107.62	95.03	12.60	-11.52
9.210	116.53	125.77	116.53	9.23	21.51
9.220	116.36	125.50	116.36	9.14	-0.17
9.230	114.38	124.22	114.38	9.84	-1.99
9.240	108.62	117.13	108.62	8.52	-5.76
9.250	96.46	108.70	96.46	12.24	-12.16
9.260	116.05	125.40	116.05	9.35	19.59
9.270	115.20	127.11	115.20	11.91	-0.85
9.280	111.99	121.30	111.99	9.31	-3.21
9.290	107.12	119.67	107.12	12.55	-4.87
9.300	92.95	104.34	92.95	11.39	-14.17
9.310	117.08	127.00	117.08	9.93	24.13
9.320	116.04	125.66	116.04	9.62	-1.04
9.330	111.96	121.69	111.96	9.73	-4.08
9.340	107.41	118.67	107.41	11.26	-4.55
9.350	95.80	107.80	95.80	12.00	-11.61
9.360	118.43	129.14	118.43	10.71	22.63
9.370	115.50	127.01	115.50	11.51	-2.93
9.380	111.98	122.95	111.98	10.98	-3.52
9.390	106.52	119.99	106.52	13.46	-5.45
9.400	93.81	106.59	93.81	12.79	-12.72
9.410	117.43	125.78	117.43	8.35	23.62
9.420	114.61	123.37	114.61	8.75	-2.82
9.430	112.73	122.42	112.73	9.70	-1.89
9.440	107.80	117.40	107.80	9.60	-4.93
9.450	93.41	105.08	93.41	11.66	-14.39
9.460	117.88	127.25	117.88	9.36	24.47
9.470	115.55	125.81	115.55	10.26	-2.34
9.480	111.86	121.04	111.86	9.18	-3.69
9.490	106.73	117.48	106.73	10.75	-5.13
9.500	93.76	106.19	93.76	12.42	-12.97
9.510	116.93	125.73	116.93	8.80	23.17
9.520	113.69	124.45	113.69	10.76	-3.25
9.530	110.47	119.18	110.47	8.70	-3.22
9.540	106.57	115.73	106.57	9.16	-3.90
9.550	92.10	105.08	92.10	12.98	-14.47
9.560	116.45	124.86	116.45	8.41	24.34
9.570	114.99	123.40	114.99	8.40	-1.45
9.580	114.17	122.56	114.17	8.39	-0.83
9.590	107.43	116.86	107.43	9.43	-6.73
9.600	95.32	107.97	95.32	12.65	-12.11
9.610	116.69	125.39	116.69	8.70	21.37
9.620	114.79	123.96	114.79	9.17	-1.90
9.630	111.85	122.65	111.85	10.80	-2.94
9.640	106.76	115.87	106.76	9.11	-5.09
9.650	94.22	106.59	94.22	12.37	-12.53
9.660	117.69	127.69	117.69	10.00	23.47
9.670	114.42	123.03	114.42	8.61	-3.27
9.680	111.98	121.39	111.98	9.41	-2.44

9.690	106.45	116.59	106.45	10.14	-5.53
9.700	94.27	105.43	94.27	11.16	-12.18
9.710	118.02	126.67	118.02	8.65	23.75
9.720	114.75	124.72	114.75	9.97	-3.27
9.730	112.04	123.15	112.04	11.10	-2.70
9.740	106.47	115.90	106.47	9.43	-5.58
9.750	93.88	106.19	93.88	12.30	-12.59
9.760	117.36	126.78	117.36	9.43	23.48
9.770	114.46	124.45	114.46	9.99	-2.90
9.780	112.08	122.38	112.08	10.30	-2.38
9.790	107.35	118.70	107.35	11.35	-4.73
9.800	92.89	103.74	92.89	10.85	-14.46
9.810	116.86	125.39	116.86	8.53	23.97
9.820	115.16	125.24	115.16	10.07	-1.70
9.830	111.99	120.92	111.99	8.94	-3.18
9.840	106.15	117.95	106.15	11.80	-5.83
9.850	91.35	104.59	91.35	13.24	-14.80
9.860	117.79	128.24	117.79	10.45	26.43
9.870	115.23	124.75	115.23	9.52	-2.56
9.880	112.51	123.79	112.51	11.28	-2.72
9.890	107.35	118.29	107.35	10.94	-5.16
9.900	93.36	103.53	93.36	10.17	-13.99
9.910	116.10	126.35	116.10	10.25	22.73
9.920	114.74	123.83	114.74	9.09	-1.36
9.930	112.36	122.77	112.36	10.41	-2.38
9.940	107.64	118.71	107.64	11.07	-4.73
9.950	93.17	105.43	93.17	12.26	-14.47
9.960	118.04	127.21	118.04	9.17	24.88
9.970	116.27	127.73	116.27	11.46	-1.77
9.980	112.25	121.79	112.25	9.54	-4.03
9.990	106.85	116.99	106.85	10.14	-5.40
10.000	93.66	110.95	93.66	17.29	-13.19

KURTOSIS MEASURE FOR NOISE(REF TO 10E-6V)= 5.66
CREST FACTOR FOR TOTAL DURATION OF SIGNAL= 6.56
MAX VALUE OF [Leq(i)-Leq(i-1)]= 26.43
MAX VALUE OF SMALL TIME PERIOD CREST LEVEL= 17.29
AVERAGED VALUE OF NPL IMPULSIVITY DESCRIPTOR;I = 15.12
TOTAL 10 SECOND LEQ (re 1uV) =113.45

APPENDIX 5.1. Frequency response of the anechoic room, and loudspeaker system.
Pink noise recorded at the subject's head position.
N.B. No specification available below a frequency of approx 80Hz.



APPENDIX 5.2

MEDICAL FITNESS FOR THE EXPERIMENT

Persons with any of the following conditions are considered unfit for the present experiment involving sound.

Persons who, in the last year, have suffered from:

1. Pain in the ear
2. Noises in the ear (except after exposure to noise)
3. Discharge from the ear
4. Infection of the ear

Persons who at present or within the last week have suffered from a common cold.

APPENDIX 5.3

INSTRUCTIONS

Thank you for offering to participate in this study. You are going to hear 36 sounds and in each case we would like you to rate how impulsive you feel the sound to be. According to BS 4142 a noise is defined as being impulsive if there are significant impulsive regularities in the noise (e.g., bangs, clicks, clatters or thumps), or if the character of the noise is irregular enough to attract attention. The scale is from 0–9 and before the experiment begins you will be given an example of a sound that has definite impulsive character (rating of 7–9) and a sound that has no impulsive character (rating of 0–2).

Each sound will last for 30 seconds. Please rate the sound at the end of this period. At the end of each set of 12 sounds you will be given a new questionnaire for the next set of sounds.

You are free to leave the experiment at any time.

Hz	ms	SUBJECTS 1-36																																			MEAN
2.5	5	8	8	7	9	5	6	9	9	9	8	8	9	6	8	9	9	6	9	9	9	8	9	9	9	9	6	9	6	9	6	9	9	9	9	9	8	8.139
	10	7	8	7	9	6	6	9	8	8	8	6	9	5	9	9	8	9	8	8	9	8	9	9	9	9	9	9	7	7	7	9	9	9	8	8	6	8.000
	20	8	8	6	9	8	6	8	9	9	8	9	9	9	6	8	8	8	6	8	9	8	9	9	9	9	8	9	6	7	7	7	9	9	9	7	7	8.000
	40	9	8	7	9	7	7	9	8	8	7	8	9	8	7	8	8	8	6	8	8	8	9	8	9	8	9	9	7	6	9	8	9	9	8	8	9	8.056
	80	7	8	9	9	8	8	9	8	7	9	8	9	8	7	8	8	9	6	8	9	9	9	9	8	9	9	8	7	9	9	9	7	9	9	9	8	8.306
	160	6	9	8	9	7	8	7	7	8	8	8	8	8	6	8	8	9	7	8	9	7	9	9	9	8	8	8	7	9	9	9	8	9	7	8	9	8.028
5	5	8	8	6	9	7	7	9	7	9	8	7	9	7	7	9	9	8	9	7	9	8	9	9	9	8	8	9	6	7	6	8	9	6	8	7	7	7.861
	10	8	9	7	9	7	7	9	8	8	8	7	9	8	7	6	8	9	9	7	9	8	9	9	9	9	8	9	7	9	7	8	9	8	8	8	8	8.111
	20	7	8	7	8	8	8	9	7	9	7	8	9	9	8	8	8	9	7	7	9	8	9	9	9	9	8	9	6	6	7	8	8	9	8	8	7	8.000
	40	7	7	7	9	8	7	7	9	8	7	6	9	8	8	9	8	9	6	8	9	7	9	9	9	9	9	9	7	9	8	9	8	5	8	5	8	7.890
	80	6	8	6	8	9	8	8	7	6	9	7	9	8	7	9	8	9	6	9	9	9	9	7	8	9	9	9	7	9	8	6	8	9	9	8	8	8.000
	160	7	7	8	9	8	8	6	8	6	5	5	9	5	8	3	7	8	5	7	8	7	9	9	9	7	8	8	7	9	8	8	7	8	7	5	9	7.278
10	5	8	6	3	8	9	6	9	7	9	9	8	9	6	6	8	9	8	9	8	9	8	9	9	9	8	9	9	8	6	6	8	7	6	9	7	7	7.750
	10	8	7	7	9	9	7	8	7	8	7	8	9	8	7	8	8	8	9	8	9	9	9	8	9	7	9	8	8	8	8	7	8	6	9	9	8	8.033
	20	9	6	4	9	9	8	8	7	7	6	6	9	7	7	8	6	8	8	8	9	9	9	7	9	9	9	9	9	7	6	8	8	6	9	7	9	7.750
	40	7	7	3	7	8	8	8	8	7	7	7	9	7	8	8	6	8	5	9	8	9	9	6	9	8	9	7	8	7	7	7	6	6	7	5	8	7.305
	80	7	5	2	5	7	7	7	6	5	6	6	9	6	8	6	7	8	5	7	7	8	9	7	7	8	8	6	7	9	5	7	8	6	8	6	7	6.722
	160	5	4	2	3	3	5	5	4	4	5	4	4	2	6	2	5	8	2	7	7	6	7	6	8	6	4	8	6	8	6	5	5	5	7	8	6	5.222
20	5	7	5	3	5	3	9	6	6	8	5	5	8	6	7	6	3	7	8	9	7	8	9	7	9	8	8	7	7	9	7	4	7	5	8	8	5	6.639
	10	7	6	2	5	7	8	8	8	7	7	7	8	6	3	5	5	8	8	9	8	8	9	6	9	8	9	7	8	6	6	6	7	6	9	6	6	6.889
	20	7	6	4	6	5	7	8	5	7	8	7	8	7	5	4	3	8	6	8	6	7	9	7	9	9	9	8	8	9	8	5	9	5	8	6	5	6.833
	40	8	5	3	5	5	6	7	6	6	8	5	8	5	6	5	4	5	6	5	7	6	9	7	9	7	7	9	6	5	5	5	9	5	9	8	7	6.333
	80	6	5	2	4	2	5	6	3	3	5	3	6	2	5	2	1	7	1	5	3	4	8	3	7	7	7	8	6	4	4	3	4	4	5	6	7	4.528
	160	3	2	1	1	1	3	3	3	3	3	2	4	1	3	1	2	6	1	2	3	3	4	0	1	2	0	2	5	2	2	2	3	1	4	3	4	2.389
40	5	8	5	3	3	4	4	5	3	8	7	7	8	5	4	3	4	7	6	6	6	6	9	4	9	9	8	6	8	8	5	4	5	5	8	6	6	5.889
	10	6	4	2	5	4	5	6	7	7	5	6	7	6	3	2	3	6	5	4	6	3	9	4	9	6	8	6	7	3	5	4	5	5	8	6	7	5.389
	20	7	3	2	3	4	5	3	4	5	6	3	4	3	5	5	2	9	5	6	6	7	8	4	9	6	8	7	5	3	4	3	7	4	6	6	4	5.028
	40	4	3	1	5	2	3	4	3	4	4	4	3	1	2	2	1	7	1	5	4	4	6	2	4	4	5	5	3	1	3	2	1	3	3	4	2	3.194
	80	1	1	1	1	1	2	1	1	2	3	1	0	0	1	1	0	0	0	2	0	1	4	0	0	0	0	0	4	0	2	0	1	2	3	4	1	1.139
	160	0	0	0	0	0	1	1	1	4	3	1	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0.500
80	5	5	3	3	1	1	4	5	4	7	7	4	6	5	3	1	1	6	5	3	3	6	8	4	9	6	5	5	8	4	4	2	5	3	4	5	4	4.417
	10	4	2	2	2	1	2	4	2	4	4	1	3	1	2	1	1	3	1	3	6	2	8	1	7	4	4	5	6	2	3	3	2	3	3	5	4	3.083
	20	4	3	1	1	1	4	1	3	3	3	1	3	3	2	2	0	2	1	2	1	3	8	1	5	2	2	4	3	0	2	1	1	1	3	2	2	2.250
	40	1	1	0	0	0	0	0	0	3	2	0	0	0	0	0	0	1	0	2	0	1	4	0	0	1	0	0	3	0	2	1	0	1	2	1	2	0.778
	80	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	2	0	0	5	0	1	0	0	0	0	0	0.361
	160	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0.250

APPENDIX 5.4. Individual subject impulsivity scores for each synthetic sound (repetition rate in Hz, decay time in ms).

Hz	ms	SUBJECTS 1-36																																			
2.5	.5	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	40	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	80	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	160	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	40	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	80	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	160	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	5	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	20	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
	40	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	80	1	1	0	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
	160	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	1	1	1	1	0	1	1	1	0	1	0	1	1	1	1
20	5	1	1	0	0	0	1	1	0	1	0	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
	10	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
	20	1	1	0	0	0	1	1	0	1	1	1	1	1	0	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
	40	1	1	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
	80	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0	1	1
	160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
40	5	1	1	0	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	1
	10	1	0	0	0	0	0	1	1	1	0	1	1	1	0	0	0	1	1	0	0	0	1	0	1	1	1	1	1	0	0	1	0	1	1	1	1
	20	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	1	0	1	1	0	1	1	1	0	1	0	0	0	1	0	1	1	0
	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	5	1	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	1	1	0	0	1	1	0	1	1	1	0	1	0	0	0	0	0	0	1	0
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	1	0
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 5.5. Dichotomised impulsivity scores for each synthetic sound (repetition rate in Hz, decay time in ms).

APPENDIX 7.1 COMPARISON OF SUBJECTIVE AND OBJECTIVE ANALYSIS OF CEC COMBINATION NOISE STUDIES.

SECTION 1 LABORATORY STUDY.

1.1 Introduction.

Work has been performed by the EEC to investigate combinations of gunfire noise and traffic noise and is reported by Rice [A3]. This section outlines these laboratory studies undertaken at the ISVR which investigated the influence of road traffic noise on the judged annoyance of the impulsive noise.

1.2 Experimental Design.

The experiment was performed in the listening room facility at the ISVR. Each subject heard two sounds in combination; a gunfire (impulsive) noise and a traffic (background) noise. The sounds were heard at one of four equal energy levels (35, 45, 55, 65 dB L_{Aeq}) governed by the experimental design. Sixty-four subjects heard sixteen different treatments of the two five minute noise conditions.

1.3 RESULTS.

The mean annoyance scores for the impulsive noises are shown in Table A7.1 and are plotted against impulsive noise L_{Aeq} in Figure A7.1. Initial inspection suggests that for all conditions with a positive signal/noise ratio (L_{Aeq} impulsive noise - L_{Aeq} traffic noise) the annoyance response to impulsive noise appears to be independent of the traffic noise level. It is also clear that for conditions where the signal/noise ratio is -20dB or less, the annoyance ratings are negligible.

Impulsive Noise L_{Aeq} dB

Impulsive Noise L_{Aeq} dB		35	45	55	65
	35	2.25 (0)	3.50 (+10)	4.81 (+20)	7.00 (+30)
	45	2.00 (-10)	3.25 (0)	4.69 (+10)	6.25 (+20)
	55	0.38 (-20)	2.44 (-10)	4.50 (0)	7.06 (+10)
	65	0.06 (-30)	0.63 (-20)	3.38 (-10)	6.06 (0)

Table A7.1 Values of mean annoyance ratings of impulsive noise for differing levels of impulsive and traffic noise. (Signal/Noise Ratio)

The Standard Error of the Differences of the Means (SED) is 0.4435, and hence if the difference between the means of any two sounds is greater than 0.906, they may be considered to be significantly different at the 5% level of significance. Using this criterion groups can be formed of noise conditions whose annoyance scores are significantly different. At a given level of impulsive noise, groups can be used to demonstrate which levels of traffic noise (and hence signal/noise ratios) have a significant effect on the annoyance response to the impulsive noise. These groups are illustrated in Table A7.2, where the mean annoyance scores for each condition have been replaced by the mean annoyance score for each significantly different group. The signal/noise ratio is included for each condition.

Traffic Noise L_{Aeq} dB	Impulsive Noise L_{Aeq} 35	45	55	65
35	2.13 (0)	3.08 (+10)	4.67 (+20)	6.59 (+30)
45	2.13 (-10)	3.08 (0)	4.67 (+10)	6.59 (+20)
55	____ (-20)	3.08 (-10)	4.67 (0)	6.59 (+10)
65	____ (-30)	____ (-20)	3.38 (-10)	6.59 (0)

Table A7.2 Values of mean annoyance ratings of impulsive noise for significantly different groups at the 5% level of significance, for differing levels of impulsive and traffic noise. (Signal/Noise Ratio)

The groups suggest that for all conditions possessing a positive signal/noise ratio (i.e. L_{Aeq} impulsive noise $\geqslant L_{Aeq}$ traffic noise) the annoyance response due to impulsive noise is unaffected by the traffic noise level, and can be represented by a single dose-response relationship, given in Figure A7.2.

1.4 Conclusions.

The results of this laboratory study suggest the following:-

(a) If the L_{Aeq} of the impulsive noise is greater or equal to the L_{Aeq} of the traffic noise, the annoyance response to the impulsive noise is independent of the traffic noise level.

(b) If the signal/noise ratio (L_{Aeq} impulsive noise _ L_{Aeq} traffic noise) is less than zero but greater than -20dB, the traffic noise level may reduce the annoyance response evoked by the impulsive noise, at some higher impulsive noise levels, within the range 35-65 L_{Aeq}.

(c) If the signal/noise ratio is less than or equal to -20dB, the annoyance response due to the impulsive noise is negligible. In this condition the impulsive noise appears to be masked by the traffic noise.

SECTION 2 OBJECTIVE STUDY.

2.1 Introduction.

Using the software package developed in Chapter 4, sounds presented in the study described in Section 1 were objectively analysed on the computer system.

2.2 Experimental Design.

The treatments used in the laboratory study consisted of combinations of impulsive (gunfire) and traffic noise presented at seven different signal/noise ratios: +30, +20, +10, 0,-10,-20,-30 dB(A). Recordings of these conditions, together with impulsive noise and traffic noise in isolation were made at the subject's head position, and used in this objective study.

2.3 Results.

The full set of results are given in Table A7.3.

2.3.1 $K_{31.6ms}$ Descriptor.

Using the criteria for an impulsive noise, defined in Chapter 6 of $K_{31.6ms} \geq 6.9$, all noise conditions with a positive signal/noise ratio will be classed as impulsive. The condition of -10 dB signal/noise ratio will be classed in the 'grey' region of uncertainty. The criteria for a noise to be objectively classed as non-impulsive was defined as $K_{31.6ms} \leq 2.9$, and hence even conditions with a signal/noise ratio of -30 dB are not classed as impulsive. As expected traffic noise in isolation is classed as non-impulsive.

2.3.2 K_{10ms} Descriptor.

Using the criteria for an impulsive noise, defined in Chapter 6 of $K_{10MS} \geq 26.3$, only gunfire noise in isolation will be classed as impulsive. Even

IMPULSIVE L_{Aeq} dB	TRAFFIC L_{Aeq} dB	S/N RATIO dB	KURTOSIS	CREST FACTOR dB	NPL DESCRIPTOR	MAX CREST LEVELS 10ms	31.6ms	K DESCRIPTOR 10ms	31.6ms
65	0	$+\infty$	33.30	16.50	——	15.84	13.07	30.64	31.86
65	35	+30	32.30	16.65	15.35	15.60	20.36	23.37	30.63
65	45	+20	25.63	14.86	17.61	16.25	21.43	24.75	27.56
65	55	+10	23.13	16.34	15.40	12.62	17.11	17.18	19.16
65	65	0	8.34	10.52	14.78	12.38	14.07	10.33	12.70
55	65	-10	4.29	6.89	14.98	12.79	13.00	4.67	6.58
45	65	-20	4.33	6.00	14.50	12.29	12.74	3.36	3.02
35	65	-30	5.52	6.04	15.15	13.93	14.28	3.59	2.91
0	65	$-\infty$	3.69	5.54	14.39	12.53	12.76	3.31	2.69

TABLE A7.3 Impulsivity descriptor values for each noise condition.

conditions with a signal/noise ratio of +30 dB will be placed in the region of uncertainty. This suggests that the criteria proposed for the K_{10ms} descriptor, given in Chapter 6, may be too conservative and should perhaps include more sounds in the 'grey' region of uncertainty.

Conditions with a value of $K_{10ms} < 5.5$ will be classed as non-impulsive and treatments with a signal/noise ratio of less than -10 dB fall into this catergory.

Figure A7.3 shows an example of the raw signal, crest levels, L_{Aeq}s, and $L_{Aeq}(i)-L_{Aeq}(i-1)$ values measured over consecutive small-time periods of 31.6ms, for the condition with a signal/noise ratio of -10 dB.

2.4 Conclusions.

The $K_{31.6ms}$ descriptor appears to give the best correlation between the results of subjective and objective studies. If the criteria for an impulsive noise of $K_{31.6ms} \geq 6.9$ is applied to the combinations of noises, those conditions where the L_{Aeq} of the impulsive noise is greater or equal to the L_{Aeq} of the traffic noise (positive signal/noise ratio) will be objectively classed as impulsive by this descriptor. The laboratory study described in Section 1 showed that traffic noise level has no effect on the annoyance response to impulsive noise for these same conditions, which can be represented by a single dose-response relationship. The results suggest that if a condition has a value of $K_{31.6ms} \geq 6.9$ it will be subjectively judged as impulsive, and be subjectively judged as significantly more annoying than non-impulsive noise.

Conditions with a signal/noise ratio of less than 0 dB cannot be classed clearly as impulsive, or non-impulsive by the $K_{31.6ms}$ descriptor, and lie in the 'grey' region of uncertainty, discussed in Chapters 6. This may be due to the influence of the traffic noise level on the annoyance judgement of the impulsive noise for some of these conditions, which was illustrated in the laboratory study.

REFERENCE.

A3 C.G.RICE 1985 'CEC Joint project on impulse noise: Effect of road traffic level on judged annoyance'. Proceedings of Inter-Noise '85, Munich, W. Germany.

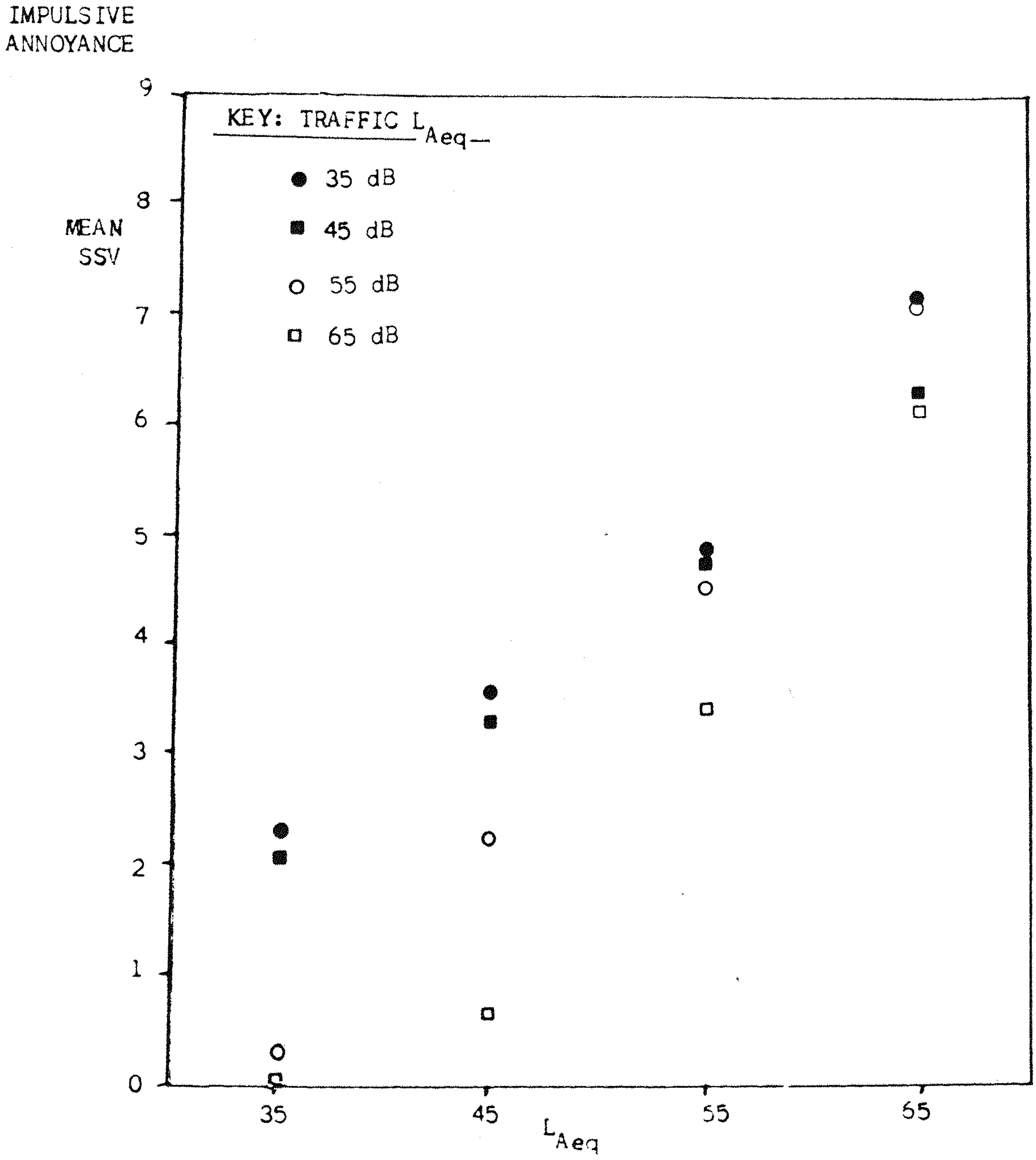


FIGURE A7.1. Plot of annoyance response to impulsive noise against level of impulsive noise, for combinations of impulsive and traffic noise.

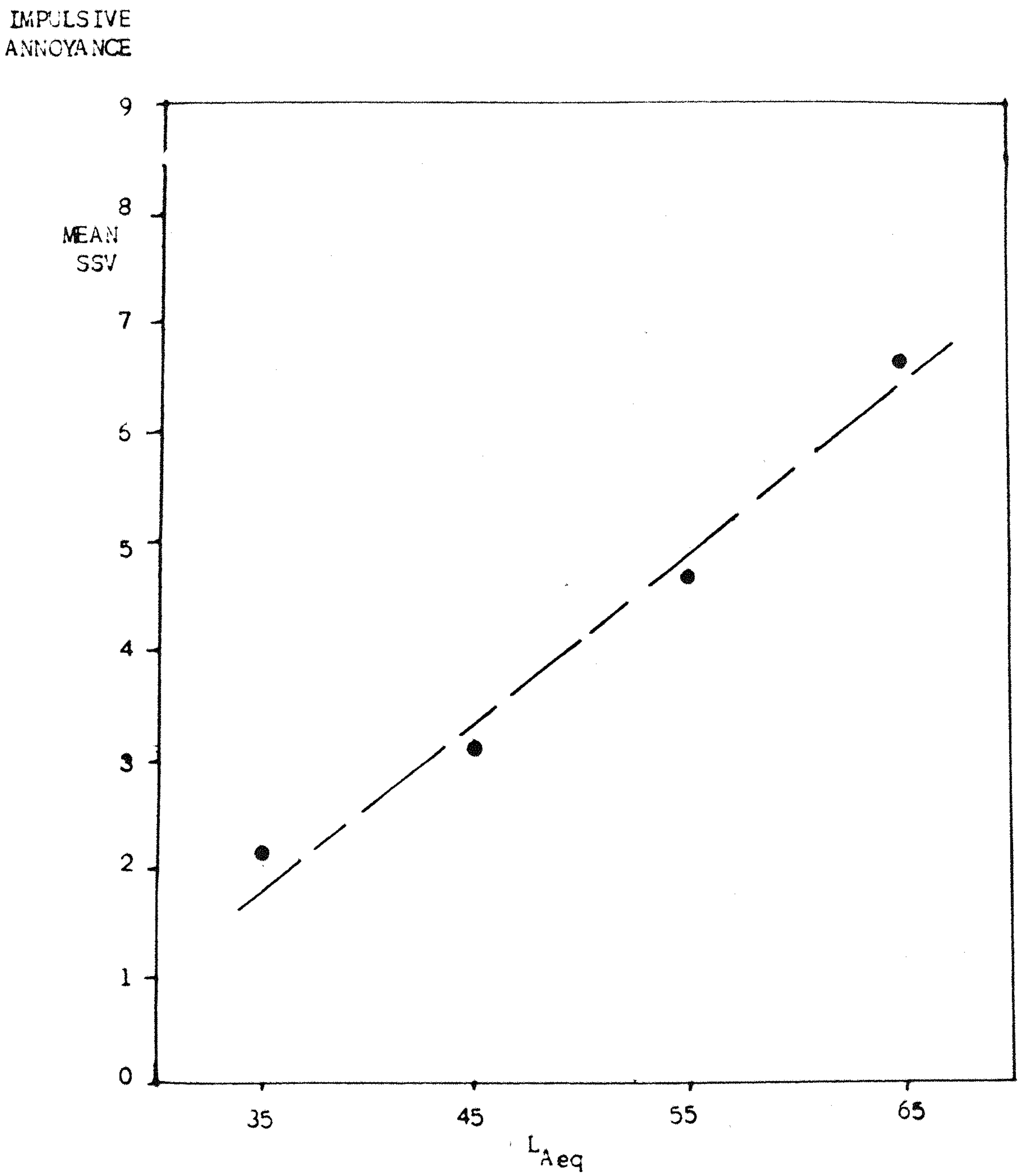


FIGURE A7.2 Plot of annoyance response to impulsive noise, for signifi- different groups of conditions, against level of impulsive noise.

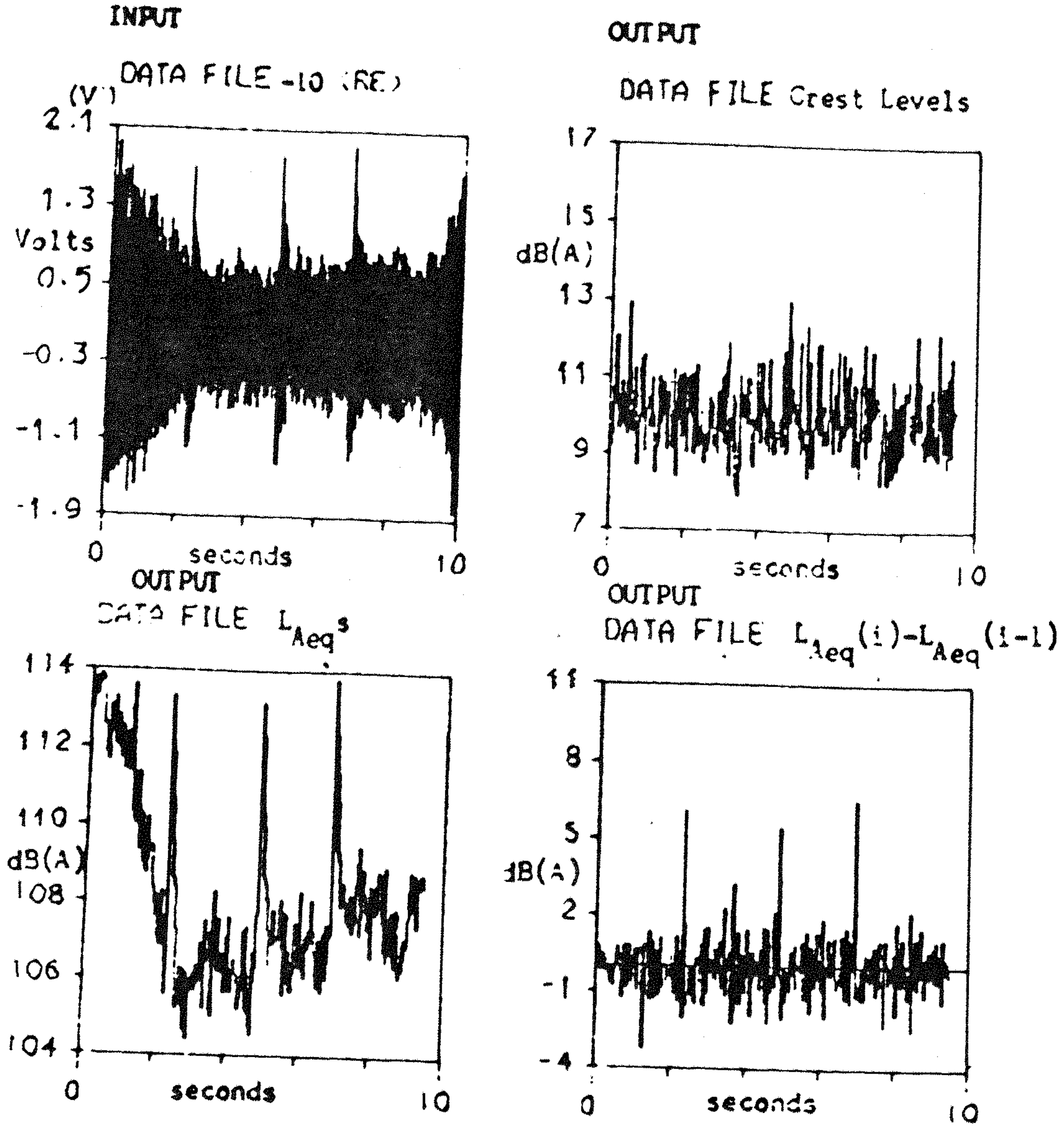


FIGURE A7.3. Gunfire (G1) at 55 dB L_{eq} in combination with traffic (T1) at 65 dB L_{eq}.
10 second segment of sound analysed over a small time period of 31.6 ms.