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AUDITORY IMPAIRMENT AND THE ONSET OF DISABILITY AND HANDICAP IN NOISE-INDUCED HEARING LOSS

D.W. Robinson, P.A. Wilkins, N.J. Thyer and J.F. Lawes

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ABSTRACT

An investigation was carried out on subjects with mild degrees of noise-induced hearing loss, in an endeavour to identify measurable characteristics of hearing that identify the points of onset of hearing disability (defined as difficulty in hearing speech in various circumstances) and of hearing handicap (defined as perceived social disadvantage resulting from the hearing loss), these concepts being understood to refer to average findings in a context of hearing loss prevention in industry.

Data were obtained from five listening tests, including simulations of real-life, and from self-assessment questionnaires, and compared in each case with corresponding results for control groups of young and older otologically normal persons who underwent identical tests. The audiological status of subjects was measured by pure-tone audiometry, temporal resolution, frequency selectivity, and off-frequency listening effect. The most sensitive measure, and the one most closely correlated with performance and self-assessment, was the pure-tone audiogram.

Percentage errors in different listening situations depend greatly on the kind of test material and the inherent difficulty of the acoustical context, and this applies irrespective of hearing loss. It is shown that the influence of test conditions is largely eliminated by comparing the performance of the impaired persons with the limit of the range of performance among normal persons. In this way an onset point for disability is identified as 30 dB hearing threshold level, average over 1, 2 and 3 kHz. In the case of handicap, there appears to be a continuous trend starting from normal hearing with no definable threshold of onset.

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FOREWORD

This report describes in detail an investigation supported by UK Medical Research Council Grant G8007081, which was carried out between 1981 and 1984.

The plan of the project was devised by two of us (PAW, DWR). The former undertook the development of the audiological test protocol and the experimental arrangements for the simulated listening situations. He also carried out the pilot tests and the initial phase of the main experiment, as well as preparing a draft of the first part of this report, until his departure in 1983 on taking up a permanent appointment elsewhere.

The conduct of the experimental work, after a short overlap period, was continued by another of us (NJT), who also undertook the computer aspects of the statistical analyses. He was assisted during most of this period in the day-to-day running of the tests by JFL, on whom devolved also the responsibility for record keeping and, in particular, the important task of locating suitable subjects.

Responsibility for the interpretation of the data, the presentation of this report, and the views expressed, rests with the principal author (DWR).

Thanks are due to Dr. R.D. Patterson, MRC Applied Psychology Unit, Cambridge and Mr. E.G.T. Johnson, British Telecommunications Research Centre, Martlesham Heath, for their help at different stages of the project, and also to the individuals participating as subjects. Production of the video recording was undertaken by the Department of Teaching Media, University of Southampton, whose cooperation is gratefully acknowledged.

D.W. Robinson

SUMMARY OF CONCLUSIONS

Scope and purpose

An investigation is described, the object of which was to determine the parameters of hearing that distinguish the onset of hearing disability and handicap in persons chronically exposed to noise. The results are specific to hearing losses extending only to the mild range. Different audiological factors probably operate at more severe levels of sensorineural hearing loss.

Tests performed

The tests comprised (a) an audiological battery of (self-recorded) pure-tone audiometry, temporal resolution, frequency selectivity and critical ratio (for two bandwidths of masker), and off-frequency listening faculty; (b) message reception performance in three simulated real-life situations including an audiovisual presentation, and speech audiometry at three levels in quiet and one level in a background of multivoice babble; and (c) a questionnaire in three parts to obtain self-assessments of hearing difficulties (disability) and perceived auditory disadvantage (handicap), the first two parts interrogating subjects' hearing in its general aspects and in nine particular situations respectively, whilst the third part obtained reactions to the simulations.

Subjects

Three groups participated in the experiments. The first group, designated YN, consisted of 20 young otologically normal persons; the second, designated NI, comprised 24 noise-exposed persons of various ages (mean 45 yr) with histories of significant (but unquantified) noise exposure and free from extraneous otological disorders; and the third, designated ON, consisted of 10 older otologically normal persons, mean age 58 yr.

Hearing levels

The pure-tone audiograms of group YN conformed closely with the international standard of normal hearing, and those of group ON with the international standard for otologically normal persons of the appropriate age, the agreement applying both to mean values and to dispersion. Hearing threshold levels in group NI varied from little above normal to substantial losses, averaging about 30 dB at 4 kHz. Five of the 24 subjects in group NI would be deemed to lie above the 'handicap' threshold according to the British Standard criterion used for hearing conservation; the remainder had lesser hearing losses.

Normalization of data

Results of tests for group YN provided normative means and standard deviations for 55 indices of impairment, listening disability and self-assessment. Data for subjects in groups NI and ON were then normalized by expressing them relative to the mean of group YN in units of the corresponding standard deviation thus facilitating comparisons between an individual's results on different tests by freeing them from the particularities of the various scales of measurement.

Audiological tests

These tests were carried out with a probe tone of 4 kHz. Significant impairments were found among the 24 subjects of group NI in respect of frequency selectivity (16 affected), temporal resolution (8 affected), critical ratio (5 affected). The older normal group also showed significant impairment of frequency selectivity, but only a slight effect on critical ratio, and no deterioration of temporal resolution. The off-frequency listening tests yielded no significant results with the high-band masker (above the frequency of the probe tone) and rather weak indications of impairment with the low-band masker. All measures except off-frequency listening (high band) correlated very highly with hearing threshold level but none was as sensitive as hearing threshold level for distinguishing between the impaired and normal groups. From other studies this is not an unexpected result for the slight or mild hearing losses which characterized the majority of subjects in groups NI and ON.

Listening tests

Average performance at the three simulations and the speech audiometry differed greatly between groups NI and ON on the one hand and YN on the other, but there were large individual differences within groups (including the young normals) on each test, and some subjects gave results differing widely across tests. The simulation of public address announcements in a station concourse was judged the most realistic, with telephone listening in noise next, and an audiovisual simulation of a social gathering less realistic though still judged on average to bear a fair resemblance to real life. These tests showed that a person's hearing ability may be seriously misjudged (either way) from speech audiometry alone. Testing in a representative range of situations is highly desirable although it presents major practical difficulties.

Correlation between the audiological and listening test results

Despite a few idiosyncratic cases, performance at the three simulations correlated significantly with the audiological tests except for temporal resolution, and most highly (about 0.7) with hearing threshold levels averaged over 3, 4 and 6 kHz. Speech audiometry also correlated significantly with hearing threshold levels, both in quiet (0.8) and in noise (0.7), the value obtained with the 1, 2 and 3 kHz frequency average being higher than with the 3, 4 and 6 kHz average, contrary to the simulations. Frequency selectivity correlated significantly with speech audiometry in quiet but (surprisingly) not in noise. Temporal resolution correlated only with speech audiometry in quiet. These partly equivocal results may reflect the relatively small impairments of the test group except for hearing threshold level. The latter dominates the audiological description of these mildly impaired subjects and seems to vindicate the traditional use of the pure-tone audiogram as the primary indicator for hearing conservation purposes.

Self-assessments

Results of the simpler questionnaire on hearing in general correlated highly (0.8) with that on hearing in particular situations. Both served to distinguish clearly between the young normal group and the impaired test subjects. It was found that the simple questionnaire was as effective as the elaborate one. Attempted distinctions between 'disability' and 'handicap' sections of the questionnaires produced no clear division of results. Self-assessments of hearing difficulty tended generally to be optimistic in comparison to actual ability, as judged by retrospective adjustments to self-rating (in the third part of the questionnaire) after experiencing the simulations. This was most marked among the older normal group, who initially rated their hearing equal to that of the young normals when, by actual performance, it clearly was not.

Correlation between self-assessments and listening test results

Comparison of questionnaire scores and performance at the listening tests showed that self-assessment is a very unreliable guide to individual hearing ability. The overall correlation (about 0.5) was comparable with that found in other studies and, although significant, it only permits broad trends of average performance to be predicted from the questionnaire results.

Correlation between self-assessments and hearing threshold levels

For reasons which are not obvious, the results of self-assessment correlated more highly with hearing threshold levels (about 0.6) than with performance at listening. The same has been observed in previous studies even when, as here, the questionnaire is structured to test a variety of hearing difficulties, not only those obviously related to auditory sensitivity.

Threshold of disability

It is argued that the point of onset of disability in terms of equivalent hearing threshold level cannot be uniquely defined on the basis of a discontinuity in a curve although recent studies have used this principle. The location of the discontinuity is both indistinct and depends on the difficulty of the test used to characterize disability; it does not even exist in situations where normal hearing persons are already in difficulty. The onset point has to be defined so as to distinguish between people, and not between situations. By defining a 'threshold of inability' in each test as the point corresponding to the 2nd percentile of normal performance, the equivalent hearing threshold level is shown to be much less dependent on the particular test, and a composite value of 30 dB for the 1, 2 and 3 kHz average (or 38 dB for 3, 4 and 6 kHz) is arrived at for a general threshold of disability. These values, though numerically greater than conventional levels of the 'low fence', do not imply any relaxation of hearing conservation standards but arise simply from a redefinition of terms.

Threshold of handicap

A procedure similar to that above was applied to the self-assessed handicap measured by questionnaire. In this case it is shown that handicap rises progressively over the entire hearing threshold level range and that a threshold for handicap is indistinguishable from the upper end of the normal range of hearing threshold level (about 10 dB for the 1, 2 and 3 kHz average).

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SYMBOLS AND ABBREVIATIONS USED

$a_1 \ldots\ldots a_{16}$	Normalized impairment indices, defined by $(A - x)/y$ or (in some cases) as composites of cognate a values.
A	General symbol for an individual test score
CR	Critical ratio, expressed in dB
CR-1	CR for octave band masker, equal to $(T_C - N_{tr})$
CR-2	CR for broadband masker, equal to $(T_B - N_{fB})$
d_{22}, d_{26}	Normalized indices of self-assessed disability, defined analogously to a
D	Disability (WHO)
FS	Frequency selectivity
FS-1	Frequency selectivity index defined by the value of T_N
FS-2	Frequency selectivity index defined by $(T_N - T_B)$
h_{23}, h_{26}	Normalized indices of self-assessed handicap, defined analogously to a.
H	Handicap (WHO)
H	General symbol for an individual value of HTL
H^L, H^R, H^{LR}	HTL in a left ear, right ear, average of left and right ears, respectively
H_i, H_{ijk}	HTL at frequency i (kHz), averaged over frequencies i, j, k respectively
HDTL	Hearing disability threshold level
HTL	Hearing threshold level
I	Impairment (WHO)
L	General symbol for a sound pressure level, in dB *re* 20 μPa
N	General symbol for a sound pressure spectrum level, in dB *re* 20 $\mu PaHz^{-1/2}$
N_{tr}	Individual value of N for octave band masker, at 4 kHz
N_{fB}	Common value of N for broadband masker, at 4 kHz
NI	Noise-induced subject group
NS	Not statistically significant

OF	Off-frequency listening efficiency
OF-H	Index of impairment of OF observed with high-band masker, equal to $(T_H - T_N)$
OF-L	Index of impairment of OF observed with low-band masker, equal to $(T_L - T_N)$
ON	Older normal-hearing subject group
$p_{16} \cdots p_{21}$	Normalized disability indices, defined analogously to a
r	Product-moment correlation coefficient
RETSPL	Reference equivalent threshold sound pressure level (audiometric zero)
s_{24}, s_{27}	Normalized overall self-assessment indices (composites of d and h)
SAN	Speech audiometry (free field) in noise
SAQ	Speech audiometry (free-field) in quiet
SD	Standard deviation
T	General symbol for threshold sound pressure level (dB *re* 20 μPa) of 4 kHz probe tone
T_C	Value of T with continuous octave band masker (in TI test)
T_m	Value of T with modulated (gated) octave band masker (in TI test)
T_Q	Value of T in quiet, equal in principle to $(H_4 + k)$, where k is the value of RETSPL at 4 kHz for the audiometric calibration in use
T_B	Value of T with broadband masker (in FS test)
T_N	Value of T with notched-spectrum masker (in FS test)
T_H	Value of T with high-band masker (in OF-H test)
T_L	Value of T with low-band masker (in OF-L test)
TI	Impairment of temporal resolution
TI-1	Temporal impairment index defined by the ratio of $(T_M - T_Q)$ to $(T_C - T_M)$
TI-2	Temporal impairment index defined by $(T_M - T_C)$
u	Weighting factor for subjects' familiarity with test situation
x	Mean value of a test score A for subject group YN
y	SD of individual test scores A for subject group YN
YN	Young normal-hearing subject group

1. INTRODUCTION

It might be supposed that the principal determining factor in setting limits for occupational noise exposure, and in compensation for hearing loss already sustained occupationally, would be the effect of the noise-induced hearing loss (NIHL) on the lives of those exposed. In practice the amount of loss is almost universally assessed from the pure-tone audiogram, despite the fact that the picture obtained in this way is known to be incomplete with respect to the perceived effects of the loss. It is not particularly surprising that the issue is to some extent side-stepped in this way since the audiogram can be determined relatively easily and without ambiguity, whereas there are great difficulties in investigating and defining the broader aspects of hearing loss.

To obviate any confusion between the meanings of terms used in this report it is necessary at the outset to make clear distinctions between three concepts required to describe the state of a person's hearing. For this purpose we have based the usage on the definitions of the WORLD HEALTH ORGANIZATION (1980) which, in the present context, reduce essentially to the following:

I - Impairment: loss or abnormality of the functioning of the ear

D - Disability: inability to perform normal human activities due to *I*

H - Handicap: limitation of an individual's role fulfilment resulting from *I* or *D*.

The relationship between these concepts and the methods used for their measurement (in the case of *I*) and assessment (in the case of *D* and *H*) have been discussed by DAVIS (1983) and by WILKINS and ROBINSON (1983). A more general review was provided by NOBLE (1978). It is evident that the impact of a noise exposure will vary according to a multiplicity of factors, even though the noise exposure may be the same. For example, some individuals suffer much greater impairment than others as measured by objective tests such as audiometry (and are then usually described as being the 'susceptible' or 'tender' type); people with essentially the same degree of hearing impairment may suffer different disabilities due to their varying capacities to comprehend auditory information; and those with similar levels of disability may be handicapped in varying degrees or not at all because of their differing personalities and life styles. Some aspects of disability are amenable to quantitative measurement, for example by means of speech audiometry, and it is possible to treat the relation between these measurements and objective impairment measures as valid - within definable statistical limits - for a given population. However, this cannot be said of disability as a whole, or of handicap, since what is normal human activity for some may be unnecessary or irrelevant for others. Even less is it possible to speak of population norms for the assessment of handicap in its broadest sense, for this concept depends on social and cultural factors that are more amenable to descriptive than to quantitative handling. Nevertheless an approach to the study of handicap - albeit an incomplete approach - can be made by identifying situations that are common or universal within the population to be studied, and to investigate the disadvantages due to hearing loss that members of that population perceive in themselves or are perceived by their peers.

Table 1: Hearing loss formulae

Source	Frequencies (kHz)	Formula	Low fence (dB re ISO 389)	Notes
Fowler (1942)	0.5, 1, 2, 4	Weighted 0.15, 0.3, 0.4, 0.15	10	1
AMA (1947)	0.5, 1, 2, 4	Variable weights (depending on HTLs)	20	1
AAOO (1959)	0.5, 1, 2	Unweighted average	25	1
ISO (1971, 1975)	0.5, 1, 2	Unweighted average	25	
NIOSH (1972)	1, 2, 3	Unweighted average	25	
DHSS (1974)	1, 2, 3	Unweighted average	40 (notional)	3
Macrae (1975-6)	0.5, 1, 1.5, 2, 3, 4	Weighted 0.2, 0.25, 0.2, 0.15, 0.1, 0.	≤3 kHz: 20 4 kHz: 25	2
CHABA (1975)	1, 2, 3	Unweighted	35	
BS 5330 (1976)	1, 2, 3	Unweighted average	30	
Berney (Ginnold, 1979)	0.5, 1, 2, 4	Unweighted average	25	4
Oregon (Ginnold, 1979)	0.5, 1, 2, 4, 6	Unweighted average	25	4
ISO (1982a)	-	None standardized	-	5
AAO (1979)	0.5, 1, 2, 3	Unweighted average	25	6
Brit. Ass. of Otolaryngologists (Anon, 1983)	1, 2, 4	Unweighted average	20	

Notes:

General: The table is not exhaustive. Most of the 'low fence' values derive from considerations of compensation; others (e.g., BS 5330, ISO, NIOSH) relate to preventive measures.

1 : The 'low fence' values were originally given in terms of pre-1969 American Standard hearing levels.

2 : 'Low fence' values later revised to 15 dB. The Australian system calculates disability for the better ear at each frequency before averaging.

3 : Compensation is payable only for 50 dB or greater.

4 : An example of individual State formulae in use in USA.

5 : The revision of ISO 1999 mentions several formulae but makes no specific recommendation.

6 : Also used in Canada (except B.C. and P.Q.) with 'low fence' at 35 dB.

2. GENERAL OUTLINE

Much has been written about the effects of hearing loss in general and of NIHL in particular, but a coherent body of scientific knowledge adequate for practical application has not been fully developed. The information, partly in its nature, is fragmentary and different criteria are in use with ostensibly the same aims. It is a significant commentary on the state of the art that the INTERNATIONAL ORGANIZATION for STANDARDIZATION (ISO, 1982a), in revising its 1975 standard on the assessment of noise for hearing conservation purposes, has actually backed away from specifying some of the essential parameters (which it formerly included), leaving it to users in different countries to decide for themselves. Only the relation between noise exposure and its audiometric consequences is fully specified: the relative importance of different frequencies and the amount of threshold shift deemed significant are not. This area has been studied extensively, but even so there are large disparities between results of different investigations; these have been averaged away, without a full understanding of the reasons for them, in the revised Standard. There has been a lesser, but still considerable, research effort into the relations between other measurable impairments of the hearing mechanism (principally the faculties of frequency selectivity and of temporal resolution) and the audiogram or the otological classification of persons with various types of hearing loss. There is a vast body of data on the intelligibility of speech under varioius test conditions and its relation to the above impairment measures. By contrast, information is much less abundant on the way that hearing loss actually affects people's everyday lives, and on the ways in which they depend upon their hearing or compensate for its deprivation by means of their other faculties. Clearly in a matter so overlaid with personal variability as this, a complete picture would be virtually unobtainable except on an individual basis, and this would be of little help in the practical matter of broad-based hearing conservation. At the same time, the use of pure-tone audiometry, or of psychoacoustical tests using abstract acoustical stimuli, or even the administration of somewhat artificial speech tests, can be seen as rather inadequate surrogates for the direct assessment of hearing handicap. The present investigation is aimed at exploring the possibilities of tests more closely related to the latter, whilst keeping in the foreground the potential practical application of the procedures used, and without abandoning the important evidence that is more easily obtained by objective tests.

Recent interest in this area has centred on proposals for legislation dealing with occupational noise (HEALTH AND SAFETY COMMISSION, 1981; COMMISSION OF THE EUROPEAN COMMUNITIES, 1982, 1984). The impact of these proposals on the makers of noise would be direct and quantifiable. On the other hand, the benefit in terms of hearing loss prevented, although apparently calculable, is subject to very large uncertainties because the long-term effects of such legislation, as well as economic and technological developments, can vitiate any numerical projections; in practice the effect in terms of hearing handicap is not overtly considered at all. It is true that the schemes under consideration are presented as being underpinned by a scientific framework (albeit they arrive at rather different criteria for noise limitation and greatly different ones for the mandatory implementation of biological monitoring), but at best they rely on the crucially important concept of a 'low fence', the minimum degree of measurable impairment (normally a pure-tone threshold shift measure) above which a disability is deemed to exist. Table 1 gives some examples. In the context of compensation payment, not only is the point of onset of disability required but also an index that describes the whole range from normal to deaf. Different indices have been used for this purpose, invariably derived from the pure-tone hearing threshold levels at different audiometric frequencies but combined in various ways and with various weightings. These in turn have resulted from attempts to correlate the audiogram with speech intelligibility; the diversity arises in part from the unlimited variety of speech tests and listening configurations that can be devised. The frequency 2 kHz appears to feature in all such formulae, e.g., the 0.5, 1, 2 kHz average recommended by the American Academy of Ophthalmology and Otolaryngology (COMMITTEE ON CONSERVATION OF HEARING, 1959), and the 1, 2, 3 kHz average in use in the U.K., both in compensation regulations and standards for hearing conservation. The role and weighting appropriate to other frequencies is much disputed. WARD (1983) discusses the difficulties in establishing an easily measured index of handicap in the context of compensation, and enumerates 11 assumptions which underpin the recent revision of the American index by the American Medical Association and the American Academy of Otolaryngology, now the 0.5, 1, 2, 4 kHz average. The British Association of Otolaryngologists (ANON, 1983) recently abandoned its previous position which was in line with U.K. official practice, in favour of 1, 2 and 4 kHz. It is instructive to note that these changes of fashion all centre around the accuracy of speech intelligibility correlations to the pure-tone audiogram, the variations arising from particular experiments in which the speech is either presented with or without background noise. Competitions between correlation coefficients, none of which differ very much, may be seen as a somewhat specious exercise if the results have little relation to hearing in the real and everyday world of the hearing impaired. The quest for optimum correlation is, of course, rationalized by the observation that loss of capacity for hearing speech is the main ingredient in the handicap, but the strength of this argument is much diminished if the 'speech' in question is artificially contrived, and the picture is in any case clouded by contradictory results obtained in different investigations.

The need for a systematic investigation of handicap associated with NIHL has been recognized for some time and the work of NOBLE (1970, 1978) is probably the most extensive to date. His method, however, is directed more at the evaluation of the individual and does not lend itself to the development of indices derivable from measurements that can be applied to populations as a whole. In the present investigation we have set ourselves a more restricted target with a practical objective, namely to study the 'onset' of handicap, in a broader context than that of speech audiometry, and to relate it to the more objective measurable attributes of hearing. The aim might be described as a study of a more generalized concept of the 'low fence'.

This report reviews the relevant previous research in this field, and then describes an experimental method which has been developed specifically to assess the onset of handicap due to NIHL. The method differs from that of previous studies in that the impairment, disability and handicap aspects of hearing loss are all brought together within a single experimental protocol. The tests were first applied to a group of normal hearing subjects to provide a baseline for comparison. Deviations from this baseline were then determined for a group of noise-exposed individuals with mild to moderate degrees of hearing loss. These comparisons illustrate the sensitivity of the method for discriminating between the exposed subjects and the normals in respect of the various impairment, disability and handicap measures used. The same tests were also administered to an older group of subjects with no history of significant noise exposure in order to provide some basis of comparison between the effects of hearing loss due to noise and that associated solely with age. Subjects with gross otological abnormality or an adverse medical history relating to hearing were excluded from each group.

3. PREVIOUS RESEARCH

3.1 *Impairment of hearing*

Extensive research data have been published relating noise exposure to impairment of auditory function as measured by pure-tone audiometry, for example, BURNS and ROBINSON, 1970; PASSCHIER-VERMEER, 1968; BAUGHN, 1966. Passchier-Vermeer's report is itself a digest of eight earlier investigations. Baughn's data were used exclusively in preparing the first ISO recommendation in 1971, the other material not being available at the time this was drafted (1967); subsequently doubts were raised about the accuracy of the data underlying the ISO recommendation, and the current revision already referred to was set in train at the instance of the United Kingdom. For this purpose an evaluation of the above data was undertaken by JOHNSON (1980) and after some adjustment and discussion in the responsible ISO Working Group a formulation based on a simple arithmetic average of the data of Burns and Robinson and of Passchier-Vermeer was adopted (ISO, 1982a). It is worth noting that even in this comparatively well-researched field quite large discrepancies remain. This arises in part from a lack of uniformity in defining an appropriate base-line of normality. From one standpoint this is taken to correspond to a young otologically screened population, from another to an unscreened age-stratified and non-exposed population matched in other respects to the noise-exposed population of interest. The uncertainties of specification are naturally greater in the latter case but against this it may be held that it is more relevant in practice.

Data in the literature are almost as discordant with regard to age-related hearing loss (with no noise involvement at all, at least, occupationally) and although a draft International Standard (ISO, 1982b) has also been arrived at to summarize these data on the basis of a review by ROBINSON and SUTTON (1979) its merit is practical convenience; there is no disguising the intrinsic discrepancies between the numerous experimental studies in this field. Another important limitation occurs in these population studies of impairment, namely the large inter-individual dispersion of hearing threshold levels even among groups that are homogeneous for age, sex and noise exposure. In dealing with the more personal concepts of disability and handicap, it would ideally be appropriate to compare the present condition of an individual with the person's initial, unimpaired state. Unfortunately that is rarely possible, and one has to assume the initial condition to be that of the population norm, although this is clearly inaccurate in most cases. It is a legitimate question to ask whether a person whose original hearing sensitivity was at the extreme sensitive end of the normal range of variability but who has since acquired a threshold shift of, say, 20 dB (and so remains within, but at the other extremity of, the normal range) is disabled in comparison to another whose hearing began and remained at the latter level. No doubt the first person would answer that he was, but this could not be tested by audiometry alone.

Despite these limitations and qualifications, existing knowledge of the relation between noise exposure, age and the audiogram justifies its use for the purposes of industrial hearing conservation and, of course, it has been so used in a variety of developing forms for many years. The audiogram is, however, a blunt instrument and provides no rational basis for setting noise limits. Recent work has emphasized that noise attacks auditory functioning in ways other than simple loss of sensitivity, and these may in the end prove to be more relevant. Research in this field has identified at least three aspects of impairment: frequency selectivity (FLORENTINE *et al*, 1980); temporal integration (CHUNG and SMITH, 1980); and temporal resolution (ZWICKER and SCHORN, 1982). The essence of impairment of these functions is that it interferes with the identification and perception of sounds at their natural levels of occurrence as distinct from the question of actual audibility. Definitive data on these effects are, however, still lacking, as also is clear evidence of their independence from hearing sensitivity and of their real implications for everyday listening abilities.

3.2 *Disability*

Disability can be measured by loss of performance at specific hearing tasks, the variety of which is almost unlimited. The test commonly used in the laboratory and clinic is speech audiometry, employing sentences or word lists presented monaurally over headphones in quiet conditions. A large number of variants have been described, which include the addition of competing noise (or other speech), free-field binaural listening, spectral or temporal filtering of the speech signal, and the addition of reverberation. The exact purpose of these modifications is not always stated, but the general idea is usually to sensitize the test (that is, enhance its power to discriminate between finer levels of disability), to provide greater realism, or to make the test more difficult (and so reduce the proportion of uninformative all-correct responses). A full account of the factors involved in speech tests, of the inherent uncertainties, and of the principles of power *v.* sensitivity in different versions of the test, has been given by LYREGAARD *et al* (1976).

Clearly, what is required in the context of determining handicap is a set of disability tests covering a representative range of communication situations encountered in daily life (or, at least, the daily lives of the population to be studied). Whilst the range of such situations is virtually unlimited as to detail, the following factors and contrasts can be identified:

(i) interactive communication or passive listening

(ii) nature of the auditory material (speech, other recognizable sounds, abstract sounds)

(iii) semantic content of the material (premonitory, interrogative, informative, neutral)

(iv) (in case of speech) the voice (normal, raised or lowered; received or deviant pronunciation; standard idiom or dialect; quality of elocution)

(v) (in case of speech) listener's familiarity with the language and lexicon in use

(vi) acoustic conditions (reverberant, typical ambient, dead)

(vii) noise or other competing acoustic stimuli

(viii) listening with one or both ears

(ix) set of the listener (attention directed to, or distracted from, the primary hearing task)

(x) visual cues

Regarding the way that these factors are realized in disability tests, it is notable that almost all focus on the task of listening as a *passive* activity, mainly because of the difficulty of structuring and scoring a two-way test. This limitation can be overcome in special circumstances, such as in telephonometric performance rating where trained crews of testers can be used to assess the quality of a communication link by interaction between talker and listener in pairs (RICHARDS, 1973).

Whatever the chosen test material, a variety of means exists for presenting it and for scoring performance. Common response modes are for the subject to repeat verbally what he heard, to write it down, or to press a labelled button. The material may be selected in different ways, likewise the available responses. The latter may be an open choice from the total available vocabulary of the subject, or a selected subset of the vocabulary (such as all meaningful monosyllables), or a strictly limited set of forced-choice alternatives (typically 4 or 6). In addition, less direct methods might be employed, such as rating the effort of listening. For example, the International Telegraph and Telephone Consultative Committee (CCITT, 1981) have specified a 5-point category scale of listening effort for the assessment of telephone transmissions, running from "complete relaxation possible" to "no meaning understood with any feasible effort".

In passive speech tests, the nature of the material and the character of the speaker's voice have received rather little attention, and are often decided on the basis of convenience and availability of recordings rather than realism. Inter-list consistency favours the construction of phonetically balanced material at the expense of realistic word frequency, whereas diagnostic potentiality favours constructing the material on the basis of maximally confusible phonemes (FOSTER and HAGGARD, 1979). Different aims motivate disability assessment as compared to audiological diagnosis, but material has not been developed specifically for the former purpose. As regards speaker's voice, GENGEL and KUPPERMAN (1980) investigated the effect of having the CID W-22 word lists read by six different speakers, and concluded that "speakers cannot be used interchangeably if consistent performance from individuals (i.e., listeners) is desired". Despite this significant factor, and the likelihood that it is further compounded by listener interaction, it is common to test with material read by a single speaker in a monotone voice.

In particular, all previous studies of speech intelligibility - even those that included noise at the listening end - appear to have employed speech produced in quiet conditions, so that the change in voice quality (and hence both realism and intelligibility) when the speaker is also present in noise is ignored.

Very few studies have considered the individual characteristics of the listener, but notable in this area is that of ABEL *et al* (1980) which demonstrated a substantial disadvantage in speech testing for those who are not fluent in the language used.

Manipulation of the acoustic factors in the above list is easier. Free-field listening tests with the speech and noise sources spatially separated have frequently been used; see, for example, CHUNG and MACK (1979). In an extension of this approach, ANIANSSON (1974) simulated a conversation across the listener as well as the speaker of interest located directly in front. Whereas the above variations have been included for realism but not evaluated factorially, the effect of reverberation on hearing-impaired listeners has been investigated in greater detail; see, for example, NABELEK and ROBINETTE (1978).

Other aspects of disability which are less frequently tested include the perception of non-speech sounds (FINITZO-HIEBER *et al*, 1980) and the spatial awareness associated with the localization of sound sources (NORDLUND and FRITZELL, 1963; HAUSLER *et al*, 1979; GATEHOUSE and PATTEE, 1983). A comprehensive assessment of disability clearly requires the development of further tests of this kind.

3.3 *Disability and impairment*

Numerous attempts have been made to determine an exact relation between the predominant measures of impairment and disability, i.e., the pure-tone audiogram and speech discrimination score. NOBLE (1973) reviewed 23 studies of this type and indicated that the results did not consistently establish an association between the two measures, and that in general the correlations were relatively weak. Given that speech perception involves auditory and cognitive processes not involved in the detection of pure tones and that there are many aspects of impairment besides loss of sensitivity at threshold, this observation is not particularly surprising. For instance, ACTON (1970) presented results which suggest that people with a mild noise-induced hearing loss in fact score better in speech intelligibility tests in noise than normals, which he attributed to their greater experience in communicating in noise.

The more recent of these studies which have included measures of frequency selectivity and temporal resolution are summarized in Table 2. It can be seen that the correlations between these individual measures of impairment and the measure(s) of disability are also not particularly strong. Significant relationships are evident, with correlation coefficients often in the range r = 0.4 to 0.8, but the trends are not consistent across the studies, so that no general conclusion can be drawn. Variable findings among the studies may relate to the many differences between the nature and detail of the tests of impairment and disability, the subject groups investigated (note especially the differences between TYLER *et al* 1982b and 1982c), or the method of analysing the data.

None of the studies in Table 2 was specifically designed to investigate the relationship between impairment and disability. Thus, in general they have not included multiple correlations of the various measures of impairment with a measure of disability. In principle, a suitable battery of impairment measures should provide a predictive relationship for at least a particular measure of disability amongst a specific group of subjects. In the one partial attempt at this approach, TYLER *et al* (1982b) found that their seven measures of frequency and temporal resolution accounted for 89% of the total variance in the scores on the FAAF test, with the two predominant measures (temporal difference limen and temporal integration at 4 kHz) accounting for 68% of the variance. Unfortunately, the audiometric threshold measures were not included in this analysis.

The principal components analysis conducted by FESTEN and PLOMP (1983) revealed results more complex than would permit any concise summary. The scores for speech in noise clustered with some measures of frequency selectivity (the critical bandwidth in simultaneous masking and the low frequency side of the psychoacoustical tuning curve (PTC) in both simultaneous and forward masking) but not others. The scores for speech in quiet cluster with the audiometric threshold, the forward and backward masking slopes and the threshold of the click in quiet. Critical ratio, and both critical bandwidth and high-frequency side of the PTC in forward masking appear to be related to both the effects indicated by the two clusters, whereas the high-frequency side of the PTC in simultaneous masking, the threshold of the click in noise and the width of the temporal window are only weakly related to the other measures.

Particular difficulties exist because of intercorrelations between measures of impairment. Thus, TYLER *et al* (1982b) found that when the effects of pure-tone threshold in quiet were partialled out, the correlations between frequency resolution at 4 kHz and speech discrimination generally became non-significant. In particular, BAILEY (1983) has argued that errors by the hearing impaired in the place of articulation of consonants (e.g., the distinction between the voiced plosives b and d as in *big* and *dig*) may involve either distinctions between the spectral changes of speech sounds and hence frequency selectivity, or more simply the elevated thresholds of hearing at the mid and high frequencies involved.

The inevitable complexities of assembling a battery of measures of impairment which could be used to predict disability at least in terms of speech perception, returns one to question the purpose of this endeavour. In the context of handicap, it is the search for tests of hearing ability which are free from the cognitive and linguistic aspects of speech, but which reliably predict the impact of any abnormality of hearing on speech perception. With an added requirement that the tests should be relatively simple to conduct and to perform, it would appear that there is scope for the development of a single disability test based on the perception of speech-like sounds. Such a test could in theory encompass all the more

Table 2: Some studies relating disability and impairment (other than hearing sensitivity).
(A key to the abbreviations is given at the end of the Table.)

Source	Impairment measure(s)	Disability measure(s)	Best correlation	Subjects	Comments
GENGEL (1978)	FD at 0.5, 1.5, 3 kHz	Discrimination of V in words, C in (different) words	0.5 – 1 (NS) (rank order	SN 5	SCHARF's (1978) review cites 2 other studies with similar high correlations but 2 more with low correlations
BONDING (1979)	PTC at 1 kHz (metric $d_{1\ oct}$)	Monosyllables 1. Unfiltered, Q 2. Filtered, N	 - - 0.7 (***)	SN 21 33	"No monotonic relationship" in case 1. HTL and d_{1oct} related in a non-liner manner. Also CB found not to correlate with speech scores.
DRESCHLER & PLOMP (1980)	CR CB (CPN)	SRT (sentences) 1. Q 2. N (2 metrics) V discrimination in triadic comparisons 1. F1 metric 2. F2 metric	 0.6 (NS) 0.9 (**) 0.8 (**) -0.4 (NS)	SN 10 and mixed	Frequency resolution and HTL also highly correlated (r = 0.8). The metrics for SRT in N are A (related to attenuation) and D (related to distortion); higher correlation is with D. F1, F2 are positions of first and second formants.
DRESCHLER (1980)	CR at 1 kHz	As above: Q N F1 F2	0.3 (NS) 0.1 (NS) -0.1 (NS) 0 (NS)	SN 33	Author comments that results overall are in "fair" agreement" with those above, but note non-significant correlations. CR also correlated with mean HTL (r = 0.5, **)
PICK (1980)	CR at 1 kHz	CVC words 1. Q 2. N	 0.7 0.4	Patients with flat losses Σ16 Σ11	CR correlated with HTL at the same frequency (r = 0.5 – 0.7)
RITSMA et al (1980)	PTC at 0.5, 1, 2, 4 kHz (metric Q_{10})	Max. discrimination, PB words	Not reported	SN 45 ('flat' audiograms up to 60 dB HTL)	"Tremendous" spread of discrimination scores for subjects with $Q_{10} < 3$. Q_{10} and HTL correlated (r = -0.8) for 15 ears.
LYREGAARD (1982)	CR at 0.5, 1, 2, 4 kHz	SRT (nonsense words in N)	0.8	Normals 56 +SN +CL +mixed	Correlation based on CR averaged across 4 frequencies (48 ears). Best individual frauency gave r = 0.7 (***). CR also highly correlated with HTL (r = 0.7 – 0.9)
TYLER et al (1982c)	1. N masking 2. T masking 3. PTC (3 metrics) 4. TempInt (all at 0.5, 4 kHz)	PB words in N FAAF words in N	1. -0.3 (NS) 2. -0.7 (**) 3. 0.4 (**) 4. 0.3 (*)	Normals 10 NIHL 11 Other SN 10	Correlations NS at 0.5 kHz. HTL at 4 kHz correlates with: 1. r = 0.3-0.4 (** or NS); 2. r = 0.8-0.9 (**); 3. r = 0.4-0.7 (**); 4. r = 0.6 (**) Previously TYLER et al (1980) reported stronger correlations of speech with measures 1, 3, 4.

Source	Impairment measure(s)	Disability measure(s)	Best correlation	Subjects	Comments
TYLER et al (1982b)	1. TempInt 2. GD 3. TDL 4. GDL 5. PTC (3 metrics)	PAAP words in N	1. 0.7 (**) 2. -0.7 (**) 3. -0.7 (**) 4. 0.5 (*) 5. 0.7 (**)	Normals 16 SN 16	Correlations generally stronger at 4 kHz than 0.5 kHz (but measures 2 and 3 at 0.5 kHz also correlate with speech even after removing regression with HTL). HTL correlates with: 1. r = 0.4-0.7 (*); 2. r = 0.5-0.7 (**) 3. r = 0.7-0.8 (**); 4. r = 0.3-0.6 (NS, *) 5. r = 0.2-0.8 (NS, *)
PATTERSON et al (1982)	APS (3 metrics) CR (both at 0.5, 2, 4 kHz)	PAAP words, filtered, NVN, including Q condition	1. 0.8 (***) 2. -0.5 (**)	Normals E28 (24 to 76 years)	Correlanda are slope of regression line of discr mination score vs notch width and (1) passband measure fromm APS, and (2) broadband threshold (equivalent to CR). HTL also highly correlated ' APS (r = 0.9, ***) but not with CR (r = 0.3, NS)
FESTEN & PLOMP (1983)	1. CB (CFN) 2. CR 3. CB (Fwd M) 4. PTC (2 metrics) 5. PTC (Fwd M) (2 metrics) 6. TW 7. Fwd M 8. Bwd M 9. Click in Q 10. Click in N 11. TempInt	SRT (sentences) 1. Q (A+D metric)	1. 0.4 (NS) 2. 0.5 (*) 3. 0.7 (**) 4. -0.4 (NS) 5. -0.5 (*) 6. 0.2 (NS) 7. -0.9 (**) 8. -0.8 (**) 9. 0.8 (**) 10. 0.3 (NS) 11. -0.1 (NS)	SN 22 (HTL at 1 kHz 30 - 60 dB)	Metric for Q is A + D (see DRESCHLER and PLOMP, above). Metric for N is D alone. Mean HTL also correlated significantly with the following measures: 1. r = 0.4 (*) 2. r = 0.6 (**) 3. r = 0.7 (**) 5. r = -0.5 (*) 7. r = -0.8 (**) 8. r = -0.8 (**) 9. r = 0.9 (***) From a principal-components analysis, the author concluded that speech in Q is governed by HTL; in N it is "closely allied" to frequency resolution.
	1. CB (CFN) 2. CR 3. CB (Fwd M) 4. PTC (2 metrics) 5. PTC (Fwd M) (2 metrics) 6. TW 7. Fwd M 8. Bwd M 9. Click in Q 10. Click in N 11. TempInt	2. N (D metric)	1. 0.6 (**) 2. 0.6 (**) 3. 0.5 (*) 4. -0.6 (**) 5. -0.6 (**) 6. 0.3 (NS) 7. -0.3 (NS) 8. -0.2 (NS) 9. 0.2 (NS) 10. -0.1 (NS) 11. -0.2 (NS)		

Abbreviations

A - attenuation metric (speech)
APS - auditory filter shape
Bwd M - backward masking
C - consonants
CB - critical band
CFN - comb-filtered noise
CL - conductive loss
CR - critical ratio
D - distortion metric (speech)
E - ears
FD - frequency discrimination
Fwd M - forward masking
GD - gap detection
GDL - gap detection limen
HTL - hearing threshold level
N - noise
NS - not significant
NVN - noise with variable notch
PB - phonetically balanced
PTC - psychoacoustical tuning curve
Q - quiet
SN - sensorineural loss
SRT - speech reception thresho
TDL - temporal difference lime
TempInt - temporal integration
TW - temporal window
V - vowels

fundamental aspects of auditory processing, whilst not testing the more variable processes involved in the extraction of meaning from patterns of auditory information.

3.4 *Handicap*

Following from its definition two aspects of handicap can be distinguished. The first, and dominant, of these is self-perception of a disadvantaged condition. Complementary to it is the element of actual disadvantage observed or recognized by others with whom the sufferer comes into contact, without the latter necessarily being aware of it (or having adapted to this state over a period of time). The primary tool for studying the first aspect is the self-report questionnaire. The attendant uncertainties of this highly subjective procedure hardly need stressing, but it can be argued that in the last analysis this is the only way to elicit the information. Questionnaires administered by interview are liable to reflect the attitudes of the interviewer, and some studies have been criticized on this score, notably where the interview takes on the aspect of a doctor-patient consultation. The interview procedure was advocated by NOBLE and ATHERLEY (1970). NOBLE, however, later adapted the 1970 questionnaire for self-administration by paper and pencil (NOBLE, 1979). The secondary aspect of disadvantage apparent to the sufferer's peers (if not to himself) presents obvious difficulties for investigation; and this applies also to the other possible approach of discreet third-party observation of the sufferer's social behaviour pattern.

The self-report questionnaire method avoids the complications of entering, or simulating, the real-life social environment and is much the most widely used. Even here there have been relatively few studies carried out on a large enough scale to permit generalized conclusions, and not all of these have been systematically validated by subsequent application. A synopsis of the published literature is given in Table 3. A variety of target populations has been investigated, ranging from those with all types and levels of hearing loss to the more specific. Noble, for example, originally devised his hearing measurement scale (HMS) in the context of noise-induced hearing loss. Others have studied minority groups, for example, users of binaural hearing aids (MARKIDES, 1982) and employed persons with severe acquired hearing losses (THOMAS *et al*, 1982).

To date no standardized technique has been evolved for administering these questionnaires or for their construction, although it must be admitted that it is very difficult to compose a set of relevant questions that can all be answered intelligently by such diverse groups; also different investigators often have different aims. There is a particular problem in devising questions which both the normal-hearing and the impaired can answer, but this is a pre-requisite when the objective is to distinguish between them, for the purpose of defining the lower boundary to the handicapped condition. For example, questions which presume impairment on the part of respondents, or which allude, for example, to hearing aids, sit very uneasily where that presumption is not justified. In a brief review of the field, SUTER (1978) pointed out that answers to questionnaires appear to depend upon age, occupation and various other factors, and it is not always clear whether the answers should be interpreted in comparison to those of a peer, but unimpaired, group or by reference to young normal hearing. With regard to the age factor, GLORIG

Table 3: Some studies employing hearing handicap questionnaires.
(A key to the abbreviations is given at the end of the Table)

	Source	Measuring instrument	Subjects		Correlations	Comments
1	SILVERMAN *et al* (1948)	6 Qn × 5 C	Pre- and post-operative (fenestrations)	123	SAI: 0.5	SAI (Social adequacy index) is average PB word score at 3 speech levels in Q
2	DIRKS & CARHART (1962)	26 Qn × 5 C, + 15 Qn on attitude to HA	HA users, AR 18-95 Controls	417 155	-	Study concerned comparison of monaural and binaural HA
3	HIGH *et al* (1964)	*Hearing Handicap Scale* (HHS) 20 Qn × 5 C in 2 versions A, B)	Mainly CL, AR 21-72	50	HTL: 0.7 SRT: 0.7 MDS: -0.2 (NS)	Requires cooperative respondents. Susceptible to exaggeration. Measures mainly sensitivity
4	BLUMENFELD *et al* (1969)	HHS (A and B)	Normals: AR 27-59: AR 60-82:	21 25	MDS in Q: -0.5 MDS in N: -0.5	MDS measured by Rhyme Test. HHS(A) better than HHS(B).
5	SPEAKS *et al* (1970)	HHS (A)	Patients, AR 19-78: CL Mixed SN	5 6 49	HTL: 0.7 SRT: 0.7 MDS: -0.5	Speech materials were PB words, sentences in Q, sentences + competing message. Correlations highest for PB.
6	BERKOWITZ & HOCHBERG (1971)	HHS (A)	Non-pathological patients, AR 60-87	100	HTL: 0.6 SRT: 0.6 MDS: -0.3	CID W-1 words for SRT. CID W-22 words + CID List B sentences for MDS. HHS reported reliable for geriatrics.
7	PETERS & HARDICK (1974)	HHS (A and B)	Male VA patients, SN, AR 19-65	40	HTL: 0.6 SRT: 0.6 MDS: -0.5	Self-assessment compared with HHS assessment by spouse, r = 0.8
8	McCARTNEY *et al* (1976)	HHS (A) HMS (see items 16, 17)	Normals, AR 60-89	36	HTL: 0.6 (HHS) 0.5 (HMS) SRT: 0.4 0.4 MDS: -0.4 -0.4	A systematic comparison of HMS and HHS on a geriatric population
9	SCHOW & TANNAHILL (1977)	HHS (B)	Normals, MA 28 Near-normals, MA 37, Presbyacusic SN, MA 68	20 10 20	HTL: 0.7 MDS: -0.2	Categories of handicap proposed on basis of HHS
10	TANNAHILL (1979)	HHS (both forms)	SN HA candidates, AR 56-91	24	SRT: 0.6	Correlation is for pre-aided condition. Study concerned post-aided improvement
11	BRUNT (1979)	HHS	SN, AR 57-90	26	HTL: 0.7 SRT: 0.5 MDS: -0.4 (NS)	High correlation (r = 0.64) also found with Staggered Spondaic Word test (SSW)
12	TAYLOR *et al* (1967)	79 Qn × 4 C. Qns on lip reading, sign language, speech in N, telephone, meetings, noise aversion	Female weavers, NIHL, AR 45-64	39	-	Pilot study. Reaction of other household members tested but not found useful.

Table continued overleaf

Table 3 (continued)

	Source	Measuring instrument	Subjects		Correlations	Comments
13	KELL et al (1971)	20 Qn, unscaled. Sections on occupational history, communication difficulty, telephone, radio/TV, meetings, use of HA	Female weavers, NIHL, MA 64 Controls, MA 64	96 96	-	Large differences found between test and control groups in each section.
14	PEARSON et al (1973)	10 Qn × 3 (or 4) C Sections on communication with (1) family/friends (2) strangers; telephone; public meetings.	As for KELL et al above		HTL - various frequency combinations. (Values of r not given.)	"Own assessment considered too subjective for inclusion". Criticized by Noble for retaining only speech-related Qns.
15	SCHEIN et al (1970)	*Washington Hearing Scale* 7 Qn × 2 C (Yes/No), hierarchical + 1 Qn × 4 C	Clinic clients	1345	-	Inconsistent responses cast doubt on hierarchical nature of scale.
16	NOBLE & ATHERLEY (1970)	*Hearing Measurement Scale* 42 Qn × (mostly) 5 C Sections on speech hearing, acuity for non-speech sounds, localization, emotional response, speech distortion, tinnitus, personal opinion	Foundrymen, NIHL, AR 35-65	46	Highest values for HTL, SRT, HMS against relevant sections of scale: about 0.6.	Preceded by 3 pilot studies. Originally in interview form, subsequently in pencil-and-paper form (NOBLE, 1979). See also McCARTNEY et al above.
17	ATHERLEY & NOBLE (1971)	HMS	Drop forgers, NIHL, AR 36-59	18	HTL: 0.7 (best of 5 frequency combinations).	Scores compared for: HA clinic attendees, drop-forgers, metal dressers, weavers.
18	LINDEMAN (1971)	7 Qn × 2 C ("complaint" = 1, "no complaint = 0)	Foundry workers, NIHL	642	HTL 2 kHz; phonemes at 4 S/N ratios. (Values not given as coefficients.)	Netherlands study.
19	EWERTSEN et al (1973)	*Social Hearing Handicap Index* (SHI) 21 Qn × 3 C (yes or no/ doubtful/don't know or no experience)	Normals Impaired (all types, excluding HA users)	25 198	Expressed as an inequality: SHI ≥ 0.9 SRT	Danish study. SHI derived from HMS. Compromise between free choice, multiple choice. HDS discarded as less reliable. SRT refers to Danish numerals.
20	BIRK-NIELSEN et al (1974)	SHI	HA candidates, AR <50->75	551	Similar to EWERTSEN et al above.	Used to assess aided hearing improvement; best result with CL.
21	LOEB et al (1974)	6 Qn × 2-5 C	Recruits	311	HTL shift vs score increment (values of r not given).	Used to compare hearing before and after 8 weeks basic military training.

Table 3 (continued)

	Source	Measuring instrument	Subjects		Correlations	Comments
22	HABIB & HINCHCLIFFE (1978)	1 Qn x 100 C (overall subjective assessment)	Patients (a) (b) AR 16-80	69 39	HTL 2 kHz: (a) 0.3 (b) 0.4 (p < 0.01)	(a) London sample (b) Cairo sample
23	HINCHCLIFFE & GORDON (1980)	21 Qn (C not stated) Sections reflecting symptoms: hypoacusis, dysacusis, phonophobia, dys-stereoacusis, tinnitus, vertigo	Patients AR 17-75	110	HTL 2 kHz: 0.4 (vs hypoacusis section)	Additional Qns on understanding questionnaire; deprivation of enjoyment; social disadvantage.
24	GIOLAS et al (1979)	*Hearing Performance Inventory* (HPI) 158 Qn x 5 C + "don't know". Sections on understanding speech, intensity, response to auditory failure, social, personal, occupational	Persons with "communicative difficulty"	190	No data given except HPI.	Authors noted low correlation of HHS vs discrimination; scale accordingly constructed to emphasize discrimination. Shortened form (90 Qn) given by LAMB et al (1983).
25	OWENS & FUJIKAWA (1980)	HPI	Profoundly impaired	30	-	Differences between aided and unaided hearing found statistically significant on some sections of HPI.
26	WANG (1981)	HPI	Veterans, AR 18-69	148	HTL: 0.8 (speech section) SRT: 0.3 (intensity secn.) MDS: -0.3 (3 sections)	Subjects mostly with mild hearing impairments.

Abbreviations

A, B - alternative forms of HHS
AR - age range (yr)
C - (number of) response categories
CID - Central Institute for the Deaf, St. Louis
CL - conductive loss
HA - hearing aid
HHS - Hearing Handicap Scale
HMS - Hearing Measurement Scale
HPI - Hearing Performance Inventory
HTL - hearing threshold level (various frequencies and combinations)
MA - mean age (yr)
MDS - maximum (speech) discrimination score (various materials)
N - noise
NIHL - noise-induced hearing loss
NS - not significant
PB - phonetically balanced monosyllables
Q - quiet
Qn - (number of) questions
SAI - Social Adequacy Index
SHI - Social Hearing Handicap Index
SN - sensorineural loss
S/N - speech-to-noise ratio
SRT - speech reception threshold (50% correct score, various materials)
VA - US Veterans Administration

and BAUGHN (1973) and MERLUZZI and HINCHCLIFFE (1973) presented data which suggest that one's expectation of hearing ability declines with age, irrespective of extraneous impairment, which could be interpreted as progressive adaptation to the increasing age-related threshold shift. The same trend, though less pronounced, is discernible in the results of the 1954 Wisconsin State Fair hearing survey (GLORIG *et al*, 1957). Thus a self-rating of just 'not handicapped' can occur at progressively greater levels of hearing impairment with increasing age.

The questionnaires used in previous studies exhibit a great diversity of approach and form. Among the many factors governing questionnaire construction those in the list below can be readily enumerated, and examples of each of these alternatives are to be found in the literature cited:

- interview *vs* paper-and-pencil administration
- generalized *vs* particularized questions
- prolix *vs* economical wording
- number of questions (examples range from 1 to 158)
- inclusion *vs* exclusion of open-ended questions
- provision *vs* withholding of 'don't know' or 'haven't been in that situation' response options
- absolute *vs* relative judgement required (e.g., relative to the past, to other persons, etc.)
- polarity of wording: negative *vs* positive; uniformly *vs* randomly ordered
- frame of reference: the question elicits the present state or it entails recall
- type of response admitted: binary choice (yes/no) *vs* scaled.

In the case of binary choice: parallel *vs* hierarchical items
In the case of scaled response: continuum *vs* discrete steps
: unimodal *vs* neutral mid-point
: dimension of scale (e.g., 'oftenness', degree of difficulty, etc.)
: end-points defined or open
: (in case of discrete steps), the number of categories offered.

NOBLE pointed out some less obvious considerations in addition to those above. For example, some subjects will not be able to report handicap as 'frequent difficulty' with some situations for the simple reason that their handicap has led them to avoid being in such situations. He faulted one questionnaire for 'brain-teasing' and consequent subject frustration through the mixed use of positively and negatively worded questions supposedly balanced so as to average out any response bias. Writing of the use of *temporal* ('oftenness') scaling as opposed to *intensitive* ('degree of difficulty', etc.) scaling, he advocated the former on the grounds that it induces the subject to 'integrate experience over time and come up with an aggregate'; intensitive scaling (falsely) 'assumes that experience is the same from time to time in a given situation and varies only with different situations'. Similar arguments and counterarguments about the minutiae of questionnaires abound in the literature; perhaps more significant are some marked differences in attitude to the purpose and capabilities of the method. HIGH *et al* (1964), for example, extol the merits of self-report from the aspects of speed, scorability and repeatability while adding that a 'not entirely desirable aspect of the self-report scale is that it reveals handicap as viewed through the eyes of the subject'. This led them to purge their original experimental scale of all items not having face validity in a speech communication context. PEARSON *et al* (1973) decided that questions they had included on subjects' own assessments of their hearing were too subjective for ultimate inclusion, and retained only four on the basis that these correlated best with speech audiometry: there are shades of a circular argument here. By contrast, NOBLE (1970), BIRK-NIELSEN and EWERTSEN (1974), SCHOW and TANNAHILL (1977) and others emphasize that a given level of impairment is no predictor of handicap and maintain that self-report over a wide range of activities 'as viewed through the eyes of the subject' is indeed the approach to follow. In this field, the saying '*quot homines tot sententiae*' (there are as many opinions as there are people) seems to apply equally to the investigators as to those investigated. A useful summary of the more important contributions to the literature has been given by HARDICK *et al* (1980), and by GIOLAS (1983).

The assessment of behaviour in the social environment has been attempted by BIRD and TREVAINS (1978) and by THOMAS *et al* (1982), also through the medium of questionnaires. They studied the perceived effects of acquired hearing loss on the respondents' communication patterns, their social and work relationships, job proficiency and job status. Bird and Trevains also administered a questionnaire to a colleague at work or a relative of each respondent and found that these generally confirmed the self-reported difficulties. Observed behaviour could include direct scoring of communication ability, or an assessment of compensation mechanisms. For instance, in the latter category, KONO *et al* (1979) reported that people with NIHL and a noisy workplace tend to have a higher noise exposure at home. With a few exceptions, however, the validation of questionnaires by observation of behaviour remains largely unexplored.

3.5 *Handicap, disability and impairment*

A number of studies shown in Table 3 attempted to relate answers to questionnaires with measures of disability or impairment. For this to be done it is conventional to treat the handicap as though it is a *scorable* - if not strictly a *measurable* - entity. Reducing questionnaire responses to numbers certainly facilitates the search for correlations but it is an unavoidably arbitrary process. Scaling the responses on a continuum, or for example by 5- or 7-point ratings of 'oftenness' from 'never' to 'always', can be rationalized on an extension of the Thurstonian principle of equal discriminal dispersion, using a non-linear transformation if appropriate. Handicap, however, needs scaling along a multitude of dimensions and no metric principle has been established for weighting their relative importance. Furthermore, handicap is an experience for which each subject can contribute only one datum, corresponding to his actual location in this multidimensional space. In this respect it is unlike certain subjective entities (loudness, annoyance and so on) which can be systematically tested by varying the stimulus, and the validity of scaling rules thereby verified empirically. It follows that single-number rating of handicap is necessarily a weak approximation. Nevertheless some authors have addressed handicap rating directly as though it were a unidimensional entity using a degenerate questionnaire of only one item (HABIB and HINCHCLIFFE, 1978); others, notably NOBLE (1979), highlight the essential multidimensionality of the concept while at the same time applying arbitrary weights in pursuit of a single number. Such simplification may be necessary if the object is to deduce from a maximum acceptable handicap rating the corresponding admissible levels of disability, thence to impairment and finally to noise exposure. The present study recognizes the logic of this aim whilst cautioning against too simplistic a reliance on a unique cause-effect relation between noise and handicap. A profile of handicap across a number of dimensions is a more realistic means of expression and is attractive in that it offers scope for the exercise of judgement as to which of them should determine the criteria of acceptability. Massive quantities of data would, however, be required to exploit this advantage.

Clearly there is a need for further combined studies of disability and handicap to aid the interpretation of questionnaire surveys, and conversely to permit interpretation of specific disability measures. To date the measures of disability have been based upon conventional speech audiometry. As an intermediate between disability and handicap, measures should be developed which have a high degree of realism and thus permit more direct interpretation in the context of everyday communication. This would go some way towards answering the question identified by SUTER (1978): 'How much speech communication ability is needed in order to conduct the activities of daily living in a satisfactory manner?'.

3.6 *The onset of handicap and its relation to noise limits*

As we have seen, the ideal notion of setting noise limits through the medium of simple cause-effect relations allied to an acceptability criterion poses intrinsic difficulties, and these would not be dispelled even if the relations were much more accurately known than they are at present. This is not to say that some improvement cannot be made upon present practice, for this bases noise limitation simply on one or other measure of hearing sensitivity with only some general reference across to the way that this might be interpreted in terms of speech discrimination in special conditions.

Present practice only scratches at the surface of a logical system, and an intermediate stage between this and the ideal set out above would be the development of an appropriate set of task performance tests within the common experience of all members of the population. It could then be inferred that the larger the measured disability on these tasks, the greater on average the resulting handicap. This is the approach that we have followed.

In addition to the numerous studies already mentioned which have investigated the relationship between impairment (threshold shift) and disability (speech discrimination loss), two recent contributions have provided results specific to the question of onset of disability. For hearing conservation purposes it is the borderline between normality and disability rather than the higher levels of disability that are of concern, and these two studies are therefore of particular relevance to the present investigation.

SUTER (1978) assessed the intelligibility of two speech materials (everyday sentences and monosyllables) in quiet and in noise. Speech and noise were presented from two vertically adjacent loudspeakers, with the subjects listening under artificial monaural conditions, using the better ear. The 48 subjects were divided into three groups according to the audiogram of the tested ear, and the results were subsequently analyzed only on the basis of these groupings. The results are summarized in Figure 1. The differences between Suter's groups I and II were

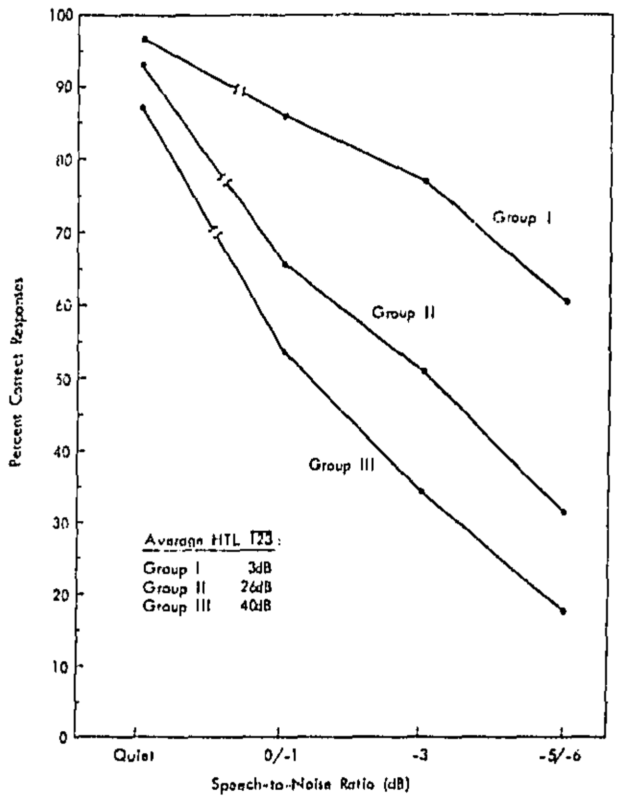

Figure 1: Mean percent correct responses of three groups as a function of speech-to-noise ratio (scores averaged over two speech materials). (After Suter, 1978)

statistically significant for three noise conditions, but not in quiet. It is evident from the Figure that a group of subjects with an average hearing threshold level (HTL) across 1, 2 and 3 kHz of 26 dB was found on average to be 'disabled' for speech heard in noise, relative to a group with normal hearing (average hearing threshold level 3 dB on the same basis). By 'disabled' we mean here a condition that is statistically distinguishable from 'normal': it does not imply any particular degree of this condition, in particular a handicapping degree. Unfortunately this presentation of grouped results does not permit a determination of the threshold of the disability, and inferences about any handicap are difficult to draw because of the unrealistic listening condition. The same data can, however, be presented in another way.

A replotting of Suter's results, shown in Figure 2, indicates that the subjects did not really fall into three distinct groups but form a continuous distribution of hearing threshold levels. From this presentation it could be argued that the threshold for this particular measure of disability is between 15 and 20 dB HTL averaged over 1, 2 and 3 kHz. Suter's results have been represented as redefining the 'low fence' at 17 dB, but the applicability of this figure to a wider definition of disability is open to question and in any case the data do not support the notion of a clear-cut breakpoint.

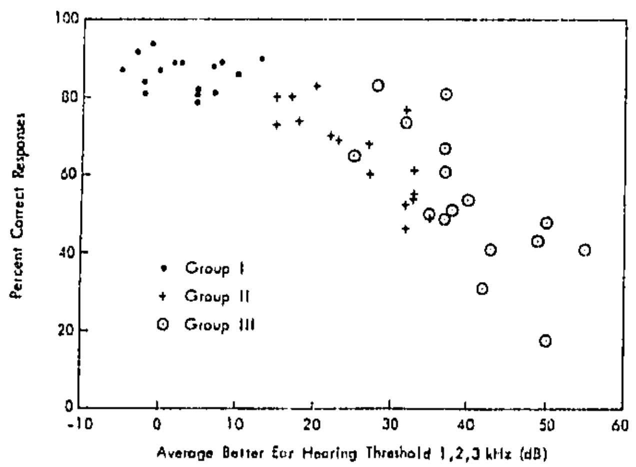

Figure 2: Mean percent correct responses (averaged over two speech materials) for speech-to-noise ratio of approximately 0 dB, as a function of hearing threshold level (average over 1, 2, 3 kHz), for 48 subjects. (After Suter, 1978)

SMOORENBURG *et al* (1981, 1982) assessed the intelligibility of Dutch sentences in quiet and four levels of noise, in each case adjusting the speech level in an adaptive manner to obtain a score of 50%, that is, the speech reception threshold (SRT). The material was presented monaurally through an earphone. The subjects were 7 young persons with normal hearing and 22 others with a noise exposure history. Left and right ears were treated separately. The results for the three higher noise levels are shown in Figure 3, where the ordinate is the difference in SRT between an individual noise-exposed ear and the average for the 14 normal ears. The authors argued that the breakpoint occurred at an average HTL of 15 dB, averaged over 1, 2 and 3 kHz, and that this corresponds to an increase of

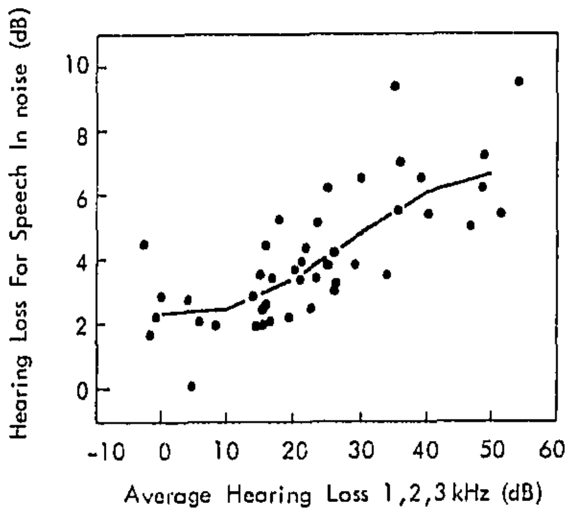

Figure 3: Average hearing loss for speech in noise at levels of 40, 55 and 70 dB(A) as a function of hearing loss (average over 1, 2, 3 kHz) for 44 ears. The curve connects average values for hearing loss classes 10 dB in width. (After Smoorenburg *et al*, 1981)

3 dB in SRT. Using the same technique, PLOMP and MIMPEN (1979) showed that the equivalent disability occurs due to purely age-related hearing loss at the age of about 65 years. The unspecified ages of Smoorenburg *et al's* noise-exposed subjects, and the limited number of those tested, rather weaken the force of this comparison.

4. SYNOPSIS OF RESEARCH AIMS AND PROCEDURES

The specific focus of the present study is the onset of handicap rather than its later development or more severe manifestations, and the experiments are designed accordingly, in the light of the experience and methods adopted by previous workers. The following is a brief summary of the parts of the test procedure that has been evolved. They are described in the hierarchical order *I-D-H* but for reasons that will become apparent they were actually administered in a different and more complicated order. A full description of the test method is given in Chapter 5.

Impairment is assessed by a short battery of audiological tests, consisting of pure-tone air-conduction threshold audiometry, frequency selectivity, temporal resolution and the off-frequency listening effect.

Disability is determined by inaccuracy of message reception in simulations of everyday listening situations. The essential acoustical and visual elements of listening to speech at a social gathering, over a public address system, and over a telephone are re-created in a laboratory setting. Performance at these tests is measured either in the conventional manner (as a percentage of the material correctly reproduced) or in terms of the subjects' ability to answer questions relating to the messages conveyed. In addition, free-field speech audiometry in quiet and noise is also administered.

Handicap is assessed by a questionnaire in three sections. Section I obtains a general self-assessment through a series of questions similar to those used in previous studies. Section II elicits attitudes to nine common kinds of communication situation (domestic, social and public) in more detail; these include familiarity with the situations described, self-assessed ability to cope, any particular difficulties encountered, and the relative importance of such difficulties in the subjects' everyday lives. Three of these nine situations correspond to the laboratory simulations described above. In these cases, additional questions (Section III) are administered at the end of each corresponding simulation test with the object of uncovering any changes in attitude to the general situation (given previously in answer to Section II of the questionnaire) as a direct consequence of actually experiencing a particular situation of the same kind.

Some general observations on this experimental plan may be noted here. Firstly, the nine 'scenarios' for Section II of the questionnaire constitute a highly condensed selection from a much larger possible range embracing the factors enumerated in Chapter 3.2. The main considerations in making this selection were subject toleration and the probability that most subjects would have some direct experience of most of the situations chosen, thus avoiding undue strain on their imagination of the associated hearing difficulties. Secondly, in an ideal experiment each of these scenarios would be mirrored in a corresponding simulation to test actual disability. In practice the simulations had to be restricted to the passive listening situations. Thirdly, Sections I and II of the questionnaire, although classified above for simplicity as testing handicap, also contain some questions relating rather to disability. The latter provide a direct test of the correspondence between subjects' self-perceived disability and their actual performance in three typical situations. Fourthly, we have chosen to classify the speech audiometry as a disability test rather than one of impairment, though the status of speech tests in the *I-D-H* hierarchy is open to debate. Fifthly, the tests of impairment are not as comprehensive as would be desirable but are, again, restricted by considerations of test duration and subject toleration. The complete tests take a little over 2 hours to administer and for operational reasons are necessarily carried out during a single visit.

To summarize, this three-pronged study is designed to provide the following information:

(a) the starting point of disability as revealed by self-assessment and measured performance in a range of listening situations of common occurrence.

(b) the onset of self-assessed handicap and its relationship to disability as determined by the two approaches in (a), and

(c) measures of impairment of hearing which individually or in combination act as predictors of the onset of handicap.

5. METHOD

This chapter describes the test method as finally implemented. In the course of its evolution, a number of pilot experiments were conducted with subjects, both normal and with various impairments. These served to refine the questionnaires, to make adjustments to the acoustical test materials and to select optimum sound pressure levels.

Testing time per subject was of necessity restricted, and no prior experience of subjective tests could be assumed. Certain more complex procedures, such as determination of psychoacoustical tuning curves, were therefore deemed impractical.

5.1 *Test methods*

This sub-chapter describes the content of the component parts of the tests under the respective headings of impairment, disability and handicap, together with some considerations leading to the choices made. The tests were in practice administered in a different order, described in Chapter 5.3. As will be seen, it was a necessary part of the plan to assess the handicap by questionnaire before the subjects were given the listening tests.

5.1.1 Impairment tests

The tests of hearing impairment related to pure-tone hearing sensitivity, temporal resolution and aspects of frequency selectivity respectively, as described below.

5.1.1.1 *Pure-tone threshold*

The air-conduction hearing threshold of each ear was tested at 0.5, 1, 2, 3, 4, 6 and 8 kHz using the self-recording technique. The audiometer was calibrated in accordance with ISO 389 AD1 (INTERNATIONAL ORGANIZATION for STANDARDIZATION, 1983) and was set to produce pulsed tones of nominal duration 250 ms at the rate of 2 per second with an attenuator sweep rate of ± 5 dB/s in 1 dB steps. The recording charts were read to the nearest integer decibel. Measured hearing threshold levels are designated by H_i where the subscript indicates the audiometric frequency; an average at frequencies i and j is indicated by subscripts ij, etc.; a superscript L or R is added where necessary to distinguish between left and right ears and the superscript LR indicates an average over both ears. For analysis the audiometric results are summarized through the following indices: H_4^L, H_4^R, H_4^{LR}; H^L_{123}, H^R_{123}; and H^L_{346}, H^R_{346}, H^{LR}_{346}. The 1, 2, 3 kHz averages follow UK practice in the area of hearing conservation (BS 5330: 1976) and assessment for disability compensation purposes. High-frequency hearing loss is characterized either by H_4 or by H_{346}, random uncertainty being reduced in the second case through taking the average, whereas H_4 is directly related to the other impairment tests described below and permits an estimate of reliability to be made since this measure was repeated (see below).

5.1.1.2 *Temporal resolution*

This was measured by the method of *simplified masking period patterns* developed and evaluated for clinical use by ZWICKER and SCHORN (1982). As illustrated in Figure 4, the resolution measure is based on a comparison

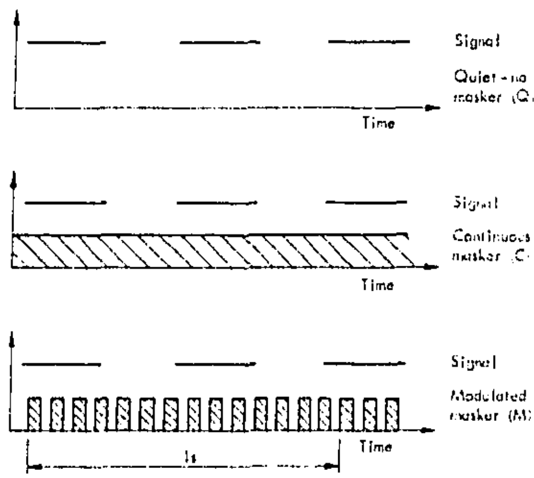

Figure 4: Schematic diagram of the stimuli used in the test of temporal resolution. The signal is a pulsed 4 kHz tone, and the masker is an octave band of random noise centred at 4 kHz.

between three monaural threshold sound pressure levels, designated T (with subscripts) and expressed in decibels, re 20 μPa referred to the artificial ear, of a tone under the following conditions: (a) in quiet, yielding T_Q; (b) when masked by a continuous random noise one octave wide centred at the tone frequency (T_C); and (c) in the same noise modulated by a square wave at 14 Hz (T_M). In each case a 4 kHz probe tone was used and the thresholds were determined by the self-recording technique with the tone pulsed (nominal duration 500 ms, repetition rate 1 per second), and the attenuator sweeping at ± 5 dB/s. The noise in the continuous regime was set individually for each ear at a level such that its one-third octave band sound pressure level in the band centred on 4 kHz was 43 dB above the threshold sound pressure level of the probe tone in quiet, that is, at the level $T_Q + 43$ dB. An exception was made when T_Q exceeded 60 dB, in which case $T_Q + 33$ dB was selected to avoid excessively loud stimuli. The results are expressed by means of indices of impairment of temporal resolution, TI-1 defined by $(T_M - T_C)/(T_M - T_Q)$ (which is Zwicker and Schorn's 'temporal resolution factor' with the sign reversed) and TI-2 defined by $(T_M - T_C)$. Note that both these quantities *increase* (from larger negative to smaller negative values) as the impairment increases. This test also yields a second estimate of H_4, obtained by subtracting from T_Q the value for 4 kHz of the reference equivalent threshold sound pressure level for the type of earphone used (TDH 39P/MX-41/AR), namely 12.0 dB. There was a slight difference between the conditions of test for T_Q and that of H_4 in the pure-tone audiometry in respect of the tone pulsing rate; otherwise this is a direct replication.

ZWICKER and SCHORN's (1982) results indicated a normal range of TI-1 from about -1.3 to -0.5, values greater than -0.5 signifying reduced temporal resolution. The power of this method to characterize sensorineural hearing impairment is not known precisely, but Zwicker and Schorn reported significantly reduced temporal resolution at 4 kHz in a group of 20 NIHL patients.

The masking noises for this test were generated by a Brüel and Kjaer random noise generator type 1405, set to produce white noise. Modulation was effected by feeding a 14 Hz square wave signal into the on/off control of the white noise generator at the remote control input socket. The output of the generator was connected to a Brüel and Kjaer filter set type 1615 and the filter output was magnetically recorded on a Nagra tape recorder type IV D. A recording of 1 min duration was made for each of the three conditions, this being sufficient to obtain accurate threshold determinations. The 50% duty cycle of the modulated noise resulted in a sound pressure level exactly 3 dB below that of the continuous noise for the same setting of the controls. This was verified acoustically with the aid of the artificial ear and an integrating sound level meter.

5.1.1.3 *Frequency selectivity*

This was determined using a notched-noise masking technique, the principle of which is as follows. If the threshold of a tone is measured when masked by a broad-band noise of uniform spectral density, the selectivity of the auditory filter is indicated by the *critical ratio* (CR), defined as the difference between the threshold sound pressure level of the tone and the sound pressure spectrum level of the noise at and around the tone frequency. A degraded auditory filter having, say, twice the normal bandwidth will yield a critical ratio 3 dB above normal, but this increment is scarcely large enough for accurate experimental observation. The sensitivity of the test is greatly increased if, instead of uniform spectrum noise, one substitutes a noise having a notch in its spectrum centred on the test tone frequency. In these circumstances doubling the bandwidth of the auditory filter may raise the tone threshold by as much as 20 dB compared to normal. PATTERSON *et al* (1982) suggested a very simple frequency selectivity test based on this; it consists simply of measuring the threshold of a 4 kHz tone in the presence of broad-band noise at a specified level having a defined symmetrical notch in its spectrum centred on 4 kHz. However, this method shares one of the objections to a conventional critical ratio determination, namely that it does not separate the effect of listening efficiency from that of frequency selectivity *per se*, although, of course, it has the advantage of enhanced sensitivity. This objection can be overcome in principle if a third measurement is made, namely the threshold of the tone masked by a noise which is the same as the notched noise but with the notch absent, that is, a broad-band uniform spectrum noise. The difference between the masked threshold levels in the uniform noise and the notched noise respectively should eliminate the effect of listening efficiency provided the subject does not change his criterion of detection. Each of these methods was used in the present tests.

The tone signal used was identical to that in the temporal resolution test described above. The noise maskers were derived from tape recordings provided by Dr R.D. Patterson and prepared following the procedure he described (PATTERSON, 1976). The uniform noise was presented to subjects at a fixed sound pressure spectrum level N_{fs} = 37 dB (defined relative to 20 μPa and a 1 Hz bandwidth) unless H_4 for the ear being tested exceeded 50 dB HTL, in which case N_{fs} was raised by 20 dB. The notched noise was presented at the corresponding level, such that the sound pressure spectrum level remote from the notch was the same as for the uniform noise. Maskers were presented uninterruptedly throughout the threshold determinations.

One of the requisite data, namely the quiet threshold, T_Q, was already to hand from the previous temporal resolution test. The additional measurements required were the threshold sound pressure levels of the 4 kHz tone under the following conditions: (a) masked by the uniform broad-band noise, yielding T_B; and (b) masked by the notched noise (T_N) (see Figure 5). Indices of frequency selectivity were obtained from the three measurements as follows: FS-1 defined simply by the value of T_N in the manner of Patterson, and an alternative index FS-2 defined by (T_N - T_B). Both FS-1 and FS-2 *increase* with increasing impairment, although all values of FS-2 are inherently negative.

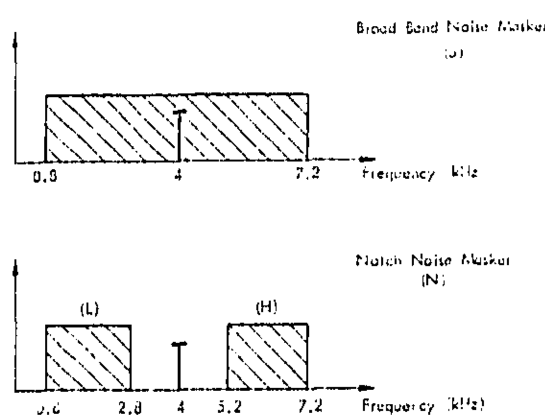

Figure 5: Schematic diagram of the stimuli used in the test of frequency selectivity. The signal is a pulsed 4 kHz tone and the maskers are alternatively a broadband random noise and the same noise with a notch in the spectrum centred on 4 kHz. Maskers are maintained continuously throughout the threshold determination. For the tests of off-frequency listening only the low (L) or high (H) parts of the notched noise spectrum are reproduced.

In addition the measurements yielded two estimates of the critical ratio: (i) CR-1, for octave-band masking noise, defined by $T_C - N_{tr}$, where $N_{tr} = L_{tr_4} - 29.5$ dB is the sound pressure spectrum level of the octave-band noise used in the temporal resolution test) and L_{tr_4} is its one-third octave band sound pressure level in the band centred on 4 kHz, and (ii) CR-2 for broad-band noise defined by $T_B - N_{fs} = T_B - 37$ dB. The constants 29.5 and 37 dB represent respectively the one-third octave bandwidth (relative to 1 Hz) of the noise used in the temporal resolution test and the sound pressure spectrum level of the noise masker in the frequency selectivity test. As with the other indices already described, CR-1 and CR-2 both *increase* with increasing impairment.

5.1.1.4 *Off-frequency listening*

The off-frequency listening effect is a subjective compensation of the centre frequency of the auditory filter to optimize detection (PATTERSON and NIMMO-SMITH, 1980). The effect is inhibited in the frequency selectivity test using the notched noise masker but can be revealed by presenting separately each of the constituent bands of the notched noise. Measures of benefit of off-frequency listening are provided by comparing the thresholds under these conditions with that obtained with the whole notched noise, viz., (a) OF-L defined by $(T_L - T_N)$, and (b) OF-H, defined by $(T_H - T_N)$, where T_L and T_H are respectively the threshold sound pressure levels of the probe tone when only the low (0.8 to 2.8 kHz) and high (5.2 to 7.2 kHz) parts of the noise spectrum are present as maskers. In principle both OF-L and OF-H will have negative values, and the smaller the magnitude of the negative number the greater the impairment of the facility for utilizing the off-frequency effect to enhance detection of the signal, that is, both OF-H and OF-L *increase* with increasing impairment of this faculty. For a symmetrical filter centred on the test tone frequency, removal of either of the constituent bands should result in a downward change of at least 3 dB in the threshold level of the tone as compared with the whole notched noise. The downward change should be substantially greater than this when off-frequency listening is operative. The values of OF-L and OF-H should accordingly have an upper bound of -3 dB, representing total absence of off-frequency listening capability. In practice, smaller negative values, perhaps penetrating the low positive range, might be expected due to measurement uncertainties.

5.1.2 <u>Disability tests</u>

The tests of hearing disability, consisting of three simulated listening situations and the free-field speech audiometry, are described below.

5.1.2.1 *Simulated social gathering.*

This represented the situation of an individual listening to another person as part of a face-to-face conversation, with another pair of persons conducting a separate conversation across the first, all of which occurs in a babble of other talkers and some background music. On the basis of information presented by PLOMP (1977) it was decided to set the combined level of the cross-conversation, babble and music at approximately 70 dB(A), which is typical for a "cocktail party" in a domestic living room. The relative levels of the competing stimuli were set by trial to avoid one or other being unduly prominent.

The speech material of primary interest to the listener consisted of names, addresses, and 7-digit telephone numbers drawn from British telephone directories. Entries were initially selected at random. An entry was retained if it was in the format of name, initial, house number, street name, town and telephone number; otherwise it was rejected and another drawing made. A set of some 50 entries of this format was compiled. This material has particular value for present purposes on a number of counts. Firstly, there are items within each entry that have widely differing probabilities of occurrence: thus, the spoken form of the cardinal numbers uses only 28 words for numbers up to 1000; telephone numbers, as spoken in standard UK practice, use a vocabulary of only 12 words (the numbers one to nine, plus "0", "double" and "thousand"); at the other extreme, surnames and street names are drawn from a much larger (and rather open-ended) vocabulary; the list of town names is long, but not as long as that of surnames, and has a somewhat greater in-built redundancy. Secondly, the material is representative of factual information that might be transmitted at a social gathering. Thirdly, and perhaps most important, it permits some interpretation of the consequences of mis-hearing any particular word or item; for instance, an error in any of the 7 digits of the telephone number renders the whole string worthless; similarly for errors in the first letters of a surname when searching a telephone directory; by contrast the identifier of a street as Road, Street, Way, Grove, etc., and the latter part of a surname, may often be corrupted without loss of identity in these circumstances.

The test was composed of 20 telephone directory entries, 5 spoken by each of 4 people whose native language was English but with some regional variation. In the list of material shown in Appendix A, the speakers are identified as JB, MS, KH and DR, the first two being female. Video recordings of a much larger corpus of material read by these speakers were made at the television studio of the Department of Teaching Media at the University of Southampton. The recordings were made with a Hitachi colour camera type FP-21, a Panasonic recorder type NV 9600, and a Sony lapel microphone type ECM 50. Special attention was given to the lighting conditions and to the sound recording technique to avoid any unnatural video or audio colourations.

The speaker faced towards the video camera and read each item from an adjacent monitor. The monitor screen also indicated when the speaker should commence each item (name, street address, town and telephone number) the timing having been predetermined to allow for written responses without unduly slowing down the proceedings. Each directory entry took about 1 min to read. Overhead, side and floor lighting provided shadow-free conditions for the video recording. The framing of each speaker was such as to obtain a head and shoulder image, approximately life-size on the television screen used in the tests.

Both ears of each speaker were fitted with a behind-the-ear tinnitus masker, Viennatone type AM/Ti, producing a broadband noise. The level was adjusted by pilot trials to produce an average elevation of speech production level equivalent to being in a free-field speech babble of 70 dB(A). The tinnitus masker was not visible to the camera. The purpose in creating a noisy talking environment in this indirect manner, rather than have the talker in actual room noise, was that it provided a noise-free recording for subsequent investigation at various speech-to-noise ratios.

The cross-conversation was provided by a stereophonic recording of a radio play, with extended pauses and sound effects edited out so as to ensure a continuous flow of interchanges between two female voices.

The speech babble was provided by repeated overlaying of separate recordings of 4 persons each reading at a constant voice level from a novel. Two separate 12-voice babbles were composed and reproduced from two separated sources in the test room.

The music consisted of material from an LP gramophone record featuring a five-piece jazz group. It was edited before re-recording, to ensure a fairly constant sound level. Solo passages, noticeably louder or softer sections, and extended pauses were deleted.

In the test presentation of the audiovisual material, the equivalent continuous A-weighted sound pressure levels L_{Aeq} of the constituent audio elements, measured at the location of the subjects' heads in the free sound field, were as follows:

Constituent sound	L_{Aeq} (dB)
Primary speech material (corrected for quiet intervals between items)	72
Cross-conversation	66
Babble	66
Music	66

The three interfering sounds combined to provide a nominal background level of 70 dB(A), and the primary material was therefore presented at a speech-to-noise ratio of +2 dB.

5.1.2.2 *Public address announcements in a concourse*

This simulation was achieved by a stereophonic presentation of tape recordings made at various locations around the concourse at Waterloo railway station. The public address system consists of a large number of loudspeakers located on the walls of the concourse. It is common experience that intelligibility of announcements is poor in some locations around the concourse. This is probably due to the highly reverberant conditions inside the building, the large distances, and, in some locations, due to the line-of-sight to the nearest loudspeaker being obscured.

The tape recordings were made using an Aiwa stereo microphone type CM-Z7 feeding a Sony portable cassette tape recorder type TC-D5M. From the corpus of material recorded, ten items were finally selected to provide a range of intelligibility, to contain material suitable for the evaluation of comprehension by direct questioning and to highlight the element of unexpectedness. A transcript of the key passages of the ten items is given in Appendix B, along with the 14 questions and their correct answers. It should be noted that some of the information given over the public address would in real life also have been available on the departure and arrival display boards or printed timetables but in these cases the questions were selected and phrased so that correct answers were unlikely to be known on the basis of prior information alone (items 1, 3 and 5). Other items contained information of a kind which would only be publicized over the public address system (items 4, 8).

The format of the test tape consisted of an introduction followed by the questions and the relevant recorded material, and a short interval to permit the answer to be written down. In 4 cases (items 4, 8, 9, 10) the material was preceded by two questions, in the remainder by one only. The introductory material and the questions were read by one of the authors (PAW). The material recorded at Waterloo was reproduced in the test room at the same level as that where it was recorded, and in terms of the equivalent continuous A-weighted sound pressure level over the duration of each announcement this varied considerably, from 57 to 72 dB(A).

5.1.2.3 *Listening over a telephone*

This was simulated for conditions where both speaker and listener are in a noisy environment. The speech material used was a further 20 items from the material recorded for the simulated social gathering (see Appendix C). The audio track of the video recording was replayed through an artificial mouth, Brüel and Kjaer type 4216, into a telephone handset attached in the normal position to the mounting fixture. The artificial mouth was located in the speech babble described in Chapter 5.1.2.1, set to a level of 70 dB(A), with the speech material reproduced at a level equivalent to the corrected equivalent continuous value of 72 dB(A) used in the simulation of the social gathering. The mixed speech and noise signal was transmitted over a telephone line and the electrical signal which would normally drive the earphone in the receiving-end handset was recorded on a Sony portable cassette tape recorder type TC-D5M. A copy of this recording was thereafter used to drive the earphone for the listening tests.

The tests were conducted with the subject holding the handset to the ear of their choice while sitting in the same speech babble as described in Chapter 5.1.2.1. For simplicity, side-tone of the local noise at the listening end was not provided. In quiet conditions this omission would not have given a satisfactory simulation, and HOLMES *et al* (1983) have reported that side-tone can even have an adverse effect on speech intelligibility when the listener is in noise. However, informal tests were carried out at the British Telecom Research Laboratories in connection with the present study and showed that the effect is less important when both speaker and listener are in noise at the levels used in the present telephone listening simulation.

5.1.2.4 *Free-field speech audiometry*

This test was administered using eight selections from the ISVR recording of the Boothroyd AB(S) word lists (see Appendix D). The material was presented at each of three speech levels, corresponding to 30, 45 and 70 dB equivalent continuous A-weighted sound pressure level (after correction for silent intervals between words), with the speech at 70 dB(A) also presented in the presence of the speech babble already described. All four conditions were repeated for each subject, as indicated in Appendix D. The resulting eight conditions were presented in a fixed order, in conjunction with the same word lists for all subjects.

5.1.3 Handicap and self-reported disability

These aspects were tested by the questionnaire method. The questionnaires of the various authors referred to in Table 3 (Chapter 3.5) were scrutinized with a view to being utilized in the present study, as this would have given the advantage of direct cross-reference to published results. None of them however, appeared to be suitable unless modified considerably. The principal reason for this is the small-to-moderate (essentially sub-clinical) levels of impairment that are of interest in the present target population. We therefore devised an instrument suited to the purpose. Many of the questions and the form of questionnaire construction are novel, but the content draws on previous studies in various aspects.

The prospective target population and the circumstances of test dictated decision on some of the factors listed in chapter 3.4. In particular, the interview method was ruled out and the time factor imposed a limit on length. It was decided to include questions both of the generalized kind (Section I) and the particularized kind (Section II), giving the opportunity to compare these approaches.

Section I (Hearing in General) consists of 14 questions, with response categories that vary both in type and number according to the nature of the question.

For Section II (Hearing in Typical Situations) it was decided to present a series of broadly similar, but not identical, sub-questionnaires, one for each of the nine situations tested. Within each of these, identified as A - J, a variety of response scales was used, including a 'temporal' scale (for familiarity with situatiion) and an 'intensitive' scale (for degree of difficulty), these two being common to all nine situations. The remaining questions (on particular difficulties, reactions to auditory failings, and degree of perceived disadvantage) were varied according to the situation. Categories of 'not applicable' were included, where appropriate, and open-ended responses were invited as an option in some places. We hoped by these devices, and by laconic phrasing, to encourage and maintain respondents' interest and attention to the task in hand. It appears to us that long check lists of questions in identical format tend to strain the language and appear contrived. Whilst easy to score they can make unreasonable demands on the patience and imagination of subjects. For our prospective population, interest in the tests would be the only reward. Each sub-questionnaire was accompanied by a verbal description prominently placed at the head of the page, and by a photograph to reinforce subjects' awareness of the situation they were being asked to respond to.

Both Section I and each part of Section II contained certain questions testing disability and others testing handicap. This permits a comparison to be made between the results for the two aspects, and also a correlation between the perceived disability and the performance at the simulations.

Section III of the questionnaire (Reaction to Simulated Situations) consists of three sub-questionnaires, for the situations (B, C and G) corresponding to the simulations described in Chapter 5.1.2. The purpose was to test the perceived realism of the simulations and to offer subjects an opportunity to modify their corresponding Section II responses if the experience of the simulations moved them to do so.

The full text of Sections I, II and III of the questionnaire is reproduced in Appendix E. The procedure of administration is described in Chapter 5.3 and the method of scoring in Chapter 6.

5.2 *Experimental arrangements, equipment and calibration*

The experiments were conducted in the Occupational Deafness Laboratory of the ISVR, located in a house at 62 University Road. The laboratory comprises a test room having dimensions 4.3 × 3.6 × 2.5 m, an adjacent control room and an ISVR-built audiometric test booth.

5.2.1 Impairment tests

The tests described in Chapter 5.1.1 were conducted with the subject seated in the booth, using equipment located adjacent to it. Pure-tone thresholds were measured with a Kamplex audiometer type AC4-C interfaced to an XYT recorder, Kamplex model AG3. For the tests of temporal resolution and frequency selectivity, an external oscillator provided the 4 kHz signal as an external input to the audiometer, and the masking noises were presented via the audiometer from a Ferrograph series 7 tape recorder.

Frequencies of the audiometer test tones were checked periodically with a Racal digital frequency meter type SA 520, and the output of each earphone was measured at a hearing level dial setting of 60 dB by means of an artificial ear, Brüel and Kjaer type 4153. The earphones were Telephonics type TDH 39P with MX-41/AR cushions, fitted to circumaural noise-excluding muffs (Amplivox Audiocups). The muffs were detached from the earphones for all measurements on the artificial ear. The audiometer was calibrated using the reference equivalent threshold sound pressure levels given for this artificial ear in ISO 389 AD1. Since the AC4-C audiometer does not have independent trim potentiometers for left and right channels, small corrections were necessary to the measured hearing threshold levels at frequencies where the two earphones were not perfectly matched. The frequencies of the test tones were accurate within 1% or better of the nominal values and stable to better than this.

Level settings for the external signals were made, in the first instance, by adjusting gain controls to give the requisite sound pressure levels in the artificial ear. Thereafter they were monitored by electrical measurements at the tape recorder output, for greater convenience. In the case of the masking noises (which were all sequentially recorded on one tape) a 4 kHz calibration signal recorded at the beginning of the same tape sufficed for the electrical check measurements. Periodically the acoustic output of the earphones was checked on the artificial ear for the external signals, using a Brüel and Kjaer frequency analyzer type 2121 and filter set type 1615 in the one-third octave band mode. The band sound pressure spectra of the masking noises differed slightly from the corresponding spectra of the electrical signals since no equalization was provided for the frequency response of the earphones. The latter were flat within ± 0.7 dB over the range 0.25 to 2.5 kHz but deviated by ± 3.5 dB between 2.5 and 7 kHz, giving rise to slight humps in the noise spectra in the 3.15 and 6.3 kHz bands and a slight depression around 5 kHz. Measurement of the spectrum of the modulated octave-band noise showed it to be exactly 3 dB below that of the parent noise, reflecting the 50% duty cycle of the square wave modulation. For all measurements on the artificial ear, the TDH 39P earphones were applied with the appropriate static force (5 N). The equipment used is shown in Table 4.

5.2.2 Disability tests

For the tests described in Chapter 5.1.2 the subject was seated in the approximate centre of the test room, as shown in Figure 6. Furnishings in

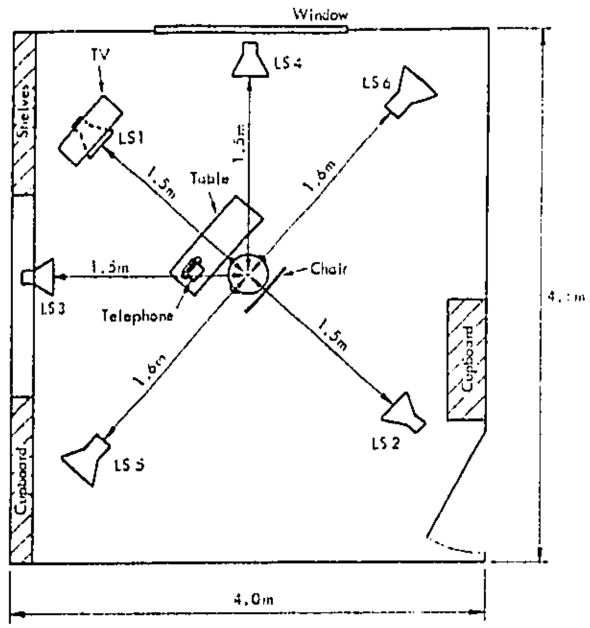

Figure 6: Schematic diagram of the layout of the test room

the room included two cupboards, a set of shelves, curtains, wall-to-wall carpet, a chair of adjustable height and back support for the subject, and a small writing table. The reverberation time of the room was between 0.50 and 0.65 s over the frequency range 125 Hz to 4 kHz. Six loudspeakers were located and oriented in the test room as illustrated in Figure 6. Loudspeaker cabinets LS 2, 3 and 4 were mounted on stands with the centre line of their cones at the nominal ear height of 1.15 m. Loudspeaker cabinets LS5 and 6 were mounted on vibration isolation pads on the floor, with their cone centre lines at a height of 0.35 m. Loudspeaker LS 1 was located beneath the television set at a height of 0.80 m. The forward axis of this loudspeaker was tilted upwards at an angle of 14° so that the axis passed through the nominal centre position of the subject's head, while keeping the distance between this point and the front of the loudspeaker the same as that for LS 2, 3 and 4. The location of LS 1 was concealed by the use of loudspeaker screening cloth (Tannoy Brown). The height of the television set was adjusted so that the mouths of the speakers in the video material of the social gathering simulation were at the same height as the subject's eyes (1.15 m).

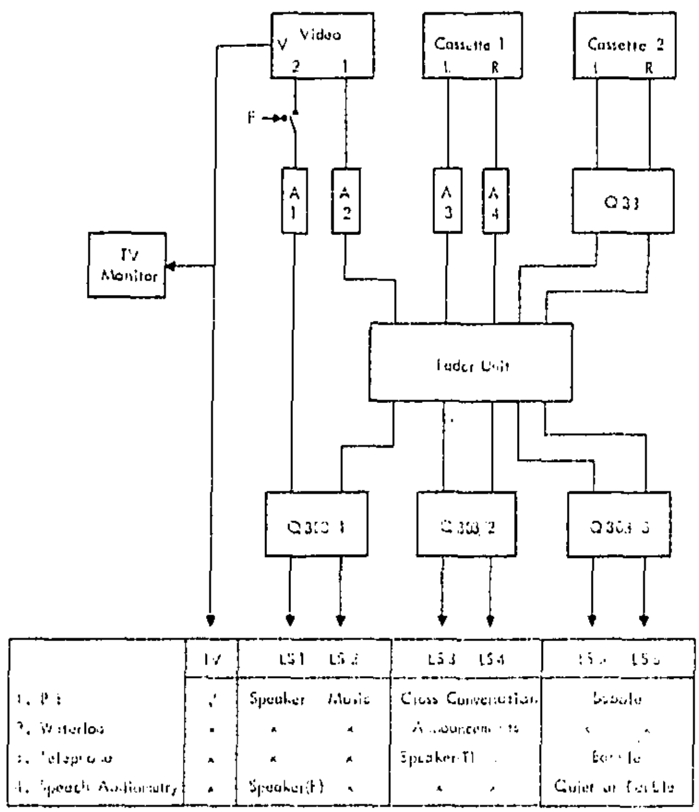

Figure 7: Schematic diagram of the equipment used for the simulations and the free-field speech audiometry

The equipment used for running the simulations was located in the control room. The schematic arrangement is shown in Figure 7 and the equipment is listed in Table 4.

For routine monitoring of the sound sources, a half-inch condenser microphone (Brüel and Kjaer type 4165) and pre-amplifier were mounted vertically on a tripod and positioned with the diaphragm at the nominal centre position of the subjects' heads, with the writing table temporarily removed. The measurements were made with a Brüel and Kjaer frequency analyzer type 2121, the overall system being checked daily with a pistonphone. During the disability tests the microphone and tripod were moved to a convenient position and used to drive an amplifier and monitor loudspeaker in the control room. Routine monitoring of the levels of speech babble, cross-conversation, music and target speech were made with the frequency weighting A and time weighting S, by means of segments of pink random noise recorded at the beginning of each of the tapes carrying these signals. Levels were read to the nearest half decibel and the gains of the various channels rarely required adjusting.

Measurements of the component parts of the sound used in the 'social gathering' and 'public concourse' simulations were made with a Brüel and Kjaer integrating sound level meter type 2218 in the A-weighted 'L_{Aeq}' mode, with the microphone in the same position as that occupied by the centre of the subjects' heads. In the case of the speech material consisting of names and addresses and word lists, the measurements were made over a complete presentation and then corrected upwards by 10 log (T/t) where T is the total measurement period and t is the estimated summed duration of the speech utterances. In the case of the public announcements, which consisted of connected speech without significant pauses, each item was measured over its actual duration and no correction was necessary.

Table 4: List of electronic equipment

Impairment tests

Magnetic tape recorder: Ferrograph, series 7.
Signal source: Wavetek synthesizer/function generator, type 171.
Frequency meter: Racal, type SA 520.
Audiometer: Kamplex, type AC4-C (automatic recording) equipped with ABJF interface.
Earphones: Telephonics type TDH 39P with MX-41/AR cushions, contained in Amplivox Audiocups.
Recorder: Kamplex, type AG3 (interfaced to audiometer).
Frequency analyzer: Brüel and Kjaer, type 2121.
Artificial ear: Brüel and Kjaer, type 4153 (complying with IEC 318), with microphone type 4134 and preamplifier.
Filter set: Brüel and Kjaer, type 1615.

Disability tests

In test room (see Figure 6)

Colour TV receiver (TV): Sony type KV 2204 UB.
Loudspeakers (LS1-LS4): Jordan Watts 100 mm single driver type Janet.
Loudspeakers (LS5-LS6): Tannoy 365/50 mm dual concentric type HPD 385A.
Telephone (T): Subscriber set type T/DCO/703 with transmitter, STC type 4050K 71/2 and receiver, STC type 4042W4 70/2.

In control room (see Figure 7)

Video cassette player (Video): Sony U-matic, type VP-1210.
Audio cassette players (Cass 1 and 2): TEAC, type A-108.
Attenuators (A1-A4): Hatfield 100 (× 1) dB, types 2120 and 2125.
Control unit (Q33): Quad, type 33.
Fader: ISVR construction with 6 slide potentiometers.
Power amplifiers (Q303/1-3): Quad, type 303.
TV monitor: Sharp television receiver (b/w), type 12P-37H.
Magnetic tape recorder (F): Ferrograph, series 7.

For sound field calibration/monitoring

Microphone: Brüel and Kjaer, half-inch condenser type 4165.
Integrating sound level meter: Brüel and Kjaer, type 2218.

5.3 *General protocol*

Subjects were booked in advance (singly) for participation in the experiment with a brief explanation of its purpose and the types of test involved. On arrival at the Laboratory, each subject completed a Registration and Consent Form (Appendix F), and then completed Sections I (Hearing in General) and II (Hearing in Typical Situations) of the Questionnaire. These were self-explanatory and were completed in most cases without any specific supervision from the experimenter. However, any queries were discussed and any additional verbal comments by the subjects were noted on the questionnaire forms. In addition to the loose-leaf questionnaire pages, a folder was provided which contained the same pages for reference and in addition 9 black and white photographs each of which illustrated one of the situations.

Auditory tests then commenced with the first simulation. The subject was seated in the test room with the table moved to a comfortable position, and given a pen, clip board and the appropriate answer sheet for that simulation. At the end of the simulation, the relevant page from Section II of the questionnaire was returned to the subject with the written instruction shown in Appendix G and an invitation to make changes, if any, to the earlier responses, using a different coloured pen. The subject was then given the relevant page from Section III of the questionnaire (Reaction to Simulated Situations). This procedure was repeated twice more, with the three simulations occurring in the fixed order Social Gathering (B), Public Address (C) and Telephone (G). The subject then performed the free-field speech audiometry test.

At this stage the session was interrupted for a refreshment break of approximately 15 minutes. On resumption, the subject undertook the tests of impairment in the fixed order: pure tone audiometry, temporal resolution, frequency selectivity and off-frequency listening.

The total duration of each test session was approximately two and a quarter hours. The complete series of tests, in order of performance was as follows:

1. Registration; general questionnaire on relevant medical and environmental history; consent form.

2. Questionnaire section I, Hearing in General (15 questions).

3. Questionnaire section II, Hearing in Typical Situations (in 9 parts, A - J, each with 4 or 5 questions) (see Appendix E).

4. Simulation of social gathering (corresponding to part B of 3), followed by Questionnaire section III(B).

5. Simulation of announcements in public concourse (corresponding to part C of 3), followed by Questionnaire section III(C).

6. Simulation of telephone listening in a noisy place (corresponding to part G of 3), followed by Questionnaire section III(G).

7. Free-field speech audiometry in quiet (at three speech levels) and in noise of 70 dB(A) (speech-to-noise ratio + 2 dB); two word lists in each condition.

8. Interval of 15 minutes.

9. Pure tone audiometry.

10. Temporal resolution, frequency selectivity and off-frequency listening tests (test material recorded consecutively on one magnetic tape).

5.4 *Subjects*

Subjects with normal hearing were recruited from staff and students of the University. Full results were obtained from 20 (13 M, 7 F) with a mean age of 22 yr. These were selected on the basis of the absence of any medical history of hearing disorder and undue exposure to occupational and recreational noise. This otologically normal group of young persons will be referred to as YN.

Subjects with a significant noise exposure were located partly from records of the audiology clinic of ISVR (2), partly by personal contact (5) and partly through local advertisement (17). At the time of compiling this report a net total of 24 noise-exposed hearing-impaired subjects (23 M, 1 F) had provided complete sets of results. A number of others were tested but only those were retained who were free from a history of otological disorder (except for one who had once received medical attention for an ear infection). These covered a wide age range (21 to 62, mean 45 yr). This group will be referred to as noise-impaired, NI, but since they do not form a homogeneous group with respect either to age or occupational noise history their results are treated for the most part on an individual basis.

To provide a further basis of comparison, a group of 10 otologically normal older persons (group ON) was also tested. These were selected on the same criteria as group YN.

Desirably a larger number of noise-impaired subjects would have been tested, to permit stratificatrion by age. In the event, expectations of obtaining larger numbers from the pay-roll of local industries did not materialize, and the location of suitable subjects was also impeded by the fact that cases of advanced or severe hearing loss were not considered suitable for the purposes of the study; also a practical limit was imposed by the distance of prospective subjects' domiciles from the University.

6. RESULTS

6.1 *Method of presentation*

Results for the young normal group YN are considered first, in terms of 55 measures derived from the tests. These are then normalized by expressing individual results as deviations from the YN group mean, measured in standard deviation units. Values for each individual of the NI group are then expressed on the same scale. The measures are grouped as *I, D or H*, and correlations within and between each of these classes are performed.

6.2 *Results for normal-hearing group YN*

6.2.1 Pure-tone audiometry

The results of pure-tone audiometry are given in Table 5 as read to an accuracy of 1 dB from the self-recording charts. At the foot of each column the mean and standard deviation are shown, together with the conversion to true hearing threshold level after correction for the audiometer calibration. In common with other studies of otologically normal young persons, the mean values appear slightly negative at mid-frequencies (2, 3 4 kHz) and slightly positive at 6 kHz. This has been argued (ROBINSON *et al*, 1979) to be an artefact of the ISO reference audiometric zero rather than a departure from otological normality, and on this basis the present group can be considered very close to normal.

Table 5: Results of pure-tone audiometry (Group YN)

Subject	Age/sex		Ear	0.5	1	2	3	4	6	8 kHz
1	23	M	L	-1	4	7	16	11	4	15
			R	-3	4	2	12	12	0	20
2	24	M	L	-4	0	-5	-7	0	9	-4
			R	0	-1	-5	3	0	4	5
3	20	M	L	2	-3	-8	-3	-2	2	-8
			R	0	-4	-6	-4	-7	5	7
4	19	F	L	0	6	-1	4	10	5	4
			R	4	0	-4	-2	5	10	-5
5	19	F	L	-10	15	5	5	4	8	10
			R	0	0	10	5	6	4	8
6	21	M	L	-1	1	-8	3	5	18	27
			R	0	2	-5	0	-4	14	8
7	35	M	L	-4	1	-6	5	12	15	8
			R	-4	2	-2	0	4	18	9
8	21	M	L	3	0	-4	-4	-6	21	-5
			R	7	1	-4	0	-5	14	-5
9	26	M	L	8	7	3	4	5	7	18
			R	1	3	2	8	-4	5	6
10	18	F	L	0	-4	-4	-3	-1	2	-5
			R	-5	-2	-5	-6	-5	10	-2
11	19	M	L	2	0	-9	-9	-9	-9	-9
			R	0	-1	-5	-4	-3	2	-10
12	19	F	L	0	-6	-1	-4	0	12	11
			R	-3	0	0	-2	-2	2	2
13	19	F	L	-4	-5	-6	-6	-8	8	6
			R	0	3	-4	2	-5	26	4
14	21	F	L	2	10	0	1	-5	14	15
			R	0	3	8	9	5	3	0
15	20	M	L	0	1	-5	-3	2	-8	-6
			R	-1	-4	-6	-1	-5	-5	0
16	19	M	L	11	8	8	0	1	-1	2
			R	15	15	16	5	-5	11	15
17	23	M	L	-5	-5	0	0	0	5	5
			R	-5	0	0	-5	0	0	0
18	28	M	L	0	1	0	2	0	2	0
			R	0	0	2	1	-1	-2	0
19	25	M	L	-1	6	-5	-4	8	18	10
			R	-5	6	0	-5	5	7	12
20	22	F	L	-5	-7	-8	-5	-6	-6	-10
			R	-8	-6	-6	-3	-5	11	-3
Mean	22		L	-0.3	1.5	-2.3	-0.4	1.1	6.3	4.2
			R	-0.3	1.1	-0.6	0.7	-0.7	6.9	3.6
SD			L	4.6	5.8	5.1	5.7	6.2	8.5	10.2
			R	4.9	4.4	6.0	5.0	5.2	7.4	7.3
True HTL (dB re ISO 389 AD1)			L	-0.8	2.0	-1.3	-0.4	1.1	2.6	5.8
			R	-1.0	0.8	0.2	-0.3	-1.9	1.1	6.3

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The last row of Table V is in error. The values of standard deviation should read: 2.4 2.4 2.0 1.9

6.2.2 Temporal resolution and critical ratio for an octave-band masker

The values of TI-1 and TI-2 (see Chapter 5.1.1.2) obtained using the continuous and modulated (gated) octave-band noise masker and a 4 kHz probe tone are given in Table 6, which also shows the values of the critical ratio CR-1 (see Chapter 5.1.1.3) obtained with the continuous octave-band masker.

Table 6: Results of temporal resolution and octave-band critical ratio tests (Group YN)

Subject	TI-1		TI-2 (dB)		CR-1 (dB)	
	L	R	L	R	L	R
1	-0.67	-0.76	-8	-13	26	28
2	-0.92	-0.56	-12	-10	28	26
3	-0.54	-0.77	-7	-10	18	21
4	-0.67	-1.17	-4	-7	18	23
5	-0.69	-0.67	-11	-8	26	28
6	-0.42	-0.67	-5	-6	26	23
7	-0.44	-1.08	-7	-13	27	28
8	-0.41	-0.77	-7	-10	22	26
9	-0.41	-0.27	-7	-4	21	21
10	-0.91	-0.64	-20	-9	28	21
11	-1.54	-0.64	-17	-7	30	24
12	-0.54	-0.47	-7	-9	18	26
13	-0.94	-0.64	-15	-9	24	24
14	-0.13	-0.85	-2	-11	21	28
15	-0.60	-1.00	-12	-13	25	26
16	-0.69	-1.07	-11	-15	33	34
17	-1.00	-0.50	-15	-10	23	23
18	-0.86	-0.75	-19	-9	24	24
19	-0.64	-1.17	-9	-14	23	27
20	-1.15	-0.25	-15	-3	9	16
Mean	-0.71	-0.73	-10.5	-9.5	24.0	24.9
SD	0.32	0.27	5.0	3.2	4.2	3.8

The values of TI-1 and TI-2 are derived from the self-recorded threshold traces read to an accuracy of 1 dB. Values of the critical ratio CR-1 are given to the nearest decibel, based on the mean calibration of the system for the 4 kHz probe tone and the mean measurement of the noise spectrum, in each case using the Brüel and Kjaer artificial ear type 4153.

A comparison is made in Table 7 between the values of H_4 obtained by pure-tone audiometry and T_Q, the threshold sound pressure level of the 4 kHz probe tone used in the temporal resolution test. The expected difference (T_Q - H_4) is 12.0 dB, this being the RETSPL value for 4 kHz used in calibrating the audiometer.

Table 7: Comparison of threshold determinations at 4 kHz

Signal source	Measure	Threshold sound pressure level, mean of 20 (dB re 20 μPa) L	R	LR av.
Audiometer(1)	H_4 + 12	13.1	10.1	11.6
	SD	6.2	5.2	5.1
Probe tone(2)	T_Q	12.1	12.9	12.5
	SD	9.5	6.7	7.5
	Difference	1.0	-2.8	-0.9
	SD	6.1	4.0	5.2

(1) Tone pulsed at 2 per second
(2) Tone pulsed at 1 per second

The results of the two threshold measurements agree on average within 0.9 dB, the higher value being obtained with the longer pulses.

6.2.3 Frequency selectivity, off-frequency listening and critical ratio for a broadband masker

The values of FS-1, FS-2, OF-L, OF-H and CR-2 (see Chapter 5.1.1.3) obtained using the constant level broadband and notched noise maskers with a 4 kHz probe tone are given in Table 8.

Table 8: Results of frequency selectivity and off-frequency listening tests, and broadband critical ratio, in decibels (Group YN)

Subject	FS-1		FS-2		OF-L		OF-H		CR-2	
	L	R	L	R	L	R	L	R	L	R
1	42	40	−23	−25	−7	−5	−10	−5	30	30
2	35	35	−29	−29	−4	−7	−5	−9	29	29
3	30	31	−25	−27	−7	−2	−7	−9	20	23
4	36	35	−19	−20	−6	−7	−9	−9	20	20
5	37	39	−23	−24	−7	−4	−12	−7	25	28
6	40	33	−18	−22	−2	−6	−10	−8	23	20
7	41	40	−19	−23	−4	−10	−8	−8	25	28
8	34	36	−24	−26	−9	−7	−7	−9	23	27
9	30	30	−23	−25	−4	−4	−6	−6	18	20
10	44	29	−18	−22	−6	−8	−19	−8	27	16
11	34	35	−26	−27	−4	−15	−9	−9	25	27
12	30	34	−30	−26	−8	−4	−10	−9	25	25
13	32	28	−28	−30	−4	−7	−10	−6	25	23
14	31	34	−27	−26	−9	−5	−2	−6	23	25
15	44	35	−17	−26	−6	−9	−15	−9	26	26
16	54	40	−16	−25	−3	−4	−23	−5	35	30
17	30	30	−30	−30	−5	0	−5	−5	25	25
18	33	38	−26	−10	−7	−4	−11	−10	24	13
19	44	40	−20	−23	−6	−5	−14	−13	29	28
20	31	30	−26	−25	−7	−6	−11	−12	22	20
Mean	36.6	34.6	−23.4	−24.5	−5.7	−5.9	−10.1	−8.1	24.9	24.2
SD	6.5	4.0	4.5	4.3	1.9	3.1	4.9	2.2	3.9	4.7

Comparison of the critical ratio determinations (Tables 6 and 8) generally shows a good agreement, with a significant correlation of individual scores (left, r = 0.732; right, r = 0.683; combined, r = 0.681) although the difference exceeds 5 dB in three ears. The mean difference (signless) is 2.4 dB. Both measures should agree for normal hearing since bandwidths of both maskers, though different, greatly exceed the normal auditory critical bandwidth at 4 kHz, estimated in the literature (LYREGAARD, 1982; TYLER *et al*, 1982c; HAWKINS and STEVENS, 1950) to be of the order 330 ± 100 Hz depending on test conditions. The mean value of CR-1 and CR-2 for 40 ears in the present tests yields a critical bandwidth estimate of 290 Hz.

6.2.4 Simulated listening situations

6.2.4.1 *Social gathering*

The results of this simulation were scored by the number of errors (out of a possible 20) for each component of the name-and-address format, viz.,

1. The initials
2. The surname
3. The house number
4. The street name
5. The street classifier (Road, Avenue, Close, etc.)
6. The town name
7. The first 3 digits of the telephone number
8. The last 4 digits of the telephone number

The results for individual subjects are given in Table 9. Columns headed 1...8 give actual numbers of errors in the above categories; the final column is the total number of errors made, expressed as a percentage of the total number of items in the test, i.e., 160 (20 names, etc., each with 8 components).

Table 9: Results of simulation of social gathering (Group YN)

Subject	Errors per component								Total errors (%)
	1	2	3	4	5	6	7	8	
1	1	5	0	4	1	1	0	0	7.5
2	2	4	1	7	0	4	0	2	12.5
3	0	5	0	7	2	6	0	1	13.1
4	0	6	0	6	0	5	0	3	12.5
5	0	5	0	2	0	6	0	0	8.1
6	0	6	0	4	0	1	0	1	7.5
7	0	10	1	9	2	4	0	5	19.4
8	1	10	2	8	1	8	1	3	21.3
9	2	7	1	3	2	4	0	3	13.8
10	0	3	0	6	1	3	1	0	8.8
11	1	5	0	2	0	5	0	1	8.8
12	1	6	0	12	1	5	0	3	17.5
13	5	13	1	13	4	10	5	6	35.6
14	0	8	1	4	0	5	0	2	12.5
15	0	3	0	3	1	4	1	1	8.1
16	0	4	0	5	1	4	0	0	8.8
17	0	5	0	5	2	2	0	3	10.6
18	1	8	0	6	0	6	0	4	15.6
19	1	5	1	6	1	4	0	1	11.9
20	2	5	0	7	1	4	1	0	12.5
Mean	0.85	6.15	0.40	5.95	1.00	4.55	0.45	1.95	13.3
SD	1.23	2.54	0.59	2.95	1.02	2.10	1.15	1.76	6.6

The fairly high overall mean error score of 13% shows that the desired condition of appreciable but not severe difficulty for those with normal hearing was attained. The mean, however, conceals a wide range of individual performance and one subject (F, 19 yr) scored nearly 5 times as many errors as subjects 1 and 6 (M, 23 yr; M, 21 yr). The errors were, as expected, mainly concentrated in items 2 (surname), 4 (street name) and 6 (town name), the overall error rate for these items being 28%. In contrast, the overall error rate for all numerals, initials and street classifiers was under 5%, reflecting the limited 'vocabulary' of such items.

6.2.4.2 *Unexpected announcements in a public concourse*

The results of this 10-part simulation were scored as 14 items (questions 4, 8, 9 and 10 were in two parts). Exact reproduction of the wording of the announcements was not required, only an accurate comprehension of the messages, and the data sheets were marked accordingly. Half-scores were awarded where the gist of a message was correctly conveyed but nevertheless was not wholly accurate.

The results for individual subjects are given in Table 10. Columns headed 1.... 10b are actual numbers of errors on each question (0, 0.5 or 1); the final column is the total number of errors made, expressed as a percentage of the total number of messages (14).

Table 10: Results of simulation of announcements in a concourse (Group YN)

Subject	Errors in each question														Total errors
	1	2	3	4a	4b	5	6	7	8a	8b	9a	9b	10a	10b	(%)
1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	7.1
2	0	0	0	0	1	0	1	1	0	0	0	0.5	0	1	32.1
3	0	0	0	1	0	0	1	0	0	0	0	0	0	0	14.3
4	0	0	0	0	1	1	1	0	0	1	0	0	0	0	28.6
5	0	0	0	1	1	0	0.5	0	0	0	0	0	0	0	17.9
6	0	0	0	1	0	0	0.5	0	0	0	0	0	0	0	10.7
7	0	0	0	1	1	0	1	1	0	0	0	0	0	1	35.7
8	0	0	0	0	1	0	1	1	0	0	0	0	0	0	21.4
9	1	0	0	1	1	0	0	0	0	0	0	0	0	1	28.6
10	0	0	0	1	1	0	1	0.5	0	0	1	0	1	1	46.4
11	0	0	0	1	1	0	1	0	0	0	0	0	0	0	21.4
12	1	0	0	1	1	0	1	0	0	0	0	0	0	1	35.7
13	1	1	0	1	1	0	1	0	0	0	0	1	0	1	50.0
14	1	0	0	1	1	0	0	1	0	0	0	0	0	0	28.6
15	0	0	0	1	1	0	1	1	0	0	1	0	0	0	35.7
16	0	0	0	1	1	0	1	0	0	0	0	0	0	0	21.4
17	1	0	0	1	1	0	0	0.5	0	0	0	0	0	0	25.0
18	1	0	0	0.5	0	0	1	0	0	0	0	0	0	1	25.0
19	0	0	0	0	0	0	1	0	0	0	0.5	0	0	0	10.7
20	0	1	0	1	0.5	0	1	0.5	0	0	1	0	0	0	35.7
													Mean		26.6
													SD		11.5

The difficulty of the items in this simulation turned out to be very variable, no errors at all being made on questions 3 and 8 (first part) as against about 75% incomprehension of questions 4 (both parts) and 6. Subjects also varied widely, with subject 13 again scoring most errors and subjects 1 and 6 again scoring least (in the ratio of about 7 to 1).

6.2.4.3 *Listening on the telephone in a noisy place*

The results of this simulation were scored in exactly the same way as the social gathering, and are given in Table 11.

Table 11: Results of simulation of listening on the telephone (Group YN)

Subject	Errors per component								Total
	1	2	3	4	5	6	7	8	errors (%)
1	11	5	0	1	0	3	0	0	13.8
2	11	16	6	16	6	15	6	10	53.8
3	1	4	1	1	0	1	0	0	6.3
4	1	8	0	7	0	5	2	2	15.6
5	0	9	0	7	0	5	0	0	13.1
6	3	7	1	11	0	6	0	1	18.1
7	2	8	0	6	1	6	0	1	15.0
8	1	8	0	4	0	4	0	2	11.9
9	0	9	0	7	1	5	0	0	13.8
10	1	7	0	4	1	7	0	0	12.5
11	6	10	0	8	0	7	0	2	20.6
12	3	12	0	7	0	12	0	2	22.5
13	0	8	0	3	0	5	0	0	10.0
14	2	6	0	9	0	5	0	1	14.4
15	1	10	0	6	0	5	0	0	13.8
16	1	9	0	5	0	4	0	1	12.5
17	2	9	0	9	0	14	1	0	21.9
18	0	9	0	10	0	8	1	0	17.5
19	1	9	1	9	0	4	0	0	15.0
20	1	10	0	7	0	7	0	1	16.3
Mean	2.40	8.65	0.45	7.05	0.45	6.40	0.50	1.15	16.9
SD	3.25	2.52	1.36	3.17	1.36	3.53	1.40	2.23	9.5

Error scores in this (monaural) test were slightly higher than in the simulation of the social gathering, for which the test material was of exactly the same kind. Errors were distributed among the 8 components of the name/address/number in much the same way, averaging 36.8% for the difficult ones (surname, street name, town name) against 5% for the easy ones (numerals, etc.). The only notable difference is that subjects had more trouble with initials in the case of the telephone listening in noise (although the average error rate was still relatively low on this item, at 12%). Remarkably, subject 13 performed very well on this test, ranking second whilst subjects 1 and 6 were only average. An exceptionally high error rate was scored by subject 2 (M, 24 yr) who was about average on both the other simulations; there was no obvious reason for this.

6.2.5 Free-field speech audiometry

Each list consisted of 10 CVC words and errors were scored out of 30. Lists were presented in the order 1....8, with 1 and 5 at 45 dB(A), 2 and 6 at 30 dB(A), 3 and 7 at 70 dB(A) (all these in quiet), and 4 and 8 at 70 dB(A) in noise (babble) providing +2 dB speech-to-noise ratio. For ease of reference the results are given in Table 12, paired as above, in order of ascending difficulty.

Table 12: Results of free-field speech audiometry (Group YN)

Subject	Number of errors per list								Av. % errors in	
	70 dB(A)		45 dB(A)		30 dB(A)		70 dB(A) + noise		quiet	noise
	3	7	1	5	2	6	4	8	1-2-3-5-6-7	4-8
1	1	0	0	0	6	2	2	2	5.0	6.7
2	5	4	0	1	4	4	8	5	10.0	21.7
3	0	0	0	2	0	2	8	3	2.2	18.3
4	0	0	0	2	7	4	9	4	7.2	21.7
5	0	0	0	2	12	6	5	4	11.1	15.0
6	0	0	0	1	7	7	5	3	8.3	13.3
7	2	1	0	1	2	10	10	6	8.9	26.7
8	0	1	3	1	2	1	4	8	4.4	20.0
9	3	0	0	1	9	9	9	10	12.2	31.7
10	0	1	0	1	12	5	5	3	10.6	13.3
11	0	2	0	0	2	4	6	3	4.4	15.0
12	1	1	1	4	12	7	10	10	14.4	33.3
13	0	1	0	1	0	0	6	8	1.1	23.3
14	0	2	2	9	3	1	12	11	9.4	38.3
15	0	1	2	2	2	14	7	9	11.7	26.7
16	0	1	0	1	9	2	3	4	7.2	11.7
17	0	1	1	2	5	8	7	3	9.4	16.7
18	0	1	0	0	4	2	8	6	3.9	23.3
19	0	1	0	3	8	5	10	3	9.4	21.7
20	0	0	0	0	6	0	9	2	3.3	18.3
Av. errors (%)	2.0	3.0	1.5	5.7	18.7	15.5	23.8	17.8	7.7	20.8
SD									3.6	7.8

The results indicate that the lists were not of equal intrinsic difficulty, in particular list 1 appears to be appreciably easier than list 5. The other pairs also show some differences. For these normal subjects, the intelligibility at 70 dB(A) in noise was comparable with that at 30 dB(A) in quiet.

In order to characterize the performance of individual subjects and minimize random error, the six results in quiet and the two results in noise have been averaged, and are given in the form of percentage errors in two right-hand columns of Table 12 respectively. The grand averages and standard deviations in these columns should not be compared directly, but are used separately as the basis for evaluating SAQ and SAN indices for the non-normal groups respectively.

6.2.6 Questionnaires

6.2.6.1 *Section I: Hearing in general*

The initial method of scoring for this Section was to award 12 points to each question (excluding Qn. 14 on use of ear protectors in occupational noise, which was not scored for group YN). Within each question, the responses were scored 0-3-6-9-12, 0-4-8-12 or 0-6-12 according to whether there were 5, 4 or 3 "boxes". Qn. 8 was scored 0 for "No", 6 for a "Yes" unless followed by "I need it louder", in which case it scored 12. The free response parts of Qns. 8 and 9 were not scored, and "not applicable" was scored 0 where this option was selected.

The questions were classified as relevant to *D* (1, 2, 3, 4, 7, 10, 12) and *H* (5, 6, 8, 9, 11, 13, 15) respectively, according to the intent of the questions. In one or two cases the classification has been found retrospectively to be slightly ambiguous (Qn. 4: "Do you think other people notice that you have any problems with your hearing?"; Qn. 9: "How do you get on with hearing the sounds of daily life?"). As will be seen, the results are not sensitive to the minutiae of classification of single questions.

Tables 13 and 14 give the results for each subject under the headings of *D* and *H* respectively. It is immediately apparent that the questions produced a widely varying range of mean responses from group YN. In particular, question 11 ("In conversation with people that you don't hear very well, do you ask them to repeat what they said?") evoked a high response score suggesting that this intended "reaction to auditory failure" was not construed as implying handicap. Three of the handicap questions (5, 6, 13) and disability question 4 evoked no response from the normal group, which is predictable. Question 2 ("Is your hearing getting worse?") should be in the same category but one subject (male student, aged 20) gave "slightly less good", and the same subject also gave the minimum non-zero response to question 15 which strictly applied only to tinnitus after work; these responses must be considered idiosyncratic. Somewhat surprisingly only 8 out of 20 considered their hearing "perfect" (Qn. 1), and a majority reported "sometimes" having "to make a special effort to hear things" (Qn. 3). Instant directional perception was claimed by only 8 out of 20 (Qn. 7). Question 12 was intended to distinguish between sensitivity and perceptive disability. None of the subjects admitted the latter but 11 out of 20 acknowledged some difficulty hearing other people if "they don't speak loudly enough".

Table 13: Questionnaire Section I: Group YN individual scores on disability questions

Subject	Score on each question							Total score
	1	2	3	4	7	10	12	as %
1	3	0	0	0	4	0	0	8.3
2	0	0	4	0	4	4	0	14.3
3	3	0	0	0	0	0	6	10.7
4	3	0	0	0	4	4	6	20.2
5	6	0	4	0	4	4	6	28.6
6	3	0	4	0	4	0	0	13.1
7	3	0	4	0	4	0	6	20.2
8	3	0	4	0	0	0	6	15.5
9	3	0	4	0	4	4	0	17.9
10	0	0	4	0	4	4	6	21.4
11	0	0	4	0	0	4	6	16.7
12	3	0	4	0	4	4	6	25.0
13	0	0	0	0	4	0	6	11.9
14	0	0	0	0	0	0	6	7.1
15	3	4	0	0	0	0	6	15.5
16	6	0	0	0	4	0	0	11.9
17	0	0	4	0	0	0	0	4.8
18	0	0	4	0	0	0	0	4.8
19	3	0	4	0	0	0	0	8.3
20	0	0	4	0	4	0	0	9.5
Av. score (%)	18	2	22	0	20	12	28	14.3
							SD	6.5

Table 14: Questionnaire Section I: Group YN individual scores on handicap questions

Subject	Score on each question 5	6	8	9	11	13	15	Total score as %
1	0	0	0	0	0	0	0	0.0
2	0	0	0	0	0	0	0	0.0
3	0	0	0	0	6	0	0	7.1
4	0	0	0	0	3	0	0	3.6
5	0	0	0	4	9	0	0	15.5
6	0	0	0	0	0	0	0	0.0
7	0	0	6	4	6	0	0	19.0
8	0	0	0	0	12	0	0	14.3
9	0	0	6	0	6	0	0	14.3
10	0	0	6	0	9	0	0	17.9
11	0	0	0	0	6	0	0	7.1
12	0	0	0	0	6	0	0	7.1
13	0	0	0	0	6	0	0	7.1
14	0	0	0	0	12	0	0	14.3
15	0	0	0	0	6	0	3	10.7
16	0	0	0	4	6	0	0	11.9
17	0	0	0	0	6	0	0	7.1
18	0	0	0	0	0	0	0	0.0
19	0	0	0	0	0	0	0	0.0
20	0	0	0	0	0	0	0	0.0
Av. score (%)	0	0	8	5	41	0	1	7.9
							SD	6.6

Further consideration of these results is deferred until the corresponding data for the impaired groups are presented.

6.2.6.2 *Section II: Hearing in particular situations*

The questions attached to the nine situations were classified, as above, under the headings of *D* and *H*. The *H* category included, for each situation, a question relating to "reaction to auditory failure", and, in the case of situations A, B and D only, a question on "how much it matters" if there are hearing difficulties (the second question was only applied to the situations judged to be of fairly common occurrence).

Question 1 on each situation was scored 1, 2 or 3 for "never", "sometimes" or "often" respectively, and this number was used as a multiplying factor for the other responses on the same sheet. Strict logic might call for a weighting of zero for "this never happens to me" but it was felt that the small weighting factor 1 might be reasonable for responses based on an inferred appreciation of the situation in question.

Question 2 on each situation (Qn. 3 in the case of situation J) was scored 0 to 60 in steps of 20 (60 was chosen as the maximum score, being the lowest common multiple of 2, 3, 4 and 5). Question 3 (except situation D, where it was omitted and situation J where it was numbered Qn. 4) was scored according to the number of items ticked (e.g., 12 points for each box in situation A, 15 each in situation B, 10 each in situation C). The "reaction to auditory failure" questions (e.g., Qn. 3, situation A) were scored by the experimenters' judgement of the importance of the descriptions (and in the case of multiple ticks, selecting the worse case), out of a total points score of 60. For example, in situation B, the responses were scored as follows:

"ask the person to speak louder" ...	20
"pretend I heard"	40
"avoid such gatherings"	60

In situations A, C, D, E, F, H the response boxes were in the same sequence as the points awarded; in situation G the first two options were rated equal, but above the third option; the fourth and fifth options were rated successively higher (steps of 15 points in this case). "Not applicable" and free-range responses were scored zero. In addition to the "familiarity" weighting from Qn. 1, a further weighting was applied in calculating the composite scores over all questions in both the *D* and *H* categories: questions J4 (in *D*) and A4, A5, B5, H4 and J5 (or 6) were weighted 0.5 and all remaining questions were weighted 1, based on a judgement of the comparative importance. It is recognized that these adjustments are rather arbitrary but some equalization of contributions from different situations appeared to be appropriate. The weighting (0.5 or 1) is already applied to the data tabulated below.

Tables 15 and 16 give the results for each subject under the headings of *D* and *H* respectively. Responses are tabulated before the application of the multiplying factors, ω. In the final column the subject's total score is given as a percentage of the maximum possible score, with $\omega = 3$ for all questions. At the foot of each individual column, the mean percentage score is shown. These values are unweighted and therefore not directly related to the grand average scores at the foot of the last column in both

Table 15: Questionnaire Section II: Group YN individual scores on disability questions

Subject	A 1	A 2	A 3	B 1	B 2	B 3	C 1	C 2	C 3	D 1	D 2	E 1	E 2	E 3
	Score on each question*													
1	3	20	0	2	20	0	2	40	10	2	20	2	20	0
2	3	20	12	2	20	15	2	40	10	2	20	2	20	15
3	2	20	12	2	20	15	2	40	10	2	0	2	40	30
4	2	20	12	2	20	15	2	40	10	3	20	2	20	15
5	2	20	12	2	20	15	2	40	10	2	20	2	20	30
6	3	0	0	3	20	15	2	20	20	3	0	2	20	30
7	3	20	0	2	40	60	2	40	10	2	20	2	40	0
8	3	0	0	3	20	15	2	20	10	2	0	2	20	0
9	2	0	0	3	20	30	2	20	10	2	20	2	20	15
10	1	20	12	2	20	30	2	40	20	2	20	2	40	30
11	2	0	0	2	20	15	2	20	10	2	20	2	20	15
12	2	20	12	3	20	15	2	40	10	2	0	2	20	15
13	3	0	0	3	20	15	2	20	10	2	20	2	0	0
14	3	0	0	2	20	15	2	40	10	3	20	2	20	15
15	3	0	0	3	20	30	2	20	20	2	20	1	0	0
16	2	20	0	2	20	30	2	40	10	3	20	2	20	15
17	2	20	12	3	0	15	2	40	20	3	20	2	20	15
18	3	0	0	3	20	15	2	40	10	2	0	2	20	15
19	2	20	24	2	20	15	2	20	20	2	20	2	20	30
20	2	20	0	3	20	15	2	20	10	2	20	2	20	15
Mean (%)	-	20	9	-	33	32	-	53	21	-	25	-	35	25
Mean ω*	2.4	-	-	2.5	-	-	2.0	-	-	2.3	-	2.0	-	-

(Table continues)

*The weight ω is the response to question 1 for each situation. Scores on the remaining questions are given before application of this weighting factor.

Table 15 (cont'd)

Sub-ject	Score on each question F 1	F 2	F 3	G 1	G 2	G 3	H 1	H 2	H 3	J 1	J 3	J 4	Weighted total score (%)
1	2	20	12	2	20	12	3	20	20	2	20	30	21
2	2	20	24	2	20	12	2	40	40	2	20	10	25
3	1	20	12	2	20	24	2	40	20	2	20	30	24
4	2	20	0	2	20	12	2	20	40	2	20	30	23
5	1	0	24	2	20	24	3	20	20	2	20	20	23
6	2	0	0	3	0	12	3	0	0	3	0	0	11
7	2	20	24	2	20	24	2	20	20	2	20	30	28
8	2	20	12	2	20	24	3	20	20	2	20	10	18
9	3	20	12	2	20	12	3	20	20	2	20	10	22
10	3	20	12	3	40	24	3	20	40	2	0	0	30
11	1	0	12	2	20	12	2	20	20	2	0	10	14
12	1	20	24	2	20	12	2	20	20	2	20	10	20
13	1	0	0	2	20	12	3	0	0	2	0	0	9
14	2	0	0	3	20	12	3	20	20	2	0	0	17
15	2	0	12	2	0	0	3	0	0	2	0	20	11
16	2	20	0	2	20	12	2	20	20	2	20	10	21
17	1	0	0	3	20	60	3	20	20	2	0	20	26
18	2	0	0	2	20	24	3	0	0	2	0	0	12
19	2	0	0	2	20	24	3	20	0	2	20	20	20
20	1	0	0	3	20	24	3	20	20	2	20	30	22
Mean (%)	-	17	15	-	32	31	-	30	30	-	20	48	19.9
												SD	5.9
Mean ω	1.7	-	-	2.3	-	-	2.7	-	-	2.1	-	-	

Table 16: Questionnaire Section II: Group YN individual scores on handicap questions

Subject	A 4	A 5	B 4	B 5	C 4	D 3	D 4	E 4	F 4	G 4	H 4	J 5/6	Weighted total score (%)
1	15	10	40	0	20	40	20	0	30	30	15	15	30
2	15	20	20	20	20	40	20	20	0	15	15	0	26
3	30	20	60	20	20	40	20	20	30	30	15	15	36
4	30	20	20	20	40	40	20	20	45	15	15	0	37
5	15	10	20	10	20	40	20	20	30	15	30	15	29
6	15	10	20	10	40	0	0	20	0	15	0	0	19
7	15	10	20	20	20	40	20	20	30	15	0	15	28
8	15	20	20	20	20	20	20	0	30	15	15	0	28
9	15	10	40	10	20	40	0	0	30	15	15	0	28
10	15	10	20	10	40	20	0	20	30	15	15	0	25
11	30	10	40	10	40	40	20	20	45	15	15	15	32
12	15	20	40	30	60	60	40	0	45	30	30	0	45
13	15	10	20	10	20	40	0	0	0	15	0	0	18
14	15	10	20	30	20	40	60	20	30	15	30	15	46
15	0	0	20	10	40	20	0	20	30	0	15	0	20
16	30	0	0	10	20	40	0	20	0	15	15	15	22
17	0	10	40	0	20	60	0	60	60	15	15	0	37
18	0	0	20	0	20	0	0	20	0	15	0	0	10
19	15	0	0	20	20	40	0	60	30	15	15	0	26
20	15	0	20	10	40	40	0	0	0	30	15	0	24
Mean (%)	52	33	42	43	47	58	22	30	41	29	47	18	28.2
												SD	8.8

*See footnote to Table 15. The same weighting factors apply.

Tables. They serve to give an indication, however, of the freedom with which the scales were used by subjects. Percentages are in all cases based on the maximum possible.

Inspection of Tables 15 and 16 reveals surprisingly high percentage scores on some questions, notably C2 (i.e., public address announcements not usually clearly heard) and D3 (i.e., usually ignore a casual remark if not properly heard). The "handicap" questions generally attracted higher scores than the "disability" questions (28% against 20%), whilst the coefficients of variation were nearly the same (30%, 31%). Familiarity with the situations was rated on average between "sometimes" and "often" for all situations except F (formal meeting around a table) and was greatest, rather unexpectedly, for H (talking to a clerk through a grille).

In order to facilitate comparison between the performance in the simulations (Chapter 6.2.4) and self-assessment by questionnaire, the relevant portions of the latter are extracted in Table 17. The "social

Table 17: Questionnaire Section II: Group YN results for situation B and situations B-C-G combined, for disability and handicap questions

Subject	Percentage score (weighted)			
	Situation B		Situations B, C, G	
	D	*H*	*D*	*H*
1	11	30	19	29
2	19	30	22	24
3	19	59	24	41
4	19	30	22	30
5	19	22	24	21
6	29	33	20	34
7	56	30	36	24
8	29	44	23	30
9	42	56	25	35
10	28	22	38	29
11	19	37	18	33
12	29	78	25	62
13	29	33	21	28
14	19	37	25	29
15	42	33	21	27
16	28	7	24	14
17	12	44	38	33
18	29	22	27	21
19	19	15	22	17
20	29	33	28	41
Mean (%)	26.5	34.8	25.1	30.0
SD	10.6	15.9	5.8	10.3

gathering", "public address announcements" and "listening on the telephone" are mirrored by situations B, C and G of the Questionnaire Section II respectively. Listening to speech in noise (as in the free-field audiometry, Chapter 6.2.5) may be compared with situation B. For completeness the B and B-C-G questionnaire results are given both for the *D* and *H* categories, although it might be expected that correlation with the simulations would be higher with *D*, since the simulations do not depend on the handicap as such. The scores are weighted as already described.

It will be recalled that the answer sheets for three of the situations (B, C, G) were returned to subjects after experiencing the corresponding simulations. A few subjects availed themselves of this to revise one or more of their previous questionnaire responses. The alterations were ignored in scoring the results, but some general inferences from them are discussed later.

6.2.6.3 *Section III: Reaction to simulated situations*

Referring to Appendix E, responses to this section of the questionnaire are coded 1-2-3-4-.... according to the box or boxes ticked for each question. Free responses where this option was exercised (for example, "Other" for Qn. 1 of the simulation of a social gathering, and "Any other comment?" for Qn. 4 of this simulation) are coded x, and no response is coded NR.

Qn. 3 of simulation 3 is coded 1 for right-handed subjects, that is, those writing with the right hand and holding the telephone in the left; conversely it is coded 2 for the left-handed. Qn. 4 is coded 1 for those who normally hold the telephone in the same hand as used for the test, 2 for the contrary (meaning that the test was awkward for them in this respect). Telephonically ambidexterous subjects are coded 3. No subject (fortunately) tried both to hold the telephone and write with the same hand.

Table 18 gives a summary of the results for the YN group. Some questions (e.g., Qn. 2 on each simulation) admitted of only one response and the totals for these equal the number of subjects in the group (20); others admitted of multiple responses, so that the totals are variable.

The mean results for the "degree of difficulty" questions (Qn. 2 in each case) lie between "a bit difficult" and "quite difficult", the social gathering proving to be slightly easier than the other two.

The "resemblance" responses (Qn. 4 of the first and second simulations, Qn. 6 of the third simulation) were reasonably satisfactory, lying between "very closely" and "in some ways" in each case. Subjects found the reproduction of the public address announcements to be quite realistic, and were (not surprisingly) somewhat less convinced by the audiovisual scenario of simulation 1, although 7 out of 20 awarded even this the accolade of very close resemblance.

Table 18: Summary of responses of YN group to Section III of the Questionnaire.

Question	Number of occurrences of each coded response 1	2	3	4	5	6	7	x	NR	Total	Av.*
Simulation 1 (social gathering)											
1	4	3	8	10	6			0	0	31	
2	1	11	8	0					0	20	2.35
3	6	0	8	1	6	1	1	0	0	23	
4	7	10	3	0				0	0	20	1.80
Simulation 2 (announcements in a concourse)											
1	0	0	16	9	5	5	0	2	0	37	
2	0	11	8	1					0	20	2.50
3	9	7						5	0	21	
4	16	4	0	0				0	0	20	1.20
Simulation 3 (telephone listening in noise)											
1	7	1	1	10	7	0		3	0	29	
2	0	10	7	2				0	1	20	**2.58
3	17	3							0	20	
4	9	9	2						0	20	
5	3	17	4					0	0	24	
6	8	10	2	0				0	0	20	1.70

* The rating scales (easy = 1.... almost impossible = 4, etc.) are treated metrically for this purpose.

** Excludes the "no response" category

6.2.7 Normalized indices of impairment, disability and handicap

For subsequent comparison between the YN and the impaired groups, the YN group results are re-expressed in a normalized form, as distributions with zero mean and unit standard deviation. For example, the left ear hearing threshold level H_4 is transformed to the variable $a_1^{L} = (H_4^{L} - 1.1)/6.2$, the constants being those in the 4 kHz column of Table 5.

Table 19 lists the normalized indices. The symbol a is used for those derived from the impairment measures, p for those derived from the listening performance tests (simulations and free-field speech audiometry), d and h respectively for those derived from the 'disability' and 'handicap' questions of the questionnaires, and s (for 'self-assessment')

Table 19: Normalized indices

Normalized index	Quantity characterized		x	y	Unit
a_1^L		left ear	1.05	6.18	dB
a_1^R	HTL, 4 kHz	right ear	-0.70	5.16	dB
a_1		LR av.	0.18	5.11	dB
a_2^L		left ear	-0.42	4.68	dB
a_2^R	HTL, av. 1,2,3 kHz	right ear	0.37	4.40	dB
a_2		LR av.	-0.02	4.09	dB
a_3^L		left ear	2.32	5.17	dB
a_3^R	HTL, av. 3,4,6 kHz	right ear	2.30	3.44	dB
a_3		LR av.	2.31	3.88	dB
a_4^L		left ear	-0.708	0.316	1
a_4^R	TI-1	right ear	-0.734	0.266	1
a_4		LR av.	-0.721	0.172	1
a_5^L		left ear	-10.5	5.05	dB
a_5^R	TI-2	right ear	-9.5	3.17	dB
a_5		LR av.	-10.0	2.83	dB
a_6	Composite temporal resolution impairment measure		$a_6 = (a_4 + a_5)/1.801$		
a_7^L		left ear	36.6	6.55	dB
a_7^R	FS-1	right ear	34.6	4.00	dB
a_7		LR av.	35.6	4.69	dB
a_8^L		left ear	-23.4	4.50	dB
a_8^R	FS-2	right ear	-24.5	4.30	dB
a_8		LR av.	-24.0	3.58	dB
a_9	Composite frequency selectivity impairment measure		$a_9 = (a_7 + a_8)/1.797$		
a_{10}^L		left ear	24.0	4.16	dB
a_{10}^R	CR-1	right ear	24.9	3.76	dB
a_{10}		LR av.	24.4	3.46	dB
a_{11}^L		left ear	24.9	3.86	dB
a_{11}^R	CR 2	right ear	24.1	4.70	dB
a_{11}		LR av.	24.5	3.77	dB
a_{12}	Average of critical ratios CR 1 and CR 2 (LR av.)		24.5	3.81	dB
a_{13}^L		left ear	-10.1	4.87	dB
a_{13}^R	OF H	right ear	-8.1	2.20	dB
a_{13}		LR av.	-9.1	2.75	dB

(Table continues)

Table 19 (cont'd)

Normalized index	Quantity characterized		x	y	Unit
a_{14}^{L}		left ear	-5.7	1.94	dB
a_{14}^{R}	OF-L	right ear	-5.9	3.15	dB
a_{14}		LR av.	-5.8	1.65	dB
a_{15}	Composite measure of off-frequency listening impairment		$a_{15} = (a_{13}+a_{14})/1.492$		
p_{16}	Errors at simulation 1 (social gathering)		13.3	6.56	%
p_{17}	Errors at simulation 2 (announcements)		26.6	11.5	%
p_{18}	Errors at simulation 3 (telephone)		16.9	9.50	%
p_{19}	Composite measure of errors on three simulations		$p_{19} = (p_{16}+p_{17}+p_{18})/1.993$		
p_{20}	Errors at SAQ, av. 30, 45, 70 dB(A)		7.7	3.65	%
p_{21}	Errors at SAN, 70 dB(A), S/N = +2 dB		19.9	7.81	%
d_{22}		score on D Qns	14.3	6.55	%
h_{23}	Q'nnaire Secn.I	score on H Qns	7.9	6.59	%
s_{24}		composite score	$s_{24} = (d_{22}+h_{23})/1.737$		
d_{25}		score on D Qns	19.9	5.92	%
h_{26}	Q'nnaire Secn.II	score on H Qns	28.2	8.78	%
s_{27}		composite score	$s_{27} = (d_{25}+h_{26})/1.662$		
d_{28}			26.5	10.6	%
h_{29}	As d_{25} etc. but "situation B" only		34.8	15.9	%
s_{30}			$s_{30} = (d_{28}+h_{29})/1.428$		
d_{31}			25.1	5.76	%
h_{32}	As d_{25} etc. but "situations		30.0	10.3	%
s_{33}	B, C and G only		$s_{33} = (d_{31}+h_{32})/1.464$		

for combined measures of D and H from the questionnaires. For each entry, the normalized index for an individual is equal to $(A_i - x)/y$ where A_i is the individual score in the original scale. The unit in which x, y and the original measure A are expressed is included in the Table for reference. Note that for the indices a_1, a_2 and a_3 the HTL means (x) are uncorrected for calibration, and correspond to the individual data in Table 5.

6.3 *Results for noise-impaired group NI*

The results for the NI group are given in the series of Tables 20-32 in the same order and format as Tables 5-6 and 8-18 for the YN group. An evaluation of the NI group results relative to normals is made in Chapter 6.3.7.

6.3.1 Pure-tone audiometry

Table 20 gives the results of the pure-tone audiometry (cf. Table 5). The mean hearing threshold level of the group (last block of Table 20)

Table 20: Results of pure-tone audiometry (Group NI)

Subject	Age/sex		Ear	0.5	1	2	3	4	6	8 kHz
101	53	M	L	4	4	18	24	27	45	28
			R	7	7	20	6	15	36	27
102	49	M	L	9	0	2	12	36	47	39
			R	14	5	3	13	35	54	48
103	50	M	L	8	3	3	4	0	65	35
			R	3	-4	2	2	0	20	30
104	59	M	L	8	42	46	58	55	26	15
			R	18	35	49	48	38	32	27
105	37	M	L	2	9	8	11	11	12	21
			R	2	5	6	20	23	27	40
106	62	M	L	25	40	66	70	55	85	85
			R	12	15	43	44	40	62	70
107	62	M	L	25	37	32	45	66	82	75
			R	23	20	25	55	52	61	75
108	52	M	L	47	64	63	52	37	32	15
			R	30	63	50	35	18	17	16
109	32	F	L	9	8	5	12	6	16	20
			R	4	6	3	15	13	5	5
110	23	M	L	-2	0	10	4	3	23	7
			R	3	0	7	0	0	23	4
111	21	M	L	5	8	6	6	2	12	-9
			R	6	6	0	4	-1	26	15
112	46	M	L	13	12	26	42	48	64	53
			R	5	4	9	22	38	50	39
113	42	M	L	10	17	53	60	60	66	55
			R	9	16	53	56	57	63	49
114	39	M	L	3	6	2	13	26	23	13
			R	2	4	3	3	16	20	14
115	30	M	L	12	6	-4	6	11	20	-5
			R	6	6	0	14	18	20	19

(Table continues)

Table 20 (cont'd)

Subject	Age/sex	Ear	0.5	1	2	3	4	6	8 kHz
116	54 M	L	4	18	43	52	65	73	65
		R	5	4	21	30	30	41	59
117	32 M	L	9	2	19	22	29	18	5
		R	11	2	6	5	10	16	7
118	30 M	L	3	-2	5	3	4	17	6
		R	10	5	2	9	10	13	18
119	44 M	L	5	7	20	10	24	21	33
		R	12	16	3	21	17	32	41
120	49 M	L	0	2	-8	10	17	40	62
		R	0	5	15	12	34	40	48
121	57 M	L	15	28	12	32	48	63	57
		R	14	18	16	40	52	71	68
122	63 M	L	15	11	23	33	53	47	77
		R	13	5	13	31	23	33	63
123	46 M	L	20	23	12	20	13	17	10
		R	17	25	23	25	22	32	34
124	39 M	L	0	-1	-6	6	35	62	45
		R	0	6	2	2	42	48	51
Mean	45	L	10.4	14.3	19.0	25.3	30.5	40.7	33.6
		R	9.4	11.4	15.6	21.3	25.1	35.1	36.1
SD		L	10.7	16.8	21.3	21.1	21.7	23.9	27.4
		R	7.4	14.0	17.0	17.5	16.7	17.9	21.5
True HTL (dB *re* ISO 389 AD1)		L	9.9	14.8	20.0	25.3	30.5	37.0	35.2
		R	8.7	11.1	16.4	20.3	23.9	29.3	38.8

increases towards the high frequencies as would be expected for this older noise-exposed group. The dispersion, however, is large due to the wide age range and varying noise exposure histories. There is a marked, and unexplained, tendency (not statistically significant) towards greater hearing loss in the left ears, not seen in the results of the YN group.

Of the 24 subjects in the NI group, five exceeded the audiometric level deemed to represent a hearing handicap according to British Standard 5330 (H_{123} > 30 dB); these are numbers 104, 106, 107, 108 and 113. Ten subjects fell into the category identified by SUTER (1978) as departing from normal on the basis of speech intelligibility (H_{123} > 17 dB); these were the 5 already mentioned plus numbers 112, 116, 121, 122 and 123. The remaining 14 subjects all had hearing threshold levels greater than the average normal but below Suter's 'low fence': the normalized audiometric indices (Table 19) for these 14 subjects lay in the following ranges:

$$0.0 < a_1 < 7.5; \quad 0.3 < a_2 < 3.2; \quad 0.5 < a_3 < 7.9.$$

6.3.2 Temporal resolution and critical ratio for an octave band masker

Table 21 gives the results of these tests for the NI group (cf. Table 6). The mean values on both of the temporal impairment measures TI-1 and TI-2, and on the critical ratio CR-1, are all raised relative to the YN group, and the dispersions are larger in each case. The elevation is statistically significant in the case of CR-1 (left ears, $t = 3.36$, $p < 0.01$; right ears, $t = 3.52$, $p < 0.01$), but not so for the measure TI-1 (left ears, $t = 1.83$, N.S.; right ears, $t = 1.80$, N.S.) nor TI-2 (left ears, $t = 1.97$, N.S.; right ears, $t = 0.97$, N.S.)

Table 21: Results of temporal resolution and octave-band critical ratio tests (Group NI)

Subject	TI-1		TI-2 (dB)		CR-1 (dB)	
	L	R	L	R	L	R
101	-0.44	-0.64	-7	-9	23	23
102	-0.72	-0.42	-13	-5	26	26
103	-0.55	-1.75	-6	-14	20	22
104	-0.20	-0.27	-4	-7	35	33
105	-0.37	-1.08	-7	-13	26	29
106	-1.67	+0.43	-5	+3	28	25
107	0	-0.08	0	-1	26	34
108	-0.46	-0.80	-12	-12	33	24
109	-0.65	-0.24	-11	-5	30	32
110	-0.35	-0.73	-6	-11	25	27
111	-1.07	-0.86	-16	-12	26	29
112	-0.17	-0.26	-4	-5	27	22
113	-0.19	-0.20	-5	-4	34	32
114	-0.61	-0.71	-11	-15	19	44
115	-0.21	-0.60	-3	-12	26	28
116	-0.15	-0.37	-2	-6	39	28
117	-0.24	-0.61	-6	-11	28	30
118	-0.65	-0.75	-11	-12	27	28
119	-0.80	-0.57	-16	-12	30	35
120	-0.24	-0.79	-4	-15	27	33
121	-0.11	-0.21	-3	-4	30	39
122	-0.14	-0.14	-2	-3	35	46
123	-1.50	-0.65	-18	-13	37	33
124	-0.58	+0.03	-14	+1	32	30
Mean	-0.50	-0.51	-7.8	-8.2	28.7	30.5
SD	0.42	0.43	5.1	5.2	5.0	6.2

6.3.3 Frequency selectivity, off-frequency listening and critical ratio for a broadband masker

The results of these tests for the NI group are given in Table 22 (cf. Table 8). The mean values and dispersions are all raised relative to the YN group and in the case of the measures FS-1, FS-2 and CR-2 the elevation is much more marked than in the case of the temporal impairment and octave-band critical ratio measures (Chapter 6.3.2). Statistical tests

Table 22: Results of frequency selectivity and off-frequency listening tests, and broadband critical ratio, in decibels (Group NI)

Subject	FS-1		FS-2		OF-L		OF-H		CR-2	
	L	R	L	R	L	R	L	R	L	R
101	44	38	-11	-21	-2	-3	-4	-4	20	24
102	52	52	-9	-12	-2	-2	-7	-7	26	29
103	33	27	-24	-25	-2	-7	-11	-4	22	17
104	75	62	-4	-7	-2	-7	-2	-7	44	34
105	34	42	-28	-21	-4	-4	-4	+1	27	28
106	74	71	-6	-11	-1	+7	-9	+13	45	47
107	88	90	-11	-2	+1	-6	-3	-7	64	57
108	54	37	-12	-23	-4	-6	-2	-5	31	25
109	39	48	-28	-17	-1	-13	+1	-10	32	30
110	39	34	-21	-25	-8	-8	-9	-9	25	24
111	33	43	-29	-23	-5	-5	-6	-1	27	31
112	57	52	-5	-12	-4	-4	-7	-6	27	29
113	84	83	-6	-7	-1	-1	-12	-11	55	55
114	49	51	-15	-17	-5	-2	-14	-10	29	33
115	57	42	-10	-21	-6	-2	-20	-9	32	28
116	86	83	-6	-1	+2	-1	-9	-6	57	49
117	51	51	-13	-17	-5	-10	-10	-17	29	33
118	41	38	-22	-24	-8	-8	-10	-8	28	27
119	53	43	-21	-25	-11	-4	-12	-8	39	33
120	42	54	-15	-12	-4	0	-8	-9	22	31
121	64	81	-5	-7	-2	0	-4	-11	34	53
122	90	64	-1	-4	0	+1	-4	+1	56	33
123	50	47	-20	-21	-2	-5	-12	-3	35	33
124	62	62	-9	-11	+1	0	-17	-6	36	38
Mean	56.3	54.0	-13.8	-15.2	-3.1	-3.7	-8.1	-6.0	35.1	34.2
SD	18.0	17.2	8.4	7.8	3.1	4.2	5.0	5.5	12.3	10.5

gave the following results:

FS-1	left ears,	$t = 4.64$,	$p < 0.001$
	right ears	4.93	"
FS-2	left ears,	$t = 4.59$	$p < 0.001$
	right ears	4.76	"
CR-2	left ears,	$t = 3.56$	$p < 0.001$
	right ears	3.94	"
OF-L	left ears,	$t = 3.27$	$p < 0.01$
	right ears	1.94	N.S.
OF-H	left ears,	$t = 1.33$	N.S.
	right ears	1.60	N.S.

For the NI group there was a considerable difference between the mean values of CR-1 (octave band) and CR-2 (broadband), whereas the values were almost identical for the YN group. This difference might be explained on the basis of critical band widening on the part of the NI subjects and the FS tests certainly indicate such a broadening. However, this explanation is possibly spurious. As indicated by the YN group results (Chapter 6.2.3) the average critical band was of the order 300 Hz wide and this is some 9 times smaller than that of the octave-band masker. Unless the critical band is upwards of 10 times wider in the NI group than in the YN group one would therefore expect no difference between CR-1 and CR-2. This seems very unlikely to be the case for the average of the NI group, containing as it does a large proportion of only mildly impaired persons; it could, however, be the case for a few of the more impaired individuals. Examination of the data shows that the subjects mainly responsible for the mean difference between CR-1 and CR-2 are those already identified as exceeding the 'low fence' of BS 5330, and they have sloping audiograms. An alternative explanation of high CR-2 values is that the lower part of the broadband noise masker spectrum is heard much louder than that part local to the probe tone, and thus exerting a remote-masking effect exceeding the local masking. Unfortunately time limitations imposed by the experimental protocol precluded testing the frequency selectivity in more exacting detail, and the significance of raised critical ratios for the broadband masker remains indeterminate. The better basis of comparison between NI and YN subjects appears to be CR-1, and the alternative measure CR-2 has been discarded in the further consideration of the present results.

6.3.4 Simulated listening situations

The method of scoring the results of these tests was the same as that described in Chapter 6.2.4.

6.3.4.1 *Social gathering*

The results of this simulation for the NI group are given in Table 23 (cf. Table 9). The pattern of errors in this name-and-address task is similar to that for the YN group, the greatest difficulty again being experienced with the surnames and the street and town names, whilst comparatively few errors were made on the initials, street classifiers and numeral groups. The grand average error score for the NI group was 26.2%, twice as many as for the YN group, and the dispersion was also nearly twice as large (11.0% compared to 6.6%).

Table 23: Results of simulation of social gathering (Group NI)

Subject	Errors per component 1	2	3	4	5	6	7	8	Total errors (%)
101	0	1	0	0	0	2	0	3	3.8
102	4	11	4	12	6	12	0	3	32.5
103	1	7	0	6	3	2	0	2	13.1
104	1	12	1	12	5	12	3	16	38.7
105	1	6	0	12	1	7	0	0	16.9
106	2	12	0	13	2	7	3	5	27.5
107	3	12	3	13	8	8	1	12	37.5
108	3	8	1	13	3	12	5	7	32.5
109	0	6	0	6	0	3	1	2	11.3
110	3	10	0	7	0	4	2	5	19.4
111	3	12	1	16	4	10	2	10	36.3
112	3	14	0	11	3	9	3	6	30.6
113	4	13	2	12	2	9	7	9	36.3
114	4	10	4	12	6	7	3	18	40.0
115	0	7	1	5	1	4	1	2	13.1
116	3	10	2	5	2	4	1	7	21.2
117	0	4	0	7	3	6	2	4	16.3
118	2	9	0	9	4	8	1	1	21.2
119	1	9	8	13	3	8	3	12	35.6
120	1	6	2	8	1	3	2	1	15.0
121	8	8	7	15	6	11	6	12	45.6
122	2	12	1	10	4	8	1	6	27.5
123	4	9	1	9	0	4	4	6	23.1
124	1	14	0	11	7	10	3	9	34.4
Mean	2.25	9.25	1.58	9.88	3.08	7.08	2.25	6.58	26.2
SD	1.85	3.25	2.21	3.76	2.34	3.22	1.87	4.84	11.0

6.3.4.2 *Unexpected announcements in a public concourse*

The results of this simulation for the NI group are given in Table 24 (cf. Table 10). The grand average error rate was twice as high as for the YN group (52.5% compared to 26.6%), and the pattern is similar. However, whereas the YN group made no errors at all on questions 3, 8a and 10b, all questions elicited errors in the NI group. Particularly notable is the differing performance on this and the name-and-address tasks on the part of subject 101.

Table 24: Results of simulation of announcements in a public concourse (Group NI)

Subject	Errors in each question														Total errors
	1	2	3	4a	4b	5	6	7	8a	8b	9a	9b	10a	10b	(%)
101	1	0.5	0	1	1	0	1	1	0	1	0	1	0	1	60.7
102	1	1	0	1	1	0	1	1	0	1	1	0.5	0	1	67.9
103	1	0	0	0.5	1	0	0	1	0	1	1	0	0	0.5	42.9
104	1	0	1	1	1	1	1	1	0	1	1	0.5	0.5	1	78.6
105	1	0	0	0.5	1	0	1	1	0	1	1	0	0	0	46.4
106	0	0	0	1	1	0	1	1	0	1	1	0	0.5	0	46.4
107	1	0	0	1	1	1	1	1	1	1	1	0	1	1	78.6
108	0	0	0	1	1	0	1	1	0	0	0	1	1	1	50.0
109	0	0	0	1	1	0	1	0	0	0	0	1	1	1	42.9
110	0	1	0	1	1	0	1	1	0	0	1	0	0	0	42.9
111	1	0	1	1	1	0	1	1	0	0	1	0	1	0	57.1
112	1	0	0	0	1	0	1	0	0	1	0	0	0	0	28.6
113	1	1	0	1	1	0	0	1	1	1	0	0	0	1	57.1
114	0	1	0	1	1	0	1	1	0	1	1	1	0	1	64.3
115	0	0	0	1	0	0	1	1	0	1	0.5	1	0	0	39.3
116	1	0	1	1	1	0	0	1	0	1	0	0	0	1	50.0
117	0	0	0	1	0	0	1	1	0	1	0	0	0	0	28.6
118	0	0	0	0	1	0	1	1	0	0	0	0	0	1	28.6
119	1	0	0	1	1	0	1	1	0	1	1	1	1	1	71.4
120	0	0	0	1	0	0	1	0.5	0	0	0	0	0	0	17.9
121	0	1	1	0	1	0	0	1	0	1	0	1	0.5	1	53.6
122	0	1	0	1	1	0	1	0.5	0.5	1	1	1	1	1	71.4
123	1	1	1	1	1	0	1	1	0	0	1	0	0	1	64.3
124	1	1	0	1	1	1	1	1	1	1	0	1	0	0	71.4
														Mean	52.5
														SD	16.8

6.3.4.3 *Listening on the telephone in a noisy place*

The results of this simulation for the NI group are given in Table 25 (cf. Table 11). As with the YN group, the mean error rate was slightly higher on this monaural task than in the simulated social gathering (29.0% compared with 26.2%) but the pattern of the errors across items was similar. As with the YN group, there was a markedly greater error rate on initials compared with the social gathering, and a markedly lower error rate on telephone numbers.

The overall error rate (29.0%) compares with 16.9% for the YN group, a lesser difference than in the case of the preceding simulation.

Table 25: Results of simulation of listening on the telephone (Group NI)

Subject	Errors per component								Total
	1	2	3	4	5	6	7	8	errors (%)
101	2	9	0	10	0	6	0	2	18.1
102	9	13	2	15	2	12	3	3	36.9
103	5	9	0	6	0	4	1	2	16.9
104	13	17	4	17	5	13	7	9	53.1
105	3	5	2	10	0	6	0	0	16.2
106	9	11	2	13	3	11	2	6	35.6
107	9	13	1	13	4	7	2	1	31.3
108	6	10	0	12	1	10	2	1	26.2
109	0	7	0	7	1	7	2	1	15.6
110	4	11	0	12	1	12	4	2	28.8
111	1	10	2	11	0	12	2	9	29.4
112	7	11	3	14	1	10	1	4	31.9
113	12	16	4	17	5	13	5	8	50.0
114	6	12	3	17	5	14	3	10	43.7
115	5	10	2	10	1	7	0	3	23.8
116	8	10	4	12	1	10	3	4	32.5
117	7	13	0	13	0	9	0	0	26.2
118	4	5	0	8	0	3	0	0	12.5
119	2	8	0	9	0	9	1	10	24.4
120	5	7	0	8	0	5	0	0	15.6
121	6	10	0	6	1	9	0	1	20.6
122	13	11	1	12	0	9	7	5	36.2
123	4	7	1	8	0	8	2	5	21.9
124	13	15	5	16	10	12	4	4	49.4
Mean	6.38	10.42	1.50	11.50	1.71	9.08	2.13	3.75	29.0
SD	3.79	3.12	1.62	3.41	2.48	3.01	2.09	3.34	11.6

6.3.5 Free-field speech audiometry

The results of these tests for the NI group are given in Table 26 (cf. Table 12). Relative to the YN group, the error rate was dramatically greater in the quiet conditions (mean over three levels 20.0% compared to 7.7%); in the background noise condition the difference was less marked (30.3% against 20.8%) but the dispersion was much greater. The intelligibility at 70 dB(A) in noise was comparable with that at 30 dB(A) in quiet, the same result as with the YN group.

Table 26: Results of free-field speech audiometry (Group NI)

Subject	Number of errors per list								Av. % errors in	
	70 dB(A)		45 dB(A)		30 dB(A)		70 dB(A) + noise		quiet	noise
	3	7	1	5	2	6	4	8	1-2-3-5-6-7	4-8
101	0	1	2	3	26	16	5	7	26.7	20.0
102	0	1	7	1	7	10	12	6	14.4	30.0
103	1	2	2	1	6	3	12	5	8.3	28.3
104	7	3	13	21	20	20	16	13	46.7	48.3
105	0	1	2	1	21	11	12	6	20.0	30.0
106	14	6	23	28	30	30	29	28	72.8	95.0
107	11	7	11	10	17	18	12	15	41.1	45.0
108	5	6	23	20	27	30	21	20	61.7	68.3
109	0	1	0	1	6	4	7	2	6.7	15.0
110	6	1	0	1	4	4	7	7	8.9	23.3
111	0	2	4	0	12	5	8	15	12.8	38.3
112	2	2	5	3	3	4	9	9	10.6	30.0
113	7	5	11	11	16	13	11	10	35.0	35.0
114	8	1	5	4	7	12	8	2	20.6	16.7
115	0	1	0	2	2	3	1	1	4.4	3.3
116	2	3	2	1	8	4	7	7	11.1	23.3
117	2	1	2	2	8	8	5	5	12.8	16.7
118	2	2	0	0	0	0	4	1	2.2	8.3
119	2	1	1	6	3	10	13	16	12.8	48.3
120	0	1	4	3	0	1	8	6	5.0	23.3
121	0	4	6	2	5	9	10	8	14.4	30.0
122	4	2	0	0	5	2	3	5	7.2	13.3
123	3	1	1	2	1	5	9	5	7.2	23.3
124	1	4	5	3	6	12	5	4	17.2	15.0
Av. errors (%)	10.7	8.2	17.9	17.5	33.3	32.5	32.5	28.2	20.0	30.3
SD									18.5	20.0

6.3.6 Handicap and disability questionnaires

The method of scoring the questionnaire results is described in Chapter 6.2.6.

6.3.6.1 *Section I - Hearing in general*

The results of this questionnaire for the NI group are given in Tables 27 (cf. Table 13) and 28 (cf. Table 14) for the questions classified as relevant to *D* and *H* respectively.

Table 27: Questionnaire Section I: Group NI individual scores on disability questions

Subject	Score on each question							Total score
	1	2	3	4	7	10	12	as %
101	6	4	0	0	0	4	0	16.7
102	6	4	4	0	4	0	0	21.4
103	3	4	4	0	4	0	6	25.0
104	6	8	4	0	4	4	6	38.1
105	9	8	8	6	8	4	12	65.5
106	12	8	8	12	4	8	6	69.0
107	6	4	8	12	4	4	6	52.4
108	6	4	8	6	4	0	0	33.3
109	6	8	4	6	4	4	6	45.2
110	3	0	4	6	4	4	6	32.1
111	6	0	4	6	4	4	6	35.7
112	6	4	8	0	8	4	6	42.9
113	9	8	12	12	4	8	12	77.4
114	6	8	4	12	8	4	6	57.1
115	3	0	4	6	4	4	6	32.1
116	9	4	8	6	4	4	6	48.8
117	3	0	4	0	4	0	6	20.2
118	3	0	4	6	8	4	6	36.9
119	3	4	4	6	4	0	6	32.1
120	3	4	4	6	4	4	6	36.9
121	6	4	4	6	4	0	0	28.6
122	3	0	4	0	0	0	0	8.3
123	12	4	8	12	0	4	0	47.6
124	3	0	4	12	4	0	6	34.5
Av. score (%)	48	32	44	48	35	25	42	39.1
							SD	16.7

Table 28: Questionnaire Section I: Group NI individual scores on handicap questions

Subject	5	6	8	9	11	13	15		Total score as %
101	0	0	0	0	0	0	0		0.0
102	0	0	0	0	6	0	0		7.1
103	0	0	0	0	6	0	0		7.1
104	0	8	12	0	9	0	0		34.5
105	4	4	12	8	9	4	0		48.8
106	8	8	12	4	9	4	6		60.7
107	0	4	12	4	6	4	3		39.3
108	4	4	6	4	6	4	0		33.3
109	0	0	0	4	6	0	3		15.5
110	0	4	12	0	6	4	6		38.1
111	0	0	0	4	6	4	6		23.8
112	4	8	0	8	6	4	0		35.7
113	8	8	12	12	9	4	3		66.7
114	4	8	12	8	9	4	6		60.7
115	0	0	12	0	6	0	0		21.4
116	8	8	12	8	9	8	6		70.2
117	0	0	0	4	12	0	6		26.2
118	4	4	0	4	6	4	6		33.3
119	0	4	0	8	6	0	6		28.6
120	0	0	0	0	9	0	3		14.3
121	0	0	0	4	6	0	3		15.5
122	0	0	0	0	0	0	0		0.0
123	12	12	12	4	6	8	0		64.3
124	0	0	0	0	6	0	3		10.7
Av. score (%)	19	29	44	31	55	19	23		31.5
								SD	21.4

Referring first to Tables 27 and 13, the comparison of the NI and YN groups shows a very large increase in self-rated disability (39.1% compared to 14.3%) and a proportionate increase in the dispersion. The contrast is apparent on each of the 7 questions. Even larger differences are revealed in respect of the self-rated handicap questions (Tables 28 and 14) with the exception of Qn 11 ("In conversation with other people that you don't hear very well, do you ask them to repeat what they said?"). The score on this question was already rather high (41%) for the YN group and it would appear that this question is not very sensitive for comparing the impaired and non-impaired. Overall, the NI group scored four times higher than the YN group (31.5% against 7.9%) on these *8* questions.

6.3.6.2 *Section II - Hearing in particular situations*

The results of Section II of the questionnaire for the NI group are given in Tables 29 (cf. Table 15) and 30 (cf. Table 16) for the questions classified as relevant to *D* and *H* respectively.

Referring to Tables 29 and 15, the responses of the *NI* group are seen to be systematically greater than those of the YN group, other than on Qn.1 of each situation (the 'familiarity' questions) where the scores are very

Table 29: Questionnaire Section II: Group NI individual scores on disability questions

Sub-ject	Score on each question*														
	A			B			C			D		E		
	1	2	3	1	2	3	1	2	3	1	2	1	2	3
101	2	20	0	2	20	15	2	40	10	2	20	2	20	15
102	3	0	0	2	20	15	2	20	10	2	20	1	20	0
103	3	20	0	3	20	15	2	20	20	3	20	2	20	15
104	2	20	24	2	40	15	2	40	20	3	40	3	60	15
105	3	20	24	2	40	30	2	40	30	2	20	1	40	30
106	3	20	36	2	20	30	3	40	30	2	20	2	40	30
107	2	20	24	3	40	15	2	40	10	2	20	2	40	15
108	2	0	12	3	40	45	2	40	30	3	20	2	40	30
109	2	20	24	2	40	30	2	40	30	2	20	2	20	45
110	2	0	24	2	20	30	2	20	20	2	20	1	20	15
111	2	20	12	2	20	15	2	40	10	3	20	2	40	15
112	3	20	12	3	40	30	2	40	20	2	20	2	20	45
113	3	40	36	3	60	45	2	40	10	3	40	3	60	60
114	3	20	0	2	40	30	2	40	30	3	40	2	60	45
115	2	0	12	2	20	15	2	20	10	2	20	2	20	15
116	3	40	24	3	40	45	2	40	20	2	20	2	40	30
117	3	20	36	3	20	15	2	40	10	3	40	2	40	30
118	2	20	0	2	20	15	2	20	10	2	20	1	40	15
119	2	20	24	2	40	30	2	40	10	3	40	2	40	30
120	3	20	12	2	20	15	2	40	10	2	20	2	20	15
121	2	20	0	2	20	15	2	20	0	3	0	1	40	15
122	3	0	0	2	20	15	2	20	20	2	0	2	20	15
123	3	40	36	3	40	45	2	40	10	3	40	2	40	45
124	3	20	0	3	20	15	2	40	10	3	40	2	40	15
Mean (%)	·	31	26	·	50	41	·	58	27	·	40	·	58	42
Mean ω*	2.5	·	·	2.4	·	·	2.0	·	·	2.5	·	1.9	·	·

*See footnote to Table 15

(Table continues)

similar (average weighting ω over the nine situations 2.26 and 2.22 respectively, on the scale running from 0 to 3). However, some questions elicited a large difference between groups (e.g., Qns. A3 and F3) whereas others proved rather insensitive (e.g., C2 and J4). Overall, the weighted scores averaged 31.3% for the NI group against 19.9% for the YN group.

Table 29 (cont'd)

Sub-ject	Score on each question												Weighted total score (%)
	F			G			H			J			
	1	2	3	1	2	3	1	2	3	1	3	4	
101	2	20	0	1	20	0	2	20	30	2	20	10	18
102	2	20	24	2	20	36	3	20	40	2	20	0	21
103	3	0	12	2	20	36	3	20	20	3	20	20	26
104	2	40	24	2	40	48	2	20	20	3	0	10	36
105	2	20	36	1	20	36	3	20	20	2	20	20	30
106	2	20	24	2	40	48	3	20	20	2	20	20	38
107	3	40	24	3	40	48	3	40	40	2	40	20	44
108	2	20	36	2	40	36	3	20	40	2	20	20	38
109	2	20	24	2	20	36	2	20	40	2	20	30	32
110	1	0	12	3	20	24	3	20	40	3	20	20	25
111	1	0	0	2	20	12	3	20	20	3	20	10	23
112	2	20	48	2	20	24	2	20	40	2	20	30	35
113	3	60	48	2	40	60	3	60	60	2	60	30	74
114	3	20	12	2	20	48	2	20	20	2	40	30	38
115	2	20	0	2	20	12	2	20	20	2	20	0	16
116	2	0	48	2	20	24	2	40	40	2	40	20	41
117	1	20	0	3	20	12	3	20	20	2	20	20	32
118	2	20	12	2	20	12	2	40	20	2	20	10	19
119	2	20	24	3	20	24	2	40	40	3	20	10	36
120	2	20	24	2	20	12	3	20	20	3	20	10	25
121	2	20	12	2	20	12	3	20	40	3	20	10	20
122	1	0	36	3	20	12	2	20	20	2	0	10	15
123	3	20	24	3	20	24	2	20	40	2	20	20	45
124	1	40	12	2	40	12	3	20	0	2	20	0	25
Mean (%)	-	33	36	-	42	45	-	42	49	-	38	53	31.3 SD 12.7
Mean ω	2.0	-	-	2.2	-	-	2.5	-	-	2.3	-	-	

In contrast, the responses to the *H* questions generally failed to distinguish clearly between the impaired and non-impaired. Comparing Tables 30 and 16, it will be seen that there was no difference in the group mean score on Qns. A4 and B4, and very little on Qn. F4; the greatest distinction occurred on Qns. D4 and J5/J6. The overall weighted scores were 28.2% for the YN group, increasing to 34.8% for the NI group.

Table 30: Questionnaire Section II: Group NI individual scores on handicap questions

Sub-ject	Score on each question												Weighted total score (%)
	A		B		C	D		E	F	G	H	J	
	4	5	4	5	4	3	4	4	4	4	4	5/6	
101	30	10	0	10	40	40	20	0	0	0	15	15	21
102	0	10	20	10	20	40	20	0	30	15	15	15	24
103	15	20	20	10	60	60	0	20	30	15	15	0	41
104	0	0	40	10	20	60	20	60	30	15	15	0	40
105	15	10	40	20	40	40	40	20	15	15	30	15	36
106	0	10	40	10	40	60	20	20	30	15	15	15	36
107	15	10	40	0	40	40	20	20	30	30	15	0	37
108	15	10	0	20	40	40	20	20	30	15	15	15	34
109	15	0	20	10	40	60	0	20	30	15	15	15	28
110	15	0	20	0	40	40	0	20	30	15	15	15	24
111	15	20	20	10	40	20	20	20	0	45	15	30	35
112	15	20	20	20	20	40	20	40	30	15	15	0	34
113	15	20	20	30	40	40	60	20	15	30	15	30	53
114	30	20	40	20	40	40	60	20	30	15	15	0	49
115	15	10	20	20	40	60	20	20	30	15	15	15	33
116	30	20	20	30	20	40	40	20	0	30	15	15	39
117	15	20	20	20	20	60	0	20	30	15	15	15	37
118	15	10	0	20	40	40	20	20	30	30	15	15	29
119	15	10	20	10	20	40	0	60	45	15	15	15	35
120	30	0	40	0	20	40	0	0	15	45	15	0	27
121	15	20	60	10	0	0	20	20	30	30	15	0	27
122	0	10	20	10	20	20	20	20	15	15	15	0	20
123	30	30	40	30	20	40	60	20	15	15	30	0	54
124	15	20	20	20	20	40	40	20	60	30	15	15	43
Mean (%)	52	43	42	49	51	71	38	36	42	34	54	35	34.8
												SD	9.1

For completeness, the results for situation B and for situations B-C-G are extracted and presented in Table 31. Comparison with Table 17 shows that the *H* questions in these situations failed to distinguish between the NI and YN groups whereas an appreciable separation was made by the *D* questions (e.g., 37.0% compared to 26.5% for situation B).

Table 31: Questionnaire Section II: Group NI results for situation B and situations B-C-G combined, for disability and handicap questions

Subject	Percentage score (weighted)			
	Situation B		Situations B, C, G	
	D	*H*	*D*	*H*
101	19	7	18	16
102	19	22	22	21
103	29	33	28	38
104	31	37	38	27
105	39	44	31	34
106	28	37	45	40
107	46	44	49	46
108	71	22	51	27
109	39	22	36	27
110	28	15	29	26
111	19	22	22	37
112	58	44	39	30
113	87	56	57	46
114	39	44	39	37
115	19	30	18	30
116	71	56	43	40
117	29	44	28	33
118	19	15	18	29
119	39	22	34	23
120	19	30	22	33
121	19	52	16	32
122	19	22	23	23
123	71	78	45	47
124	29	44	29	35
Mean (%)	37.0	35.2	32.4	32.2
SD	20.2	16.3	11.7	8.1

6.3.6.3 *Section III - Reaction to simulated situations*

Results for the NI group on this part of the questionnaire are summarized in Table 32 (cf. Table 18). The degree of difficulty reported by this group was predictably greater on each simulation than that reported by the YN group, but the difference is not as marked as might have been expected (compare Qns. 2 of each simulation).

Both groups found the verisimilitude of the second simulation (public address) better than that of the first (social gathering), with telephone listening intermediate.

Table 32: Summary of responses of NI group to Section III of the Questionnaire

Question	Number of occurrences of each coded response									Total	Av.
	1	2	3	4	5	6	7	x	NR		
Simulation 1 (social gathering)											
1	8	8	11	13	13			0	0	53	
2	3	7	*10.5	*3.5					0	24	2.60
3	3	5	10	4	13	4	4	0	0	43	
4	9	11	3	1				0	0	24	1.83
Simulation 2 (announcements in a concourse)											
1	3	0	23	16	13	8	3	0	0	66	
2	0	8	*9.5	*6.5					0	24	2.94
3	10	2						12	0	24	
4	18	3	1	1				1	0	24	1.35**
Simulation 3 (telephone listening in noise)											
1	14	2	7	9	11	11		1	0	55	
2	1	5	14	4				0	0	24	2.88
3	21	3							0	24	
4	12	12	0						0	24	
5	1	20	13					1	0	35	
6	14	8	1	0				1	0	24	1.44**

* Subject no. 105 bracketed responses 3 and 4 in these cases.
** Excludes the "no response" category.

6.3.7 Comparison of results of YN and NI groups

Using the notation of Table 19, the individual results of each member of the NI group on a selection of the *a*, *p*, *d*, *h* and *s* indices are given in Table 33.

Table 33: Hearing of NI group relative to normal group YN

Subject	Value of normalized index (see key below)												
	a_2	a_3	a_4	a_{10}	a_7	a_{14}	p_{16}	p_{17}	p_{18}	p_{20}	p_{21}	s_{24}	s_{27}
108*+	13	7					2			14	6	3	
106*+	11	14			7					17	9	9	
104*+	11	10	2	2	7		3	4	3	10	3	4	
113*+	10	14	3		10	2	3	2	3	7		10	7
107*+	8	14	3		11		3	4		9	3	6	3
116*	6	11	2	2	10	3						8	2
121*	5	12	3	2	7	2	4						
123*	5	4		3	2			3				7	4
122*	4	8	3	4	8	3		3					
112*	4	10	2		4		2					4	
101	3	5						2		5			
119	3	4			2		3	3			3	3	
124		7	2		5	3	3	3	3	2			
102		7			3		2	3					
120		5			2							2	
105		3								3		8	
114		3			3		4	3	2	3		8	3
117		3			3								
103		3											
115		3			2							2	
109												3	
110												4	
111							3	2				3	
118												4	

*Subject exceeds the 'low fence' of Suter ($H_{123}^{LR} > 17$ dB)

+Subject exceeds the 'low fence' of BS 5330 ($H_{123}^{LR} > 30$ dB)

Key to Table entries:

"0" means an index value within normal limits (< 2.50)
"2" means an index value between 2.50 and 2.99
"n" ($n > 2$) means an index value between n and $n + 0.99$

For meaning of index symbols, refer to Table 19.

To facilitate the presentation of these data, any entry for which the value of the index was less than +2.5 is left blank, meaning that the datum is within the limits of the normal group. The other entries are simplified to the leading digit. Thus "2" means the range 2.50-2.99, "3" the range 3.00-3.99; "4" the range 4.00-4.99; and so on. These are the numbers of standard deviations of the normal group YN by which the entry in question exceeds the mean value for the normal group.

It should be noted that the cut-off value of 2.5 does not completely embrace the range of the normal data. For a Gaussian distribution it would include 99.38% of the values. Among the 1100 data for group YN (55 indices, 20 subjects) there were 8 exceedances of 2.50, some 99.27% falling below this cut-off. It seems safe to conclude, therefore, that virtually all entries that are not blank in Table 33 represent highly significant or very highly significant exceedances of normal limits.

Subjects are listed in Table 33 in order of descending values of a_2 (corresponding to H^{LR}_{123}) down to the last case for which a_2 is less than 2.5, and thereafter in descending order of a_3 (corresponding to H^{LR}_{346}).

The Table illustrates some important features of the results, the most striking of which are as follows:

1. None of the three indices a_4 (temporal resolution), a_{10} (critical ratio) or a_{14} (off-frequency listening) is very sensitive, nor does any of them taken alone appear as a good predictor of performance (disability) which is represented by the indices p.

2. The index a_7 (frequency selectivity) is sensitive and obviously correlated to a_3 (HTL at 3, 4, 6 kHz); however, it does not correspond well to the performance measures.

3. The performance measures for two of the simulations (p_{16} and p_{17}) are moderately sensitive, but at a high price in experimental complexity. Surprisingly, the third simulation (p_{18}) (telephone listening in noise) yielded very little information. Also somewhat unexpected was the marked lack of correspondence between p_{18} and p_{21} (binaural speech audiometry in noise), since the tasks were basically similar, although the telephone listening was monaural and there were more numerous distracting sounds.

4. Speech audiometry in quiet (p_{20}) correlates to some extent with that in noise (p_{21}) but there are notable exceptions: subjects 101, 105, 113, 114 and 124 gave normal performance in noise but not in quiet, whereas the reverse occurred with subject 119. The large deviations from normal on speech audiometry in quiet (p_{20}) for the first five subjects listed no doubt reflects a simple loss of hearing sensitivity, indicated by the high values of a_2 (and perhaps a_3).

5. The self-rating measures s_{24} (Questionnaire, Section I) and s_{27} (Questionnaire, Section II) appear to be poorly related to individual performance. In particular, there were some subjects (109, 110, 115, 116, 118, 120) whose self-rating of their general state of hearing was belied by performance within normal limits on all the listening tests, and others (105, 112, 123) who performed within normal limits on four of the five listening tests. On the

other hand certain subjects considered their hearing normal (101, 102, 121, 122, 124) but did not perform accordingly. The self-assessment of difficulty in particular situations (s_{27}) yielded a rather insensitive result, only 5 out of 24 subjects lying outside the normal limits. Moreover, it had been expected that this test would predict performance on the simulations (p_{16}, p_{17}, p_{18}) with some degree of fidelity, but this is not borne out by the results.

A global comparison between the a, p and s measures is given in Table 34. Here the actual numerical values for each subject are averaged under the three headings, and include values below the cut-off point applied to Table 33. Subjects are listed in rank order of descending average a_{av}. Interchanges of rank on the other average measures p_{av} and s_{av} are clearly seen; extreme cases of rank differences of 12 or more are marked with asterisk or dagger.

The Spearman rank correlation coefficients between a_{vs}, p_{av} and s_{av} are as follows:

a_{av} vs p:	0.634	($p < 0.01$)	
a_{av} vs s:	0.316	(N.S.)	
p_{av} vs s:	0.356	(N.S.)	

Thus there is a rather weak association between the mean self-assessment and either the performance or the mean impairment. Inspection of Table 33 suggests that performance is possibly more closely linked to a_2, a_3 or a_7 than to the mean measure a_{av}. The corresponding Spearman coefficients are as follows:

a_2 vs p_{av}:	0.702	($p < 0.01$)	(H_{123})
a_3 vs p_{av}:	0.614	($p < 0.01$)	(H_{346})
a_7 vs p_{av}:	0.461	($p < 0.05$)	(FS-1)

From this it appears that the mean performance is more closely related to hearing threshold level than to frequency selectivity, although there is a significant relation to the latter. This finding ignores, for the moment, differences in the relationships to the constituent parts of the performance battery (see Chapter 6.4.4).

Table 34: Global comparisons of group NI results on impairment, disability and handicap (self-assessment) measures

Subject	Impairment (audiology) a_{av}	Rank	Disability (performance) p_{av}	Rank	Self-assesment s_{av}	Rank
113	7.3	1	3.8	5	8.9	1
107	7.1	2	4.4	4	4.6	7
116	6.4	3	1.2	16*	5.7	5
106	6.3	4	6.6	1	5.9	3
121	5.9	5	2.1	11	0.9	21*
104	5.8	6	5.3	3	3.4	9
122	5.7	7	1.4	12†	-1.1	24*†
108	4.2	8	5.4	2	3.1	10
112	3.9	9	1.3	15	3.5	8
124	3.7	10	2.5	8	1.8	17
102	2.7	11	2.3	9†	0.2	22†
123	2.5	12	1.1	17†	6.1	2†
120	2.5	13	-0.2	22	1.5	18
101	2.2	14	1.4	13	-0.6	23
119	2.0	15	2.6	7	2.7	11
114	2.0	16	2.6	6	5.8	4*
117	1.9	17	0.5	20	2.0	16
115	1.8	18	-0.3	23	1.4	19
105	1.5	19	1.3	14	4.8	6*
109	1.4	20	0.0	21	2.3	12
111	0.5	21	2.2	10	2.0	15
110	0.5	22	0.8	18	2.2	13
118	0.3	23	-0.4	24	2.1	14
103	0.0	24	0.5	19	1.0	20

Note: the lower the rank number the more the impairment, etc.

*Difference of rank relative to a_{av} rank ≥ 12
†Difference of ranks on p_{av} and s_{av} differ by 12 or more

6.4 *Correlations between the measurements*

Product-moment correlations between all the variables in Table 19 were calculated, both for the combined group NI + YN (n = 44) and for the NI group alone (n = 24). In the case of the audiological impairment measures (the monaural tests) the calculations were carried out both on the basis of individual ears (2n) and left-right average values.

The resulting matrices are dissected and presented in the following sub-chapters. Inferences drawn at successive stages enable the number of variables to be reduced, by elimination of the less significant ones.

The plan of this chapter is as follows:

1. Correlations of monaural measures between left and right ear

2. Correlations between different audiological impairment measures (*a*)

3. Correlations between the audiological impairment measures (*a*) and those of performance (*p*) and self-assessment (*s*)

4. Correlations between the measures of performance at the five tasks (three simulations, speech audiometry in quiet and noise)

5. Correlations between the sections of the questionnaire (*d*, *h*, *s*) and between these and the task performance measures (*p*)

6. Multiple correlations relating performance to audiological impairment, and performance to self-assessment

6.4.1 <u>Correlations within each audiological impairment measure</u>

Correlation coefficients between the left and right ear values for YN + NI and NI group alone are given in Table 35. In this and subsequent Tables, repetition of the decimal marker is avoided by giving the values of 100 r to the nearest integer.

Correlations for the hearing threshold levels and for frequency selectivity are all highly significant, as are those for CR-2, but none of those for the TI and OF measures attain significance.

Apparent want of correlation can obviously reflect an actual absence of association, but it may result from an underlying association being obscured by random error. It is therefore worth examining the latter factor. All the tests concerned involved a simple threshold tracking task and those listed from TI onwards were done consecutively. There are grounds, therefore, for supposing that the component of random subjective uncertainty would be similar in each case. This statement requires modifying slightly in that the effect of the uncertainty on the extracted measure depends on how many threshold measurements were involved in it.

Table 35: Correlation coefficients between left and right ear measures (× 100)

Measure	Correlands	YN + NI 100 r	YN + NI Signif.	NI alone 100 r	NI alone Signif.
H_4	a_1^L vs a_1^R	88	***	79	***
H_{123}	a_2^L vs a_2^R	93	***	92	***
H_{346}	a_3^L vs a_3^R	92	***	84	***
TI-1	a_4^L vs a_4^R	-8	N.S.	-13	N.S.
TI-2	a_5^L vs a_5^R	20	N.S.	31	N.S.
FS-1	a_7^L vs a_7^R	89	***	85	***
FS-2	a_8^L vs a_8^R	76	***	70	***
CR-1	a_{10}^L vs a_{10}^R	45	**	21	N.S.
CR-2	a_{11}^L vs a_{11}^R	81	***	77	***
OF-H	a_{13}^L vs a_{13}^R	16	N.S.	14	N.S.
OF-L	a_{14}^L vs a_{14}^R	28	N.S.	30	N.S.

N.S. $p > 0.05$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Thus, it would be greater (by the order of $\sqrt{2}$) for measures derived from a difference (threshold shift) as in TI-2, FS-2, OF-H and OF-L, and less (by the order of $1/\sqrt{3}$) for those derived from averages (H_{123}, H_{346}) than for those derived from a single determination (H_4, FS-1, CR-1 and CR-2). These distinctions will slightly affect the correlation coefficients which, however, are susceptible to a larger effect, namely the actual range of the variables, there being an inverse relation. To examine the correlation coefficients in the light of these factors, the relevant data are assembled in Table 36. The measure TI-1 is omitted since this is derived in a special way as a ratio involving three thresholds and its derivation is incompatible with those of the other measures; however, on general grounds the reliance on 3 values would tend to increase the random uncertainty and it is noticeable that the correlation coefficients for TI-1 are smaller than (the already small) values for TI-2 (Table 35). Table 36 also gives the mean of the signless differences between left and right measures for each ear, as well as the root-mean-square value of these differences.

Table 36: Factors relevant to the left-right ear correlations (data are for the combined group YN + NI)

Measure	100 r (n = 44)	Number of thresholds involved	Left-right difference Range (dB)	Signless mean (dB)	R.M.S. (dB)
H_4	88	1	75	8.0	10.9
H_{123}	93	Av. of 3	66	4.3	6.6
H_{346}	92	Av. of 3	79	6.6	9.0
TI-2	20	Diff. of 2	23	5.6	7.3
FS-1	89	1	61	6.4	9.0
FS-2	76	Diff. of 2	29	5.1	6.8
CR-1	45	1	30	5.6	8.5
CR-2	81	1	53	5.7	7.9
OF-H	16	Diff. of 2	17	6.5	9.1
OF-L	28	Diff. of 2	36	4.1	5.8

The Table shows that there is a broad similarity of the values in each of the last two columns. As expected, the 3-frequency averages lead to smaller values than H_4. Unexpectedly, the values for FS-1 are *greater*, not *smaller*, than for FS-2. Given that there is also a theoretical advantage for FS-2 (see Chapter 5.1.1.3) this measure emerges as preferable to FS-1. The fact that the correlation coefficient for FS-1 is slightly larger is probably the simple consequence of the range of values being so much larger than in the case of FS-2 (both are highly significant, Table 35).

Table 36 also illustrates that OF-H is an appreciably less symmetrical function of hearing than OF-L, leading to a smaller (and non-significant) correlation coefficient. The coefficient for OF-L is also formally non-significant (at $r = 0.28$) but approaches the level $p = 0.05$ ($r = 0.30$).

6.4.2 Intercorrelations between the audiological impairment measures

These correlations were calculated both for individual ears (n = 88) and for mean values of left and right ears (n = 44). The latter yielded higher values in almost every case, and the few exceptions occurred when the values were non-significant in both cases. Only the mean-ear values are therefore considered.

The results are given in Table 37 for the combined group YN + NI (upper values) and the NI group alone (lower values). A large proportion of the coefficients are significant or highly significant, the critical values of 100 r being as follows:

	$p < 0.05$	$p < 0.01$	$p < 0.001$
upper figures	30	38	48
lower figures	40	52	63

It may be seen from the Table that, for the combined group, the following pattern* emerges:

Highly correlated: HTL vs TI, FS, CR & OF-L; H_{123} vs H_4 vs H_{346}
TI vs HTL, FS, CR-2 & OF-L; TI-1 vs TI-2
FS vs HTL, TI, CR & OF-L; FS-1 vs FS-2
CR-1 vs HTL, FS & OF-L; CR-1 vs CR-2
CR-2 vs TI
OF-L vs HTL, TI, FS & CR
OF-H vs TI-2

Less highly correlated: HTL vs OF-H
TI vs OF-H (TI-1 vs OF-H, N.S.)
CR-1 vs TI-1 (CR-1 vs TS-2, N.S.)
OF-H vs HTL, TI-2 (OF-H vs TI-1, N.S.)

Non-significant or uncorrelated: TI-1 vs OF-H
TI-2 vs CR-1
FS vs OF-H
CR-1 vs TI-2, OF-H
CR-2 vs OF-H
OF-H vs TI-1, FS, CR; OF-H vs OF-L

The pattern is similar for the NI group alone with the significance levels generally weakened. Compared with the combined group, the following correlations change from significant to non-significant:

H_4 vs OF-H; H_{123} vs CR-1; H_{346} vs CR-1 & OF-H;
TI-2 vs OF-H; CR-1 vs OF-L.

The only blocks that are wholly non-significant are OF-H vs FS and CR. There is an unexpectedly low correlation between OF-H and OF-L, which renders the concept of the combined measure a_{15} unjustified.

CR-2 correlates more highly with all other measures than does CR-1, possibly because it is not purely a measure of critical bandwidth, being very highly correlated with H_4 and H_{346} (as discussed in Chapter 6.4.1) or because the range of values is larger in comparison to random uncertainty than is the case with CR-1 (Table 36).

The measure CR-1 emerges as significantly correlated ($p < 0.01$) with TI-1 but not significantly with TI-2. This difference seems likely to be due to the way TI-1 is defined (involving as it does the 4 kHz absolute threshold which is in turn correlated with CR-1). TI-2 is the simple unmasking measure in decibels of interrupting the masker and its

* For ease of reference, entries are duplicated in the listing.

Table 37: Correlation coefficients (for left-right ear means) between the audiological immpairment measures (× 100)
Upper figures = NI + YN group (n = 44)
lower figures = NI group alone (n = 24)

Measure	Correland	a_2	a_1	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}
H_{123}	a_2	- -													
H_4	a_1	80 69	- -												
H_{346}	a_3	84 75	98 96	- -											
TI-1	a_4	51 39	72 78	69 68	- -										
TI-2	a_5	46 44	63 75	66 78	80 83	- -									
TI	a_6	51 43	72 80	71 76	96 96	94 95	- -								
FS-1	a_7	75 62	93 92	91 88	70 78	62 77	70 81	- -							
FS-2	a_8	68 53	91 91	87 85	71 83	63 80	71 85	91 89	- -						
FS	a_9	74 60	94 94	92 90	72 82	64 80	72 85	99 99	97 96	- -					
CR-1	a_{10}	52 30	61 43	56 30	37 40	13 16	28 30	72 59	60 47	69 56	- -				
CR-2	a_{11}	73 64	81 78	81 78	58 61	52 64	58 65	93 92	70 67	86 85	71 59	- -			
CR	a_{12}	68 56	80 76	77 71	55 63	41 56	51 63	92 92	72 69	86 86	87 79	95 95	- -		
OF-H	a_{13}	45 43	29 15	37 27	21 -2	38 26	30 11	18 9	13 7	16 9	9 -2	22 14	16 7	- -	
OF-L	a_{14}	43 24	67 66	67 65	51 44	46 51	52 49	65 65	67 73	67 70	44 38	50 44	54 51	23 13	- -
OF	a_{15}	51 39	56 47	61 53	42 22	49 45	48 34	45 37	45 43	46 40	30 18	37 25	37 27	77 75	73 65

calculation is independent of the absolute threshold. Inasmuch as the temporal and critical band aspects of hearing are not related in any obvious way (that is, they are conceptually orthogonal) a zero correlation would be expected, or at most a low value if there were (second-order) level dependent effects. From these considerations, TI-2 emerges as probably the truer measure of temporal impairment than TI-1 (Zwicker's measure) for the present subject group. By extension, the artificial combined measure TI, which derives from the same modulated-noise threshold in two arithmetically different ways, is not to be preferred.

In the case of the frequency selectivity measures FS-1 and FS-2, the pattern of correlations with the other variables is identical. The only distinction is that the correlation coefficients against HTL and CR are slightly larger in the case of FS-1. This again is probably due to the fact that FS-1 is derived from a single masked threshold and thus more influenced by the subjects' absolute sensitivity (HTL) than is the case with FS-2 which results from a difference (unmasking due to suppression of part of the masker spectrum). This suggests a preference for the measure FS-2, a conclusion which already emerged from the discussion in Chapter 6.4.1.

In summary, the simple correlation analysis points to the elimination of the measures TI-1, FS-1 and CR-2, and to the probability that OF-H will not figure at all prominently in correlations with the performance measures (see Chapter 6.4.4).

6.4.3 Intercorrelations between the performance measures

Differences in the relative performance at speech audiometry in quiet (SAQ) and noise (SAN) as between normals and persons with sensorineural impairments have frequently been reported in the literature, and attributed to the influence of speech distortion occasioned by deficits in frequency selectivity, temporal resolutions and spatial discrimination. This is not to say, however, that the results of SAQ would not be highly correlated in a population occupying a continuum from normal through varying degrees of sensorineural hearing loss. Table 38 shows that this correlation was in fact high, $r = 0.84$ for the combined group YN + NI, 0.86 for group NI alone.

Turning to the simulations, Table 38 shows that the intercorrelations are all highly significant ($p < 0.01$ or $p < 0.001$), but the actual magnitudes of the coefficients (0.54–0.71) are not particularly large which indicates that different faculties were to some extent being tested, in accordance with the intention of the tests. Differences between the tasks in these simulations included the factors of listening condition, audiovisual as opposed to purely audible presentation, a variety of distracting sounds, high fidelity versus pre-distorted speech, different response modes, and so on. Against this, they all shared a similarity to SAN in that the target material was speech presented in acoustically adverse conditions. In this respect they all differed from SAQ. However, a striking feature of the results seen in Table 38 is that the simulations as a whole correlated more closely with SAQ than with SAN (being non-significant for group NI in each case against SAN, even for the combined 3-simulation measure p_{10}). There is no obvious explanation for these apparently anomalous results.

Table 38: Correlation coefficients between the performance measures (speech audiometry and simulations) (× 100)
Upper figures: NI + YN group (n = 44)
lower figures: NI group alone (n = 24)

Measure		P_{20}	P_{21}	P_{16}	P_{17}	P_{18}	P_{19}
SAQ	P_{20}	– –					
SAN	P_{21}	84 86	–				
Sim. 1	P_{16}	43 34	46 38	– –			
Sim. 2	P_{17}	45 30	36 20	71 54	– –		
Sim. 3	P_{18}	48 41	30 22	57 62	60 57	– –	
All sims.	P_{19}	52 41	44 32	89 87	90 83	80 84	– –

6.4.4 Correlations between the audiological and performance measures

These results are given in Table 39, with the audiological measures reduced in number as already described.

The pattern that emerges for the combined group is as follows:

Highly correlated:	SAQ	vs	H_{123}, H_{346}, TI-2, FS-2
	SAN	vs	H_{123}, H_{346}
	Sim.1	vs	H_{123}, H_{346}, FS-2, CR-1, OF-L
	Sim.2	vs	H_{123}, H_{346}, FS-2, CR-1, OF-L
	Sim.3	vs	H_{123}, H_{346}, FS-2, CR-1, OF-L

Less highly correlated: Sim. 3 vs TI-2

Non-significant or uncorrelated:	SAQ	vs	CR-1, OF-L
	SAN	vs	FS-2, CR-1, OF-L
	Sim.1	vs	TI-2
	Sim.2	vs	TI-2

The pattern of the correlation coefficients is similar for the NI group alone but the values are all smaller and in several cases they are non-significant where the value for the combined group was significant or highly significant.

It is interesting to note that SAQ correlates more highly with the HTL values than does SAN, a well-known result, and that the correspondence in both cases is closer with H_{123} than with H_{346}; curiously exactly the opposite applies to the simulations; the performance in each case correlates more highly with H_{346} than with H_{123}.

The results in Table 39 embody some of the principal data of this study. They indicate that the principal determinants at the speech performance tasks are the pure-tone thresholds and the frequency selectivity parameters, with the temporal impairment index more weakly, although positively, related. The pattern is markedly different for both modes of speech audiometry.

6.4.5 Intercorrelations between the self-assessments

These correlations are given in Table 40. It is apparent that there is a highly significant association between the two parts (D and H) of each questionnaire section, as well as between sections I and II as a whole. This indicates a good measure of consistency but a want of distinction between the responses to questions intended to reflect disabilities and handicap respectively.

All values in the Table are very highly significant ($p < 0.001$).

Table 39: Correlation coefficients between performance and selected audiological measures (× 100)
Upper figures: NI + YN group (n = 44)
lower figures: NI group alone (n = 24)

Performance measure		Audiological measure					
		H_{123}	H_{348}	TI-2	FS-2	CR-1	OF-L
		a_2	a_3	a_5	a_8	a_{10}	a_{14}
SAQ	p_{20}	83 83	66 59	38 34	46 31	21 -4	27 12
SAN	p_{21}	69 73	52 51	29 20	25 14	6 -10	9 -2
Sim. 1	p_{16}	55 41	66 49	24 14	53 40	50 44	38 25
Sim. 2	p_{17}	51 29	61 34	19 10	53 29	52 44	43 36
Sim. 3	p_{18}	49 39	60 52	32 35	55 60	48 35	45 42
All Sims.	p_{19}	60 43	72 53	28 22	60 50	58 49	48 39

For critical values of 100 r, see Chapter 6.4.2.

Table 40: Correlation coefficients between the self-assessments by questionnaires (× 100)
Upper figures: NI + YN group (n = 44)
lower figures: NI group alone (n = 24)

		Questionnaire Section I			Questionnaire Section II		
		d_{22}	h_{23}	s_{24}*	d_{25}	h_{26}	s_{27}*
Questionnaire Section I (hearing in general)	d_{22}	- -					
	h_{23}	87 82	- -				
	s_{24}*	96 94	97 96	- -			
Questionnaire Section II (hearing in particular situations)	d_{25}	74 69	80 77	79 77	- -		
	h_{26}	57 63	61 68	62 69	71 81	- -	
	s_{27}*	76 76	78 78	80 91	95 97	85 87	- -

* The measures s embrace both the disability (d) and handicap (h) measures in each Section.

6.4.6 Correlations between self-assessments and performance measures

These results are given in Table 41 for the combined group YN + NI and group NI alone. The pattern that emerges for the combined group is one of highly significant correlations ($p < 0.01$ or $p < 0.001$) for all assessments from Section I of the questionnaire and for the total assessment from Section II, against all of the performance measures. The *D* questions from Section II (d_{25}) also correlate highly with all performance measures except SAN, and this case is still significant at a lower level ($p < 0.05$). Correlation coefficients for the *H* questions of Section I (h_{26}) are, however, consistently lower than for the *D* questions: h_{26} *vs* SAN is not significant, whilst against the other performance measures it is significant at $p < 0.05$ or better.

A fair measure of association is thus demonstrated between the self-assessments and the performance. The numerical values of the correlation coefficients are nevertheless not large (typically 0.5) so that any relationship can only be asserted on a population basis: large individual discrepancies are evident in the data.

Table 41: Correlation coefficients between performance and self-assessments (× 100)
Upper figures: NI + YN group (n = 44)
lower figures: NI group alone (n = 24)

Performance measures		Self-assessments					
		Questionnaire Section I			Questionnaire Section II		
		d_{22}	h_{23}	s_{24}	d_{25}	h_{26}	s_{27}
SAQ	P_{20}	55 41	48 33	53 38	46 33	30 20	49 38
SAN	P_{21}	44 37	41 32	44 36	35 29	25 13	38 31
Sim. 1	P_{16}	51 22	48 24	52 24	42 28	33 31	44 35
Sim. 2	P_{17}	48 -2	43 1	47 0	44 20	31 22	42 21
Sim. 3	P_{18}	46 24	40 27	44 27	49 39	39 42	51 46
All Sims.	P_{19}	56 18	51 20	55 20	51 34	39 37	52 39

The pattern of the correlation coefficients for the NI group alone is, with one exception, similar to that for the combined group, but the numerical values are smaller (though positive) and only attain significance in a few cases ($r > 0.39$). The exception is the correlation between Simulation 2 (public announcements) and Questionnaire Section I (hearing in general). Both for d_{22} and h_{23} (and consequently for the aggregate self-assessment s_{24}), there is apparently a total absence of correlation ($r < 0.02$).

It might have been expected that the performance in three particular situations (the simulations) would have been more closely correlated with the self-assessment under Section II of the questionnaire which likewise related to particular situations than with Section I. No such picture emerges from Table 41, however. More particularly, there might have been a closer relation between the Section II self-assessment on situations B, C and G and the performance at the three corresponding simulations. The relevant data are presented in Table 42 for the combined group YN + NI. The correlation coefficients for situations B-C-G alone are in all cases smaller than for the whole 9-situation self-assessment, and markedly so for the sub-section of *H* questions (h_{32} compared with h_{28}, against each simulation and all simulations). The values for d_{31} and s_{33} all remain highly significant ($p < 0.01$) but are all non-significant for h_{32}. It is clear that detailed examination of the questionnaire responses at this level of sub-division is unrewarding.

Table 42: Correlation coefficients from combined group YN + NI between performance at the simulations and the self-assessment of disability and handicap in three corresponding situations B-C-G (× 100)

Values for the self-assessments on all 9 situations, extracted from Table 41, are shown for comparison in parentheses

	D-questions	*H*-questions	*D* + *H*
	d_{31}	h_{32}	s_{33}
Sim.1	41 (51)	20 (48)	40 (52)
Sim.2	44 (48)	13 (43)	40 (47)
Sim. 3	42 (46)	15 (40)	39 (44)
All Sims.	48 (56)	19 (51)	45 (55)

6.4.7 Prediction of performance by multiple correlations

Mutliple correlations between the p and a variables and between the p and s variables were carried out by means of the STEPREG computer program. This first computes the linear regression between the dependent variable (one or other of the p variables) and the most highly correlated of the independent variables. It then computes the linear regressions, taking in the first already calculated, for each of the remaining independent variables and selects that for which the F-ratio (variance explained by regression/residual variance about the regression function) is greatest. It proceeds similarly until all variables are included. The significance of including any of the independent variables after the first can be tested by the ratio of explained variances after and before its inclusion.

6.4.7.1 *Prediction from audiological measures*

The dependent variables were individually the indices p_{20} (SAQ), p_{21} (SAN), p_{16} (simulation 1), p_{17} (simulation 2), p_{18} (simulation 3) and p_{19} (all simulations), and the multiple independent variables chosen were a_2 (H_{123}), a_3 (H_{346}), a_5 (TI-2), a_8 (FS-2), a_{10} (CR-1) and a_{14} (OF-L), using the mean ear values.

In the case of SAQ and SAN, the first independent variable selected was a_2 because that gave the greatest correlation (Table 39). In both cases the next variable, selected by program, was a_{10} (the critical ratio measure) with highly significant F-ratios ($p < 0.01$ for SAQ, $p < 0.001$ for SAN). No further variables were individually significant, although 7% additional variance could be accounted for in SAN by running the program to its termination.

The regression equations showed, however, that the coefficients for a_{10} were negative, in both cases. This result points to the existence of non-linear relations between the dependent and independent variables (since both a_2 and a_{10} individually correlated positively and significantly with SAQ and SAN).

In the case of the simulations, the first variable was a_3 (H_{346}). For simulations 1 and 2 (social gathering and public announcements, respectively) and for all-simulations, the second variable selected by STEPREG was a_5 (TI-2); no significant second variable was found for simulation 3 (telephone listening in noise). Again it was found that the coefficient of the second variable was negative in each case, presumably for the same reason as before.

An abbreviated summary of these stepwise multiple regressions is given in Table 43, together with the regression formulae re-expressed in terms of the original measured quantities. The increment in explained variance on introducing the second independent variable is appreciable in each case (excluding Simulation 3), but not statistically significant; $p = 0.05$ requires a variance ratio exceeding 1.6 for DF 41, 40 and the greatest occurring value was 1.26 (in the case of SAN). However, the persistence of the pattern of the selected variables suggests an underlying common factor in the aggregate.

Table 43: Summary of multiple correlation and regression analysis between performance scores and audiological measures, for the combined group YN + NI (n = 44)

Dependent variable	Measure	Independent variables	Explained variance (%)	Regression formula for % error score
p_{20}	SAQ	a_2	69.1	$6.45 + 0.833\ H_{123}$
		a_2, a_{10}	76.0	$31.74 + 0.991\ H_{123} - 0.985(CR\text{-}1)$
		All a	76.4	-
p_{21}	SAN	a_2	47.2	$18.92 + 0.742\ H_{123}$
		a_2, a_{10}	59.6	$55.54 + 0.975\ H_{123} - 1.427(CR\text{-}1)$
		All a	66.8	-
p_{16}	Sim.1	a_3	44.0	$14.36 + 0.395\ H_{346}$
		a_3, a_5	50.5	$22.66 + 0.527\ H_{346} - 1.023(TI\text{-}2)$
		All a	53.8	-
p_{17}	Sim.2	a_3	37.5	$29.87 + 0.634\ H_{346}$
		a_3, a_5	45.5	$8.06 + 0.888\ H_{346} - 1.964(TI\text{-}2)$
		All a	47.8	-
p_{18}	Sim.3	a_3	35.7	$16.92 + 0.386\ H_{346}$
		All a	39.2	-
p_{19}	All sims.	a_3	51.7	*
		a_3, a_5	58.2	*
		All a	60.9	-

* A total score for all simulations in un-normalized units cannot usefully be defined; p_{19} is a composite of normalized scores (see Table 19).

Note: The regression formulae in one variable give only broad-brush indications of the trends. The variables are not linearly related (see Chapter 7.3). The regression formulae in two variables represent a closer fit to the experimental data but lack meaningful interpretation, the negative coefficients being artefactual.

The key findings that emerge from this analysis are as follows:

1. Both modes of speech audiometry are better represented by H_{123} than by H_{346}; the converse applies to the simulated situations.

2. Frequency selectivity does not appear explicitly in any of the regression formulae.

3. SAN is a slightly weaker function of hearing threshold level than SAQ. The mean rate of deterioration is of the order 0.8% of phonemes per decibel.

4. Errors at Simulations 1 and 3 (both name-and-address tasks) are almost identical functions of hearing threshold level (high frequencies). The mean overall rate of deterioration (about 0.4% per decibel) is only half that for the CVC material of the speech audiometry, but this reflects the influence of the 'easy' (limited vocabulary) elements; for the difficult parts the rate would be much higher (see Tables 23 and 25).

5. Errors at Simulation 2 (public announcements) have a stronger dependence on hearing threshold level, comparable with the speech audiometry.

6. About 3/4 of the variance in SAQ and 2/3 of that in SAN can be accounted for by the audiological measures; for the aggregate of the simulations the fraction is about 3/5.

7. The correlation coefficients are sufficiently large to permit reasonably confident group predictions.

6.4.7.2 *Prediction from self-assessments*

Calculations similar to those above were carried out with the self-assessments as the independent variables, in the first case with the four variables d_{22}, h_{23}, d_{25} and h_{26}, and in the second case with the two composite variables s_{24} and s_{27}. As may be seen from Table 41, d_{22} and s_{24} are the leading correlands in each performance test except Simulation 3. Inclusion of a second variable in no case increased the explained variance appreciably, indicating that the various parts of the self-assessment were measuring essentially the same thing. In the resulting regression formulae the coefficients of the second variable were all positive, if included, but the F-ratio tests in the STEPREG program were far below the significant level at step 2.

Since they shed no additional light on the interpretation of the data, the four-factor results are omitted here. Table 44 summarizes the results of the two-composite-measure regressions. It shows that the "particular situations" questionnaire was rather less successful than the "general hearing" questionnaire in predicting performance (with the exception of Simulation 3). This was not the expected result and is rather disappointing in view of the thought and labour lavished on its creation. The explained variance ranges from 20 to 32% only, which can be regarded as a devastating commentary on the value of the questionnaires if the object were to employ them to assess people's hearing capability without actually testing it.

Table 44: Summary of the 1-factor and 2-factor regression analysis between performance scores and self-assessments, for the combined group YN + NI (n = 44)

Dependent variable	Measure	Independent variable	Explained variance (%)
p_{20}	SAQ	s_{24}	28.2
		s_{27}	23.8
		Both	29.4
p_{21}	SAN	s_{24}	19.8
		s_{27}	14.3
		Both	19.9
p_{16}	Sim. 1	s_{24}	26.8
		s_{27}	19.3
		Both	27.0
p_{17}	Sim. 2	s_{24}	22.2
		s_{27}	17.7
		Both	22.8
p_{18}	Sim. 3	s_{24}	19.7
		s_{27}	26.0
		Both	26.4
p_{19}	All sims.	s_{24}	30.4
		s_{27}	26 9
		Both	32.1

6.5 *Results for the older group with normal hearing (ON)*

The subject group ON consisted of 6 females and 4 males with 'clean' otological and environmental histories, save for war-time (small-arms) exposure on the part of three of the males. The mean age was 58 years (range 51-65).

They were tested in an identical manner to the subjects of the YN and NI groups.

6.5.1 Pure-tone audiometry

The results of the pure-tone audiometry are summarized in Table 45 (values given are corrected for audiometer calibration).

Table 45: Summary of results of pure-tone audiometry for group ON (n = 10)

		Hearing threshold level re ISO 389 (dB)						
		0.5	1	2	3	4	6	8 kHz
Mean	left ears	8.4	8.5	15.2	16.7	19.6	26.8	31.0
	right ears	9.5	9.1	11.4	14.9	18.3	25.4	32.1
SD	left ears	8.8	6.6	12.3	12.6	14.2	15.4	20.1
	right ears	4.6	6.3	8.5	7.9	10.1	15.6	22.0

The typicality of this group, and the relation of their mean hearing threshold levels to those of the YN and NI groups, are illustrated in Table 46. Here the results are expressed relative to the YN group, and in the last row of the Table they are compared with the standardized values (ISO, 1982b) for the median of an otologically normal population aged 58 years, weighted 6F/4M. The correspondence is remarkably close, considering the size of the group.

Table 46: Comparison of hearing threshold levels of the three test groups and standardized presbyacusis data for an otologically normal population with the same mean age as group ON

Group	Relative mean hearing threshold level (L/R av)						
	0.5	1	2	3	4	6	8 kHz
YN (datum)	0	0	0	0	0	0	0
NI	10.2	11.5	18.8	23.2	27.6	32.3	30.9
ON	9.9	7.4	13.9	16.2	19.4	24.3	26.0
Standard population aged 58 years	5.6	6.4	10.2	14.6	18.9	23.0	28.5

Although only a vestigial notch appears in the mean audiogram of the noise-impaired group, it is entirely absent from the ON group, for which the hearing threshold levels increase progressively at the high frequency end. Otherwise the threshold levels of the two groups are of the same order of magnitude. The hearing threshold levels of the NI group, however, are up to four times greater than would be accounted for on the basis of presbyacusis alone (using the median of the standardized data for age 45 years, weighted 23 M/1 F, as the criterion). At 3 kHz, for example, the observed threshold elevation of 23.2 dB compares with a standardized presbyacusis value of 8.3 dB. These findings serve to confirm the validity of the group descriptions as "noise-impaired" and "older normals" respectively.

6.5.2 Main test results

The results of all tests on the ON group are presented in summary form in Table 47, where they are compared directly with those of the YN and NI groups. The tests of temporal resolution, frequency selectivity and critical ratio are represented by the preferred measures already discussed.

The Table reveals a number of features (see below), the most striking of which is that, despite actual impairment and loss of performance, the ON subjects considered their own hearing to be normal. The distinction between the ON and NI groups on temporal impairment is also noteworthy: this faculty does not appear to be influenced by age alone.

ON resembles NI in:	HTL, FS, SAQ, SAN and all three simulations;
ON resembles YN in:	TI, OF-H and all self-assessments;
ON is intermediate in:	CR;
ON is worse than NI in:	OF-L.

Table 47: Comparison of summarized test results for groups YN, NI and ON (Standard deviations for the measures marked * are for left-right ear averages)

Measure	Unit of measurement	Means YN	Means NI	Means ON	Standard deviations YN	Standard deviations NI	Standard deviations ON
Audiological impairment:	dB						
H_{123}*		0.1	18.0	12.6	4.1	16.2	7.1
H_4*		-0.4	27.2	19.0	5.1	18.2	11.4
H_{346}*		0.3	28.0	20.3	3.9	17.1	10.2
TI-2*		-10.0	-8.0	-11.3	2.8	4.2	2.4
FS-2*		-24.0	-14.5	-14.5	3.6	7.6	6.1
CR-1*		24.4	29.6	27.6	3.5	4.4	2.3
OF-L*		-5.8	-3.4	-1.8	1.6	3.0	1.9
OF-H*		-9.1	-7.1	-10.6	2.7	4.0	5.5
Speech audiometry:	% phoneme errors						
SAQ		7.7	20.0	20.1	3.6	18.5	6.2
SAN		20.8	30.3	34.3	7.8	20.0	12.2
Simulations:	% max. poss. score						
Sim. 1		13.3	26.2	27.4	6.6	11.0	16.7
Sim. 2		26.6	52.5	50.4	11.5	16.8	21.1
Sim. 3		16.9	29.0	20.9	9.5	11.6	9.2
Questionnaires:	% max. poss. score						
Section I - D		14.3	39.1	14.5	6.5	16.7	10.5
- H		7.9	31.5	9.7	6.6	21.4	6.9
Section II - D		19.9	31.3	21.5	5.9	12.7	3.5
- H		28.2	34.8	26.2	8.8	9.1	5.8

6.6 *Subjects' amendments to self-assessments*

Section III of the questionnaire, administered in parts immediately following each of the three simulations, afforded subjects the opportunity to revise their assessments (made prior to the simulation tasks) of the three corresponding situations (B, C, G) presented in Section II of the questionnaire. The latter contained a total of 13 questions, and on average (over all subjects) there were response amendments to 2 of these, the proportion being highest among the ON group.

Table 48 shows how the changes were distributed between groups, questions and situations. Changes had not been expected in response to Qn.1 (since that depended on past experience) and few changes were volunteered.

<u>Question 2</u>: For situation B, all the changes were in the direction of a higher score (with the exception of one subject in group NI); that is, they had previously overestimated their ability to "clearly hear the person opposite". The same applied (again with one exception) to Situation C, and to Situation G (with no exceptions).

<u>Question 3</u>: Scores were in all cases increased by the addition of one or more categories of particular difficulty. In Situation B, all the ON group changes involved at least the addition of "having to concentrate hard", and in Situation C the most popular additions throughout the three subject groups were "background noise" and "catching the important words".

<u>Question 4</u>: Changes were few in Situations B and C. One subject each in the NI and YN groups changed the response to "get anxious" in Situation C. There was no systematic pattern to the changed responses in Situation G.

<u>Question 5</u>: All the changes here indicated that hearing difficulties in this situation (B) mattered more than the subjects had previously stated.

These results show rather clearly that self-assessment, in the absence of demonstration, tends to be optimistic and appreciably more so for the older otologically normal subjects than for those with a history of noise exposure. This distinction is confirmed by the disparity between the ON and NI self-assessment ratings in the last block of Table 47.

Table 48: Questionnaire Section III: *a posteriori* amendments to responses on Section II.

	% of subject group making changes				
	Qn. 1	Qn. 2	Qn. 3	Qn. 4	Qn. 5
Situation B (social gathering)					
YN	0	0	30	10	10
NI	4.2	20.8	37.5	4.2	12.5
ON	0	10	50	10	0
Situation C (announcements in a concourse)					
YN	0	10	40	5	-
NI	0	20.8	29.2	4.2	-
ON	10	30	50	0	-
Situation G (telephone listening in noise)					
YN	0	5	30	25	-
NI	4.2	20.8	33.3	25	-
ON	0	20	40	40	-

Key: Qn. 1 - familiarity with situation
Qn. 2 - audibility
Qn. 3 - particular difficulties
Qn. 4 - reaction to difficulty
Qn. 5 - "how much does it matter?" (not asked for situations C and G)

(For details of questions, see Appendix E)

7. INTERPRETATION OF RESULTS

7.1 *Clarification of concepts*

Distinctions between impairment, disability and handicap were drawn at the outset of this report, and maintained in categorizing the tests performed. The purpose has been to attempt a determination of the boundary between normal and non-normal in respect of these categories and to relate one to the other. In this context, terms such as 'low fence', 'threshold of disability', 'onset of handicap', etc. can be convenient shorthand but they must be given some precise meaning in relation to the tests performed. In the following sub-chapters each basic concept is discussed and applied to the experimental results.

7.2 *Threshold of impairment*

Here one is faced with alternative intepretations, on at least two counts. Using the concise definition of impairment (to hearing) as 'loss or abnormality of the functioning of the ear' we must immediately abandon the first in the present context. A loss can only be asserted if one knows both the initial and final states, the difference being that which is lost, and this cannot be determined from examination of the final state alone. Turning to 'abnormal', it is obvious that this condition can only be asserted if one knows what is normal, and this in turn implies the existence of a homogeneous population-based norm, with unavoidable statistical overtones. However, this is insufficient. Common sense tells us that what is clearly abnormal at the age of 18 (for example, a pure-tone hearing threshold level of 40 dB) may be quite commonplace at the age of 70. Abnormality, therefore, might be taken to depend on certain variables, of which age is the obvious example, and accordingly the threshold of impairment would also depend on these. It is important to note that there is a certain contradiction between the definition (in section 1) and its elaboration in the text (section 4) of the WHO (1980) publication. In the latter place degrees of impairment are asserted as fixed ranges of hearing threshold level, implying that aged persons have impaired hearing. This may accord with everyday notions but it does not accord with the notion that such persons are abnormal. A consequence of accepting the fixed criterion (in effect, the young otologically normal as baseline) is that 'impairment' in the general population – on this definition – tends to be so prevalent as to debase the term. However, we do not presume to resolve this question here but will sidestep it by introducing the sub-categories of *imperfection* and *abnormality*. The thresholds of these are respectively fixed and age-dependent, and in either case are to be defined in terms of a specified fractile of the relevant baseline population. Herein lies the second aspect of alternative interpretation: which fractile should be selected to represent the boundary of 'perfection' or 'normality'? In principle these thresholds could be given along each 'dimension' of the audiological tests but the interpretation of the present results and comparison with existing data is best served by reference to the average hearing threshold levels, specifically $H_{123}{}^{LR}$ and $H_{346}{}^{LR}$.

Figure 8 illustrates the relevant information. The relation between HTL, age and fractile of population has been derived from the standardized presbyacusis data (ISO, 1982b) as tabulated by SHIPTON (1979). The values illustrated are for a male population which excludes overt aural pathology and significant noise exposure (for details of the original data and procedure used in arriving at the standardized values, see ROBINSON and SUTTON, 1978 and 1979). In the references cited, dispersion data are only given for left/right ear averages at individual frequencies. Examination of a mass of comparable data has shown that the dispersion of 3-frequency average values is markedly smaller and can be summarized as approximately 2/3 of the mean value for the constituent frequencies. This factor has been applied to produce Figure 8. It turns out that by using a non-linear scale of age the whole diagram reduces to straight lines.

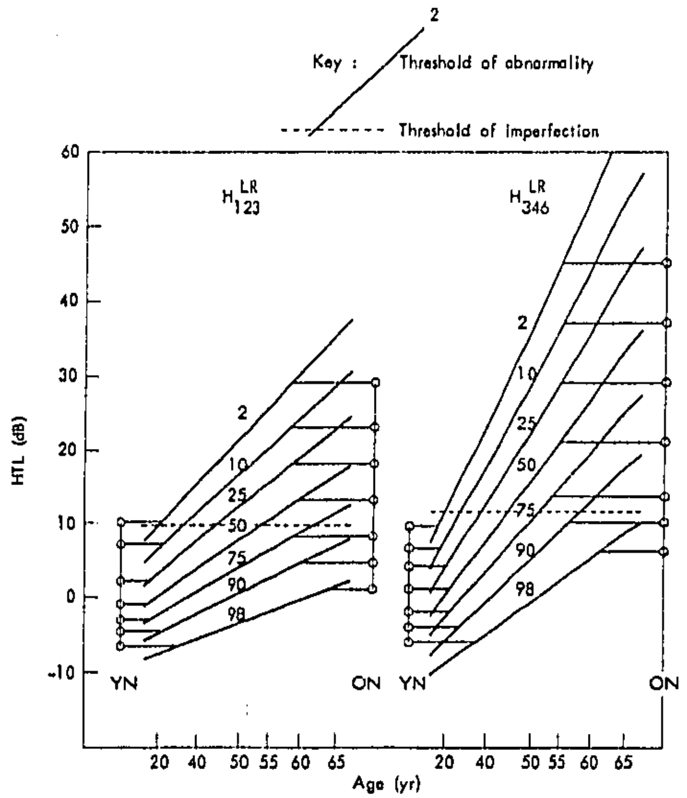

Figure 8: Distributions of hearing threshold levels as function of age, illustrating thresholds of imperfection and abnormality. Experimental data for groups YN and ON are shown to left and right of each diagram (data are true hearing threshold levels). Extreme percentiles for group ON are extrapolated.

The thresholds of imperfection and abnormality may be defined respectively as the dotted lines and the 2nd percentile lines. The existence of hearing threshold levels exceeding these thresholds implies a (highly probable) real deviation from the respective baseline, but whether this is of any consequence depends on whether it is above or below the level of the disability threshold (see below).

The experimental data for groups YN and ON are included on Figure 8 and are seen to conform well to the model for the respective mean ages (24 and 58 yr). Whereas YN and ON were both homogeneous groups, this did not apply to NI. The distribution of hearing threshold levels in this group, being adventitious, is of no particular interest here and it is not shown in this Figure.

7.3 *Threshold of disability*

Here again one receives a mixture of enlightenment and ambiguity from the WHO classification. Disability is given as "any restriction or lack (resulting from an impairment) of ability to perform *an* activity in the manner or within the range considered normal for *a human being*" (our italics). As above, what might be considered normal for one human being might be considered exceptional for another, for example where the activity is developmentally related as in the understanding of speech. In the specific classification of disabilities (section 3.2), the items relating to communication by hearing are given as "loss or reduction of the ability to receive verbal messages" or "other audible messages". For reasons exactly parallel to those above, it is useful to introduce sub-categories, in this case, *inability* and *abnormality*. The former implies an absolute deviation from young otologically normal performance, the latter a deviation from that of a baseline population matched to the individual in question (e.g., by age). The corresponding thresholds are to be set by reference to the upper (poorest) performance limit within these populations. In principle such thresholds can be found for any number of different activities which, in the present context, consisted of listening to and reproducing an assortment of spoken messages. The 'reproducing' was required to be exact in the case of the speech audiometry (SAQ and SAN) and of Simulations 1 and 3; in Simulation 2 redundancy facilitated receiving the 'carrier' part of the message without necessarily hearing every word but the scorable target item had to be perceived exactly.

It is also pertinent to question what is meant by "*an* activity" in the WHO definition. The corollary of this is that a person may be "disabled" - on this definition - if his capability is out of normal limits for a certain activity though he may be pefectly competent at all other activities of a human being. This is surely contrary to the ordinary understanding of the word. The definition, thus, might better read: "Disability, for a given activity, is ... any restriction ... etc", but the corollary then is that there are as many potential 'disabilities' (but we prefer to say 'inabilities' or 'abnormalities') as there are activities. The term disability might be better reserved for the notion of a constellation of inabilities affecting performance in a cognate range of activities, for example, the class of 'understanding spoken speech'. The difficulty of determining the threshold of disability, defined in this more general way, is how to weight the 'inabilities' in all the possible circumstances, given that they are necessarily unequal (dependent, for example, on speaker, acoustics, semantic content and numerous other variables). This inequality is exemplified in the present tests.

Figure 9 illustrates the results obtained. The distributions of error rates at the five tasks were considerably skewed in some cases and estimation of the percentile points was accomplished by free-hand curve fitting, with the cumulative distribution transformed to the 'arithmetical probability' scale.

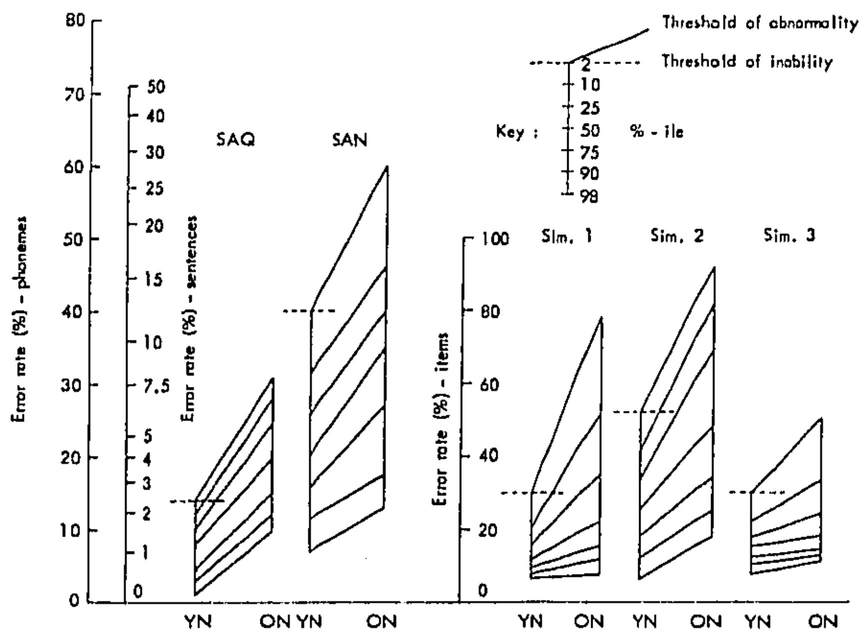

Figure 9: Distribution of error scores at the five listening performance tests, for groups YN and ON, illustrating thresholds of inability and abnormality. Scores for SAQ and SAN may be read on either of the left-hand scales (see Figure 10).

In all five cases, there is a large overlap between the YN and ON group distributions, more so than in the case of the hearing threshold levels. Although they are not much different at the low error-rate end, they diverge considerably at the upper end, that is, the threshold of abnormality rises sharply with age. In the case of Simulation 2 (public announcements) it would appear that the threshold could reach the level of total inability to receive the messages correctly a little beyond the age of 60 years. This, though realistic, proved to be indeed a very difficult test for some subjects, and even for the young normals the inability threshold was around 50% (as defined by the 2nd percentile).

In the case of the simulations, the error-rate distributions, and hence the inability thresholds, apply only to the specific situations and tasks involved and cannot be directly compared with other data. The results can, however, be indirectly related to one another, as discussed in the next sub-chapter. The SAQ and SAN results are susceptible of more immediate interpretation, by transformation of the results into terms of conversational speech. To do this the responses, originally scored as phoneme errors, were re-scored as word errors, and thence converted to sentence intelligibility for conversational speech using established data (Medical Research Council, 1947). The steps in conversion are illustrated in Figure 10, and the results can be seen in Figure 9 where alternative ordinate scales are shown for the SAQ and SAN distributions. A useful gauge point, quoted by HOOD and POOLE (1977), is the equivalence of 90% sentence intelligibility and 40%-correct word score on speech audiometry, or 36% phoneme error score on the present data. This error rate was not surpassed by any subject in groups YN or ON for the speech-in-quiet tests at 45 dB or 70 dB but it sharply distinguished YN from ON at 30 dB where

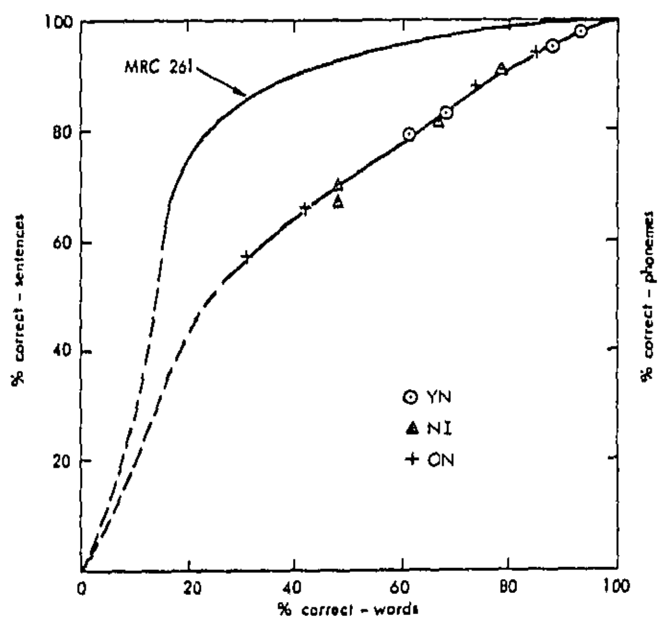

Figure 10: Relations between phoneme, word and sentence intelligibility scores in speech audiometry.

only 10% of the YN group failed against 70% of ON. In the speech-plus-noise test (S/N ratio, +2 dB), only one subject in YN against 50% of those in ON failed by this criterion.

It is obvious that the error rates in simulations of the kind employed here depend on the intimate details of the test situations, and that the absolute values are not of primary interest, but rather the relative performance of the young normal group and that of the others. In order to make these comparisons the data require to be transformed to a unified scale in the manner described in the following sub-chapter.

7.4 *The low fence*

The low fence may be regarded as a device for expressing the threshold of disability as an equivalent value in a scale of impairment (specifically, the scale of hearing threshold level), the assumption underlying this being a high correlation. It is well known that this assumption fails in general for severe hearing losses, since such a relation established for conductive hearing loss (on the basis of speech intelligibility) does not fit in cases of sensorineural hearing loss. However, it has been shown rather convincingly (HOOD and POOLE, 1971) that this shortcoming scarcely applies in hearing loss amounting to less than 31 dB (average 0.5, 1, 2 kHz). Up to this level of sensorineural hearing loss, it appears that the speech audiogram is virtually indistinguishable from that in conductive hearing loss of the same amount, and unchanged in form from that of normal hearing.

Previous studies have postulated low fence values ranging from 40 dB (H_{123}) downwards (see Table 1) and recent research data have suggested values of 15 dB (SMOORENBURG *et al*, 1981) or 17-19 dB (SUTER, 1978). We have demonstrated a fairly high correlation between hearing threshold levels and the performance tests (Table 39). The necessary conditions for translating the threshold of disability to an equivalent audiometric low fence are therefore broadly satisfied.

The relevant data are illustrated in the series of Figures 11-20. Each pair of figures displays the test scores for individual subjects in the YN and NI groups plotted against H_{123}^{LR} and H_{346}^{LR} (true values). The ON group result is represented by the median coordinates.

At first glance, the large scatter appears rather unpromising but by a smoothing process it was possible to extract the underlying relationship between test score and hearing threshold level. Moving medians of scores were first determined in bands of 15 dB (25 dB at the high end where the data are sparse), overlapping at 5 dB intervals). These values are shown connected by the full line. The relationship was then approximated in the form of two straight lines (shown broken) fitted to these values, a horizontal portion at the level of the median score of the YN group, and a sloping portion fitted to the upper range of hearing threshold level. Their intersection forms a knee point to which further reference is made below. In several cases the knee point could be pinpointed with some precision because the slope and intercept of the sloping portion were insensitive to the inclusion or exclusion of data points (that is, medians) near the knee. The roughness of the data makes for some uncertainty in the case of Simulation 2, so that alternative lines are shown; there is no clear evidence of a horizontal portion in these cases, which is consistent with error rate increasing continuously from the already high starting point given by the YN group. The length of the horizontal portion, where this exists, can be interpreted as the reserve of hearing for young normals in the situation in question and it is evidently considerable for the speech audiometry in quiet. The erosion of the reserve for those with hearing thresholds between that of young normals and the knee point is no doubt accompanied by a psychic cost but does incur an actual performance penalty.

The level marked by the arrow on the right hand margin of each diagram is that of the 2nd percentile of the YN distribution, which is the threshold of inability as we have defined it. By reading off the graph one arrives at an estimate of the corresponding hearing threshold level. In the case of SAQ *vs* H_{346}, there might appear to be ambiguity due to the secondary plateau in the data; however, the evidence points to the higher value (read from the steeper curve) because in the critical case one would expect the hearing threshold level at 3, 4, 6 kHz to exceed that for the lower frequency combination, 1, 2, 3 kHz. It will be recalled that the correlation coefficient for SAN and SAQ was higher for H_{123}, which also predisposes to preferring Figure 11. The resulting estimates are given in Table 49. Values underlined are for the frequency combination with the higher correlation coefficient against test score.

Table 49: Estimates of hearing threshold level at the inability threshold defined by the 2nd percentile of young normal performance

Test	Hearing threshold level	
	H^{LR}_{123}	H^{LR}_{346}
SAQ	29	40
SAN	34	>50
Sim. 1	29	37
Sim. 2	27/30	29/30
Sim. 3	30	36

Before drawing conclusions from the numerical values in Table 49, some remarks should be made about the data. In the first place, there is a striking difference of slope of the relation above the knee point as between SAQ or SAN (*vs* H_{123}) and the remainder. Secondly, the median score for the ON group is anomalously high relative to the YN/NI data both for SAQ and SAN whereas it fits the curve reasonably well for the three simulations. Beyond encapsulating this in the statement that perception of phonemes appears to be somewhat more eroded by age than by a combination of noise and lesser age producing equivalent hearing threshold levels, we can find no explanation. Thirdly, it is important to note that the YN 2nd percentile performance in SAQ (14% phoneme errors) is well inside the gauge point previously mentioned – in fact it implies only about 2% loss of sentence intelligibility (Figure 9). In the case of SAN, this percentile is only just above the gauge point (12%). Consequently it could be argued that the value inferred from the SAQ tests (29 dB H_{123}) should be discounted in favour of that from SAN (34 dB) (see Table 49).

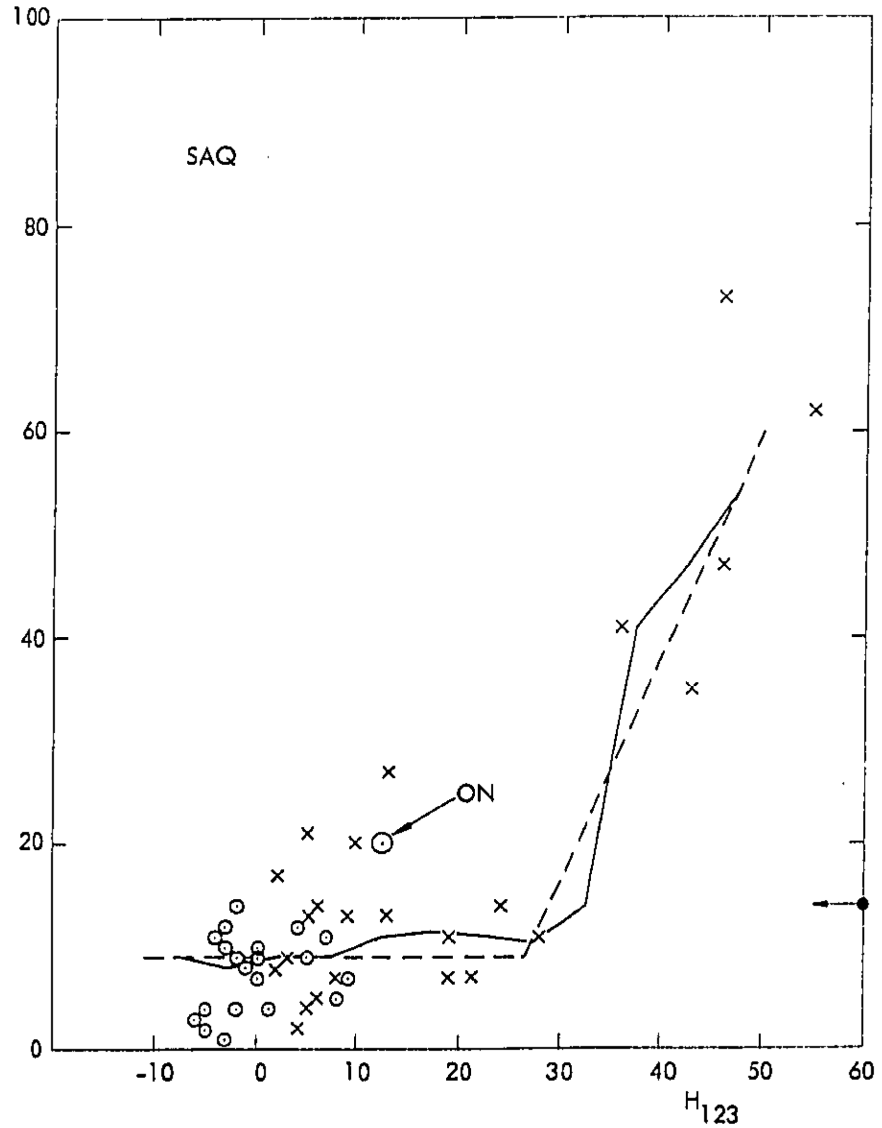

Figure 11: Percent phoneme error scores at SAQ (speech audiometry in quiet, average of three levels) against hearing threshold levels H_{123}^{LR} (average of 1, 2, 3 kHz, both ears).

Key: o Group YN; x Group NI (individual values)
Group ON (median values)

Line connecting moving medians
Two-straight line approximation

The arrow at right indicates the 2nd percentile score for group YN.

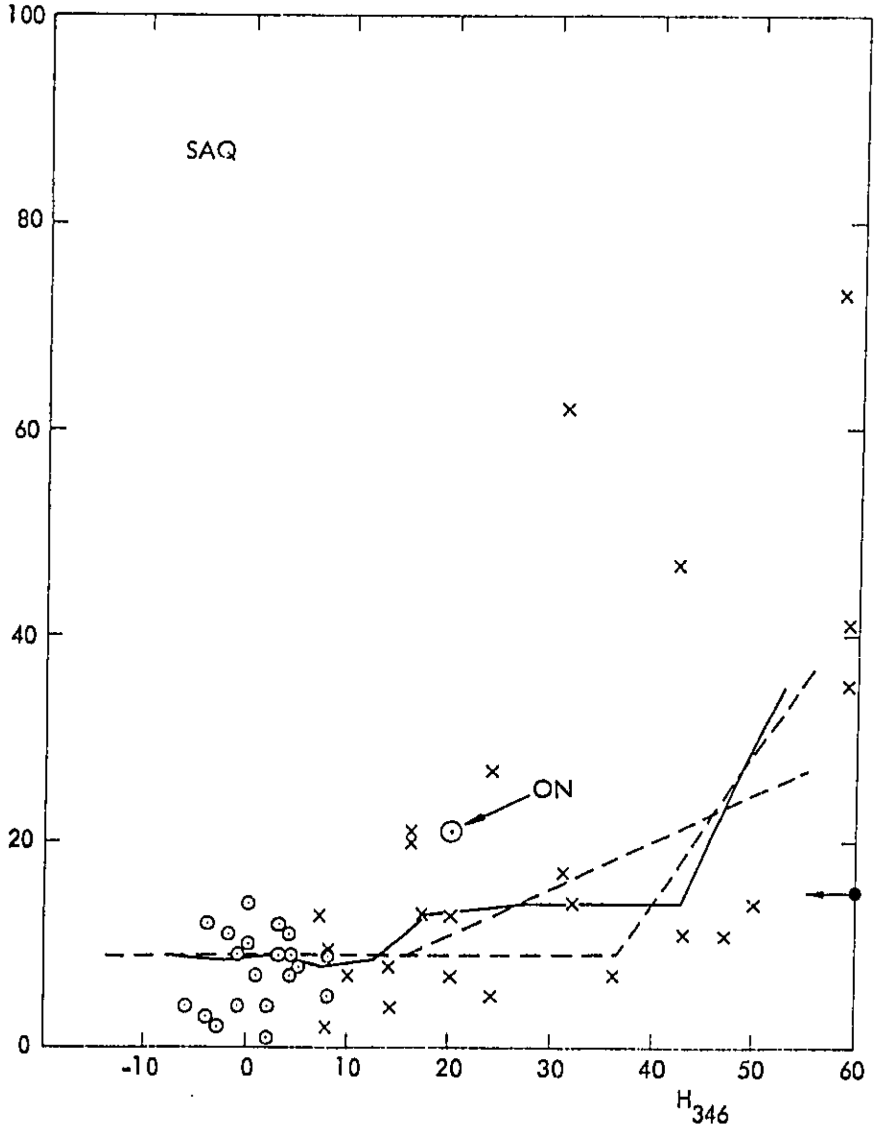

Figure 12: Percent phoneme error scores at SAQ (speech audiometry in quiet, average of three levels) against hearing threshold levels $H_{346}{}^{LR}$ (average of 3, 4, 6 kHz, both ears).

Key: see Figure 11.

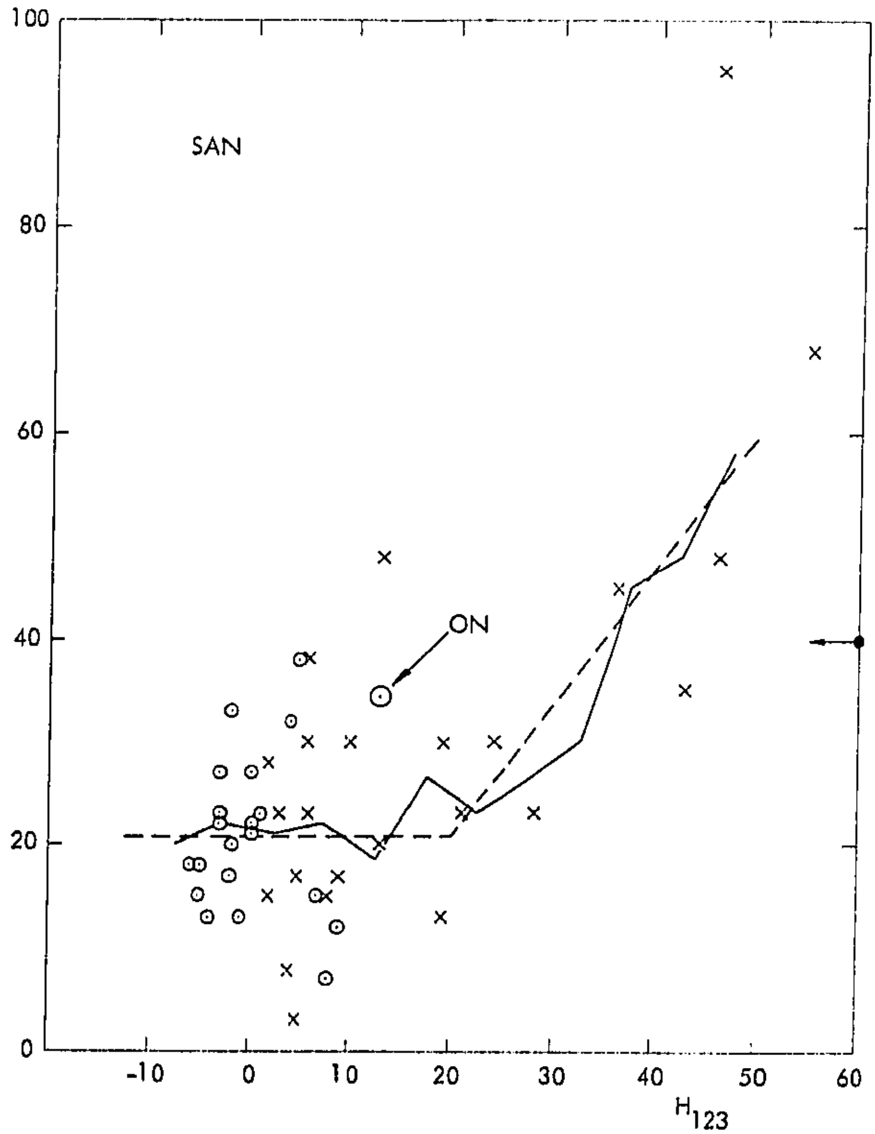

Figure 13: Percent phoneme error scores at SAN (speech audiometry at speech-to-noise ratio +2 dB) against hearing threshold levels H_{123}^{LR} (average of 1, 2, 3 kHz, both ears).

Key: see Figure 11.

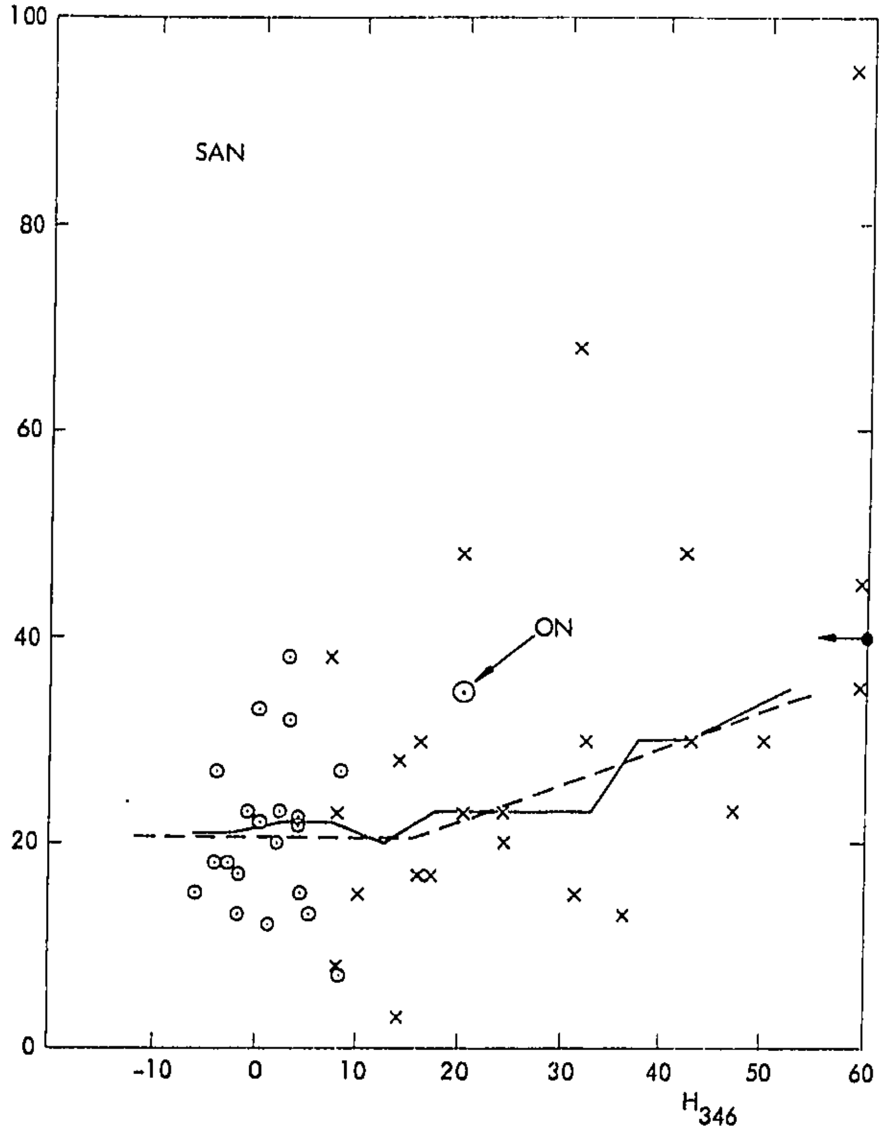

Figure 14: Percent phoneme error scores at SAN (speech audiometry at speech-to-noise ratio +2 dB) against hearing threshold levels H_{346}^{LR} (average of 3, 4, 6 kHz, both ears).

Key: see Figure 11.

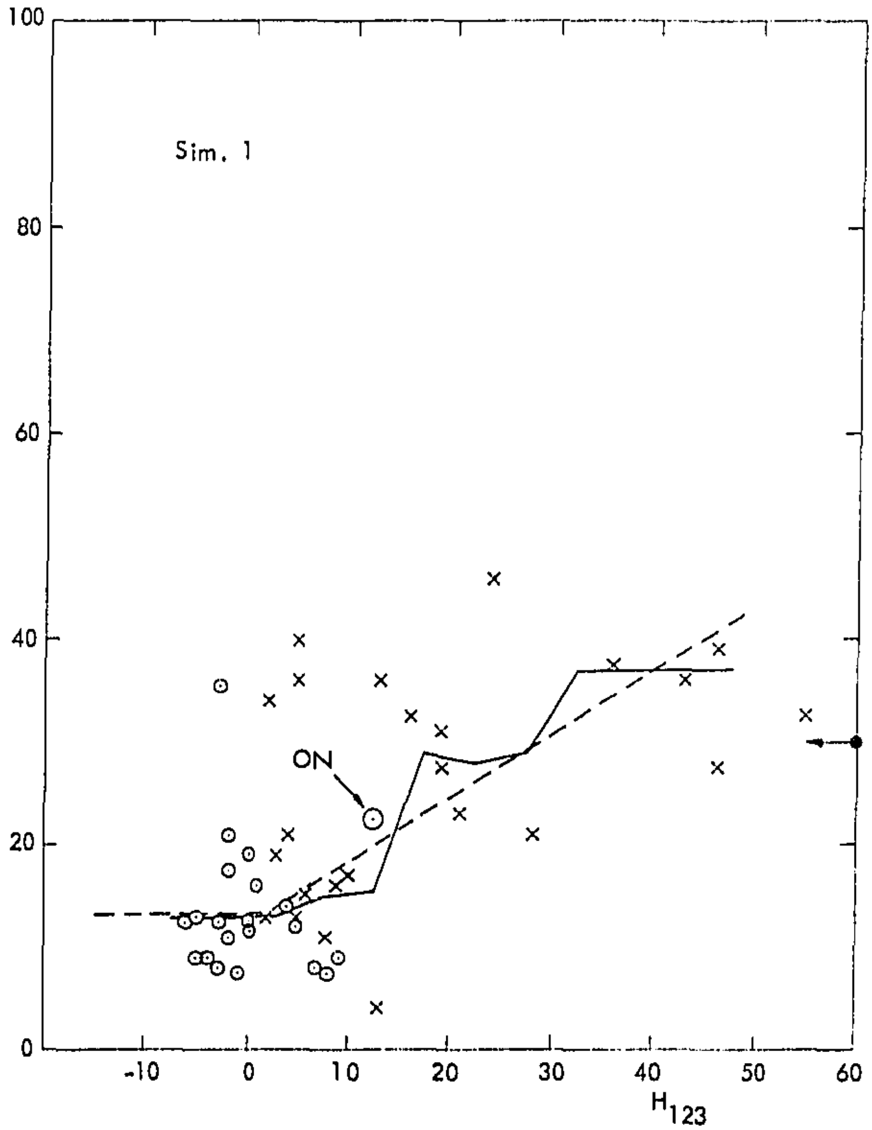

Figure 15: Percent item error scores at Simulation 1 (social gathering) against hearing threshold levels H_{123}^{LR} average of 1, 2, 3 kHz, both ears).

Key: see Figure 11.

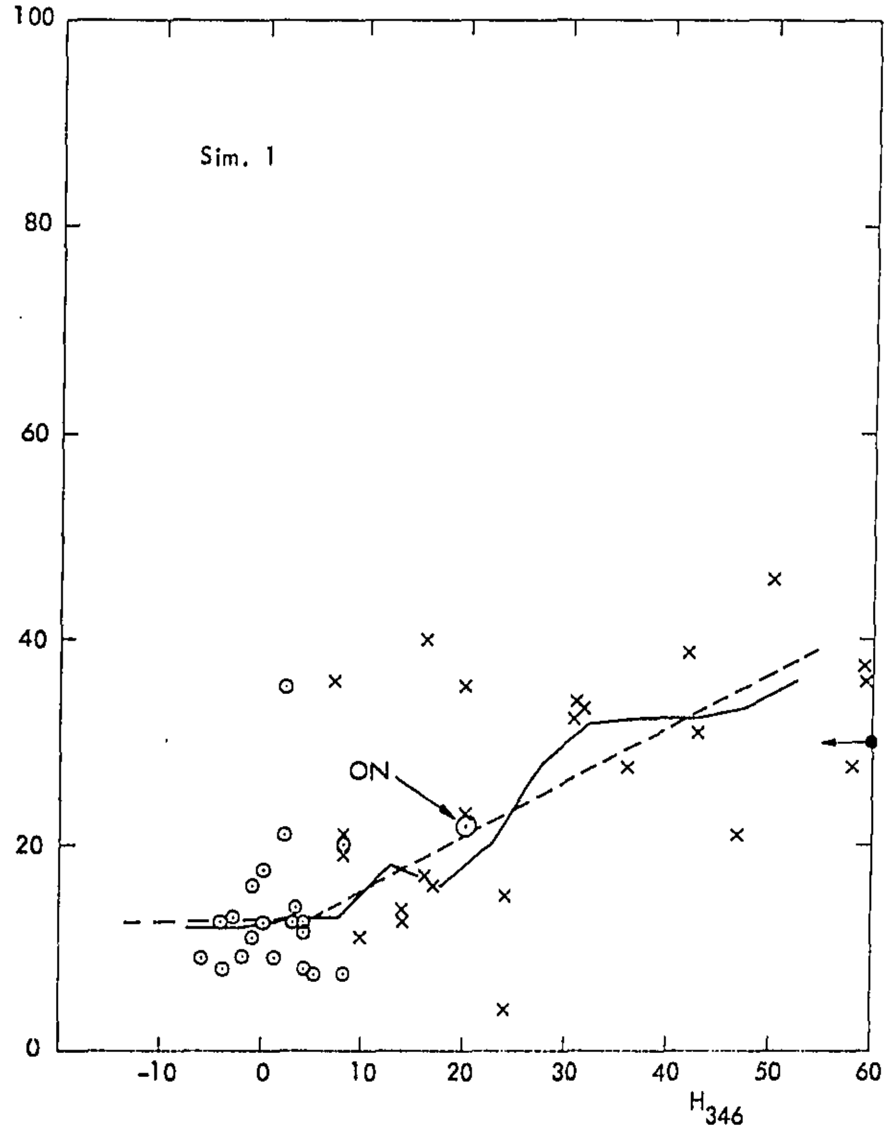

Figure 16: Percent item error scores at Simulation 1 (social gathering) against hearing threshold levels H_{346}^{LR} (average of 3, 4, 6 kHz, both ears).

Key: see Figure 11.

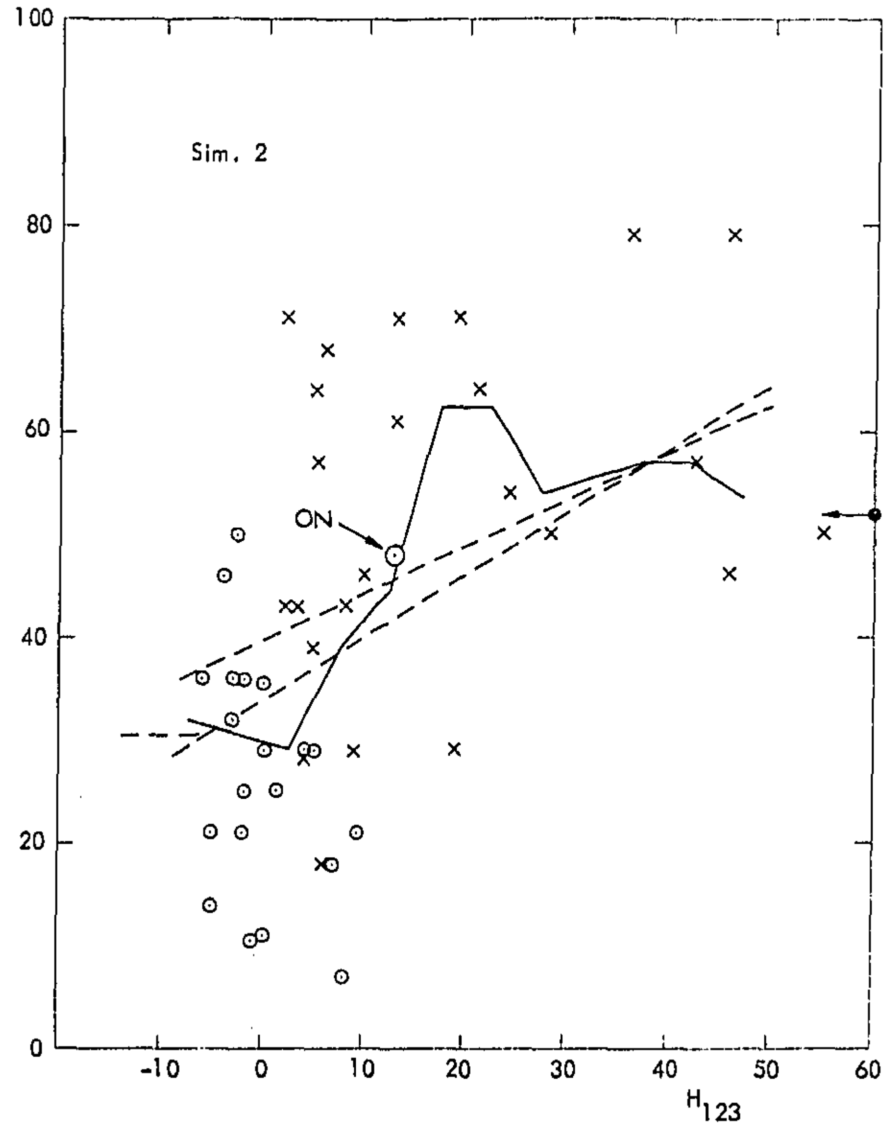

Figure 17: Percent message error scores at Simulation 2 (public address announcements in a concourse) against hearing threshold level H_{123}^{LR} (average of 1, 2, 3 kHz, both ears).

Key: see Figure 11.

Note: The straight line approximation in this case lacks, or shows only vestigially, a horizontal segment.

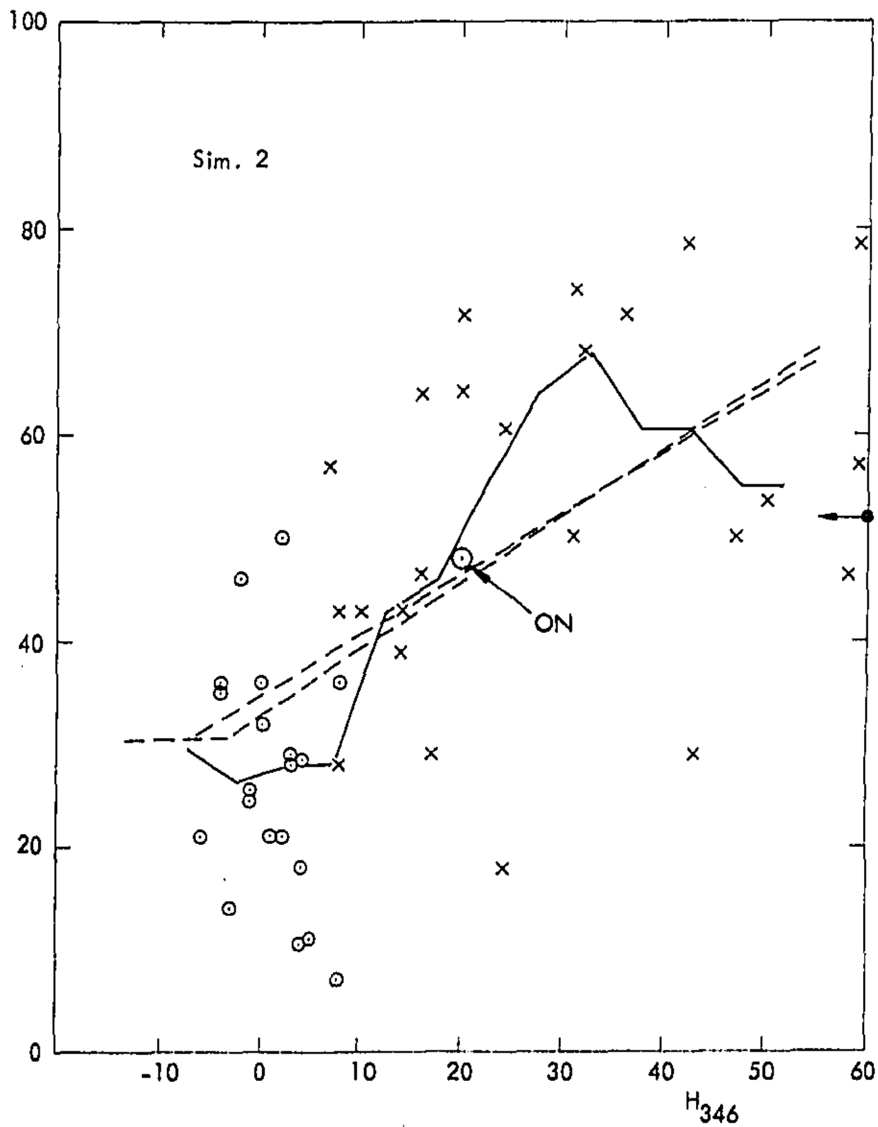

Figure 18: Percent message error scores at Simulation 2 (public address announcements in a concourse) against hearing threshold level H_{346}^{LR} (average of 3, 4, 6 kHz, both ears).

Key: see Figure 11.

See also Note to Figure 17.

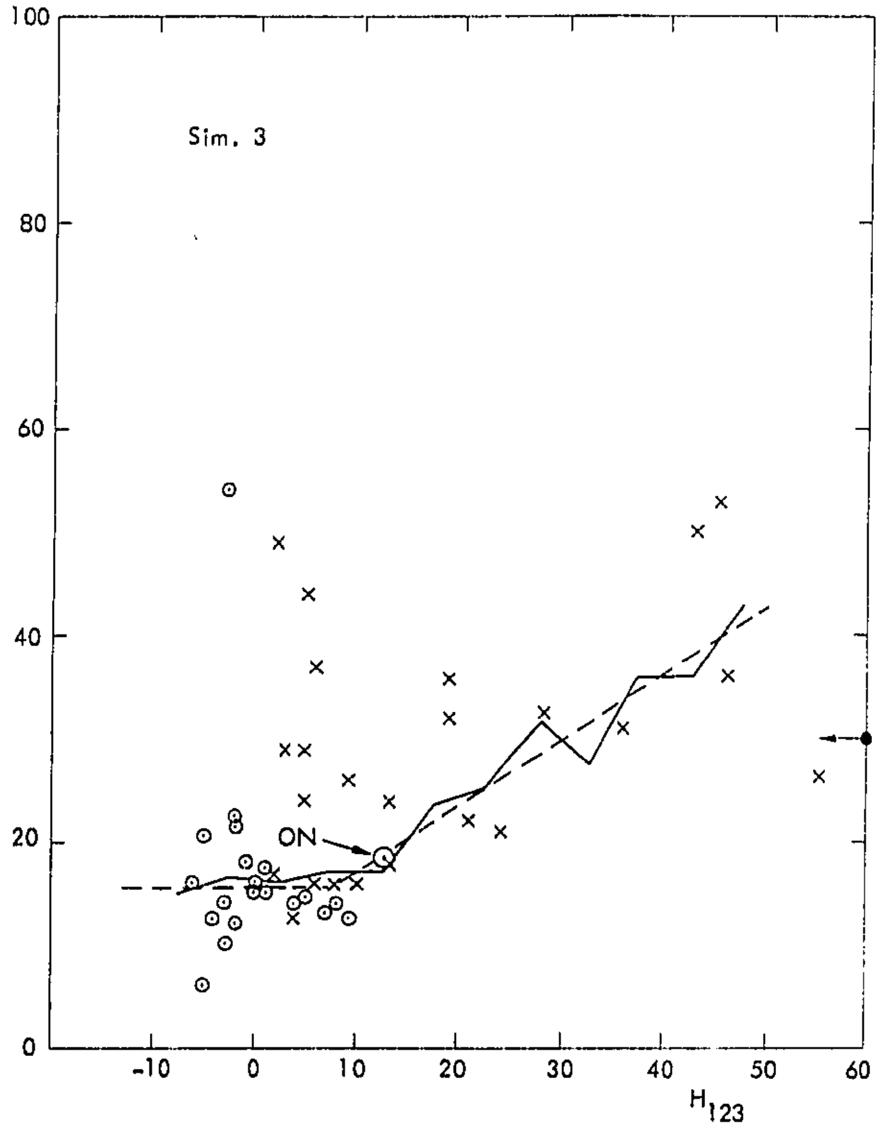

Figure 19: Percent item error scores at Simulation 3 (telephone listening in a noisy place) against hearing threshold levels H_{123}^{LR} (average of 1, 2, 3 kHz, both ears).

Key: see Figure 11.

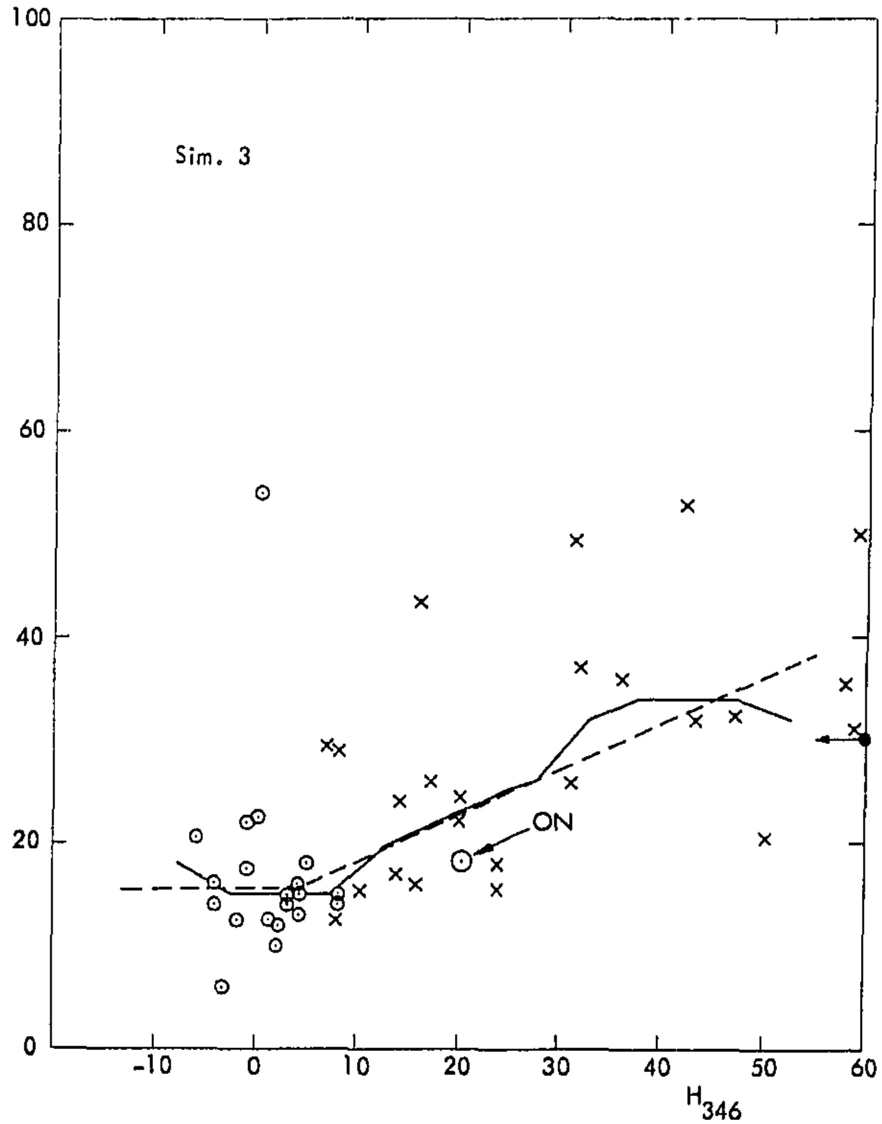

Figure 20: Percent item error scores at Simulation 3 (telephone listening in a noisy place) against hearing threshold levels $H_{346}{}^{LR}$ (average of 3, 4, 6 kHz, both ears)

Key: see Figure 11.

Fourthly, the slope of a relation derived from group data does not necessarily coincide with that for individuals as their hearing declines: individual slopes might well be steeper but originate from different knee points. The reduced slopes for the simulations compared to the speech audiometry is partly explained by the smaller correlation oefficents, but there is probably another contributory factor. This is described by HOOD and POOLE (1971) to explain why deaf subjects show less disability in understanding speech than would be expected from the audiogram:

> "... it can be presumed that in normal circumstances the redundant information in speech adds little to its intelligibility. To the deaf subject, however, matters are very different and as his deafness increases he is obliged to capitalize on whatever speech information comes his way. Consequently in the course of time he will learn to make use of minimal clues ..."

and hence make less errors than would a normal-hearing person suddenly arrived at this condition, or one for whom a reduction of the acoustic signal were substituted for the hearing loss.

The fifth point to note is that the threshold estimates of inability in terms of 1, 2, 3 kHz are fairly consistent. Bearing in mind the uncertainty of the value derivable from Simulation 2, the result might be stated as 31 ± 3 dB. The picture is less clear in terms of 3, 4, 6 kHz, but where the estimation is fairly well defined (SAQ, Sim. 1, Sim. 3) the value could be summarized as 38 ± 2 dB. This is quite consistent with the value of 31 dB at the lower frequencies. In fact a linear regression of $H_{346}{}^{LR}$ on $H_{123}{}^{LR}$ for the combined groups YN and NI (n = 44) yielded the relation:

$$H^{LR}_{346} = 1.05\, H^{LR}_{123} + 7.1 \text{ dB}$$

If the values were wholly consistent and independent of test situation it would happily dispose of the problem of weighting various inabilities, since the common value would uniquely identify the onset of disability. As it is, they are reasonably but not wholly consistent and independent*, and it is impossible on the present data to determine whether this is a consequence of measurement uncertainty or a reflection of intrinsic differences of inability threshold in the various situations. Certainly the latter are involved to some extent, as can be seen from the fact that the estimates would differ to a different extent if a percentile other than the 2nd had been selected (because the slopes are unequal).

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*Lest the apparently more 'permissible' value of 34 dB for SAN than the 29 dB for SAQ ($H_{123}{}^{LR}$) should appear paradoxical in face of the well-known fact that speech hearing in noise is more liable to erosion by sensorineural hearing loss than speech hearing in quiet, the actual values in Table 26 should be recalled. More errors were in fact committed in noise than in either of the quiet tests at speech levels of 45 and 70 dB, and almost the same number as at speech level 30 dB. The paradox results from the fact that the dispersion in SAN was considerably greater among the YN group than in SAQ. The SAQ results have been handled as an amalgam of the three speech-in-quiet conditions.

Specifically, the consistency would be diminished if one descended to the 10th percentile, and at the knee points (50th percentile) it would virtually evaporate. This, however, brings us to a very important point which requires a little digression.

If a task is fairly easy, both normal and mildly impaired persons may perform it without loss of performance - in which case there is no inability - or normals may perform without loss and the impaired persons with some loss of ability. If the task is sufficiently difficult, neither will perform it without loss of performance and both will exhibit inability but in different degrees. So will persons with higher levels of impairment. Hence disability cannot be inferred simply from inability, but only from the differential performance of the normal and the impaired. That is why we have defined a threshold by reference to normal limits. If instead we had identified it as the knee point (in effect, the point at which the slightest deviation from median normal performance is discernible - the conventional 'low fence') we would arrive at the awkward conclusion that the low fence for the simulated (difficult) listening situations is equal to (if not below!) the hearing threshold level of the young normal.

In the case of SAQ and SAN under our test conditions (and those of much previous work) this anomaly does not arise because the knee point happens to be well above zero hearing threshold level (that is, there is a reserve of hearing for these situations). However, it would arise for low speech levels in quiet or for sufficiently adverse speech-to-noise ratios. Shades of this are present, for example, in KRYTER's (1973) analysis, in which he differentiates between a low fence for "start of hearing impairment for speech at an 'everyday' level" and another, 10 dB lower, for "conversational speech in the quiet". The knee points, in our view, do not provide a logical foundation for a threshold of disability, since they occur at different levels depending on the listening circumstances. The function of a 'low fence' should be, not to distinguish between *circumstances*, but between *people*. That purpose appears to be better served on the principle of reference to the limits of normal performance. It would not be necessary to labour this distinction if the approach to finding the starting point of disability had not hitherto been equated to locating the 'foot of the curve'.

Since our definition of the starting point is at variance with established practice, it seems prudent to modify the terminology, and, instead of 'low fence' we shall refer to 'hearing disability threshold level' (HDTL) as a suitably explicit term. The HDTL, then, is a value or values distilled from those in Table 49 to represent the totality of the situations, and the numerical values to be assigned to it are provisionally 30 dB for H_{123}^{LR}, 38 dB for H_{346}^{LR}. A question remaining is whether one should insert an 'and' or an 'or' between these two datum statements (recalling that, although highly correlated at $r = 0.84$, these two quantities are not absolutely predictive of one another).

What are the consequences of this proposed re-definition of the disability onset point? In terms of the facts of hearing, nothing is changed: a comparison of our speech test results with those in the literature shows them to be quite concordant. The main consequence is to remove some of the arbitrariness that attaches to traditional 'low fences', and thereby to reconcile conflicting opinions about numerical values which are found in the numerous writings on this topic, for example DAVIS (1973) commenting on Kryter's paper cited above.

A comprehensive account of the history of the low fence and the vicissitudes of its evolution is to be found in SUTER (1978). Some, at least, of the variety of formulae and values proposed has arisen from confusion of aims between clinical hearing assessment (in the individual compensation context) and the setting of noise limits via statistical predictions of hearing loss. This point has been caustically commented upon by WARD (1983), but such divergences can be resolved (see Chapter 7.5). Suter, however, also considers the more fundamental question of how to define the starting point of disability (she uses the term 'handicap' but clearly with the same meaning since her argument centres on performance at speech tests). After presenting a detailed analysis of the experimental results of her own study (see Chapter 3.6), she is driven to write: "The results of the (present) investigation have not resolved the question of the location of the point of beginning handicap, or the 'low fence'", the essence of the difficulty being that there is no clearly definable cut-off - "the fence cannot be viewed as a magical turning point". In the peroration she writes:

> "Basically, the selection of a fence is a social issue. It rests on the question of how much speech communication ability is needed in order to conduct the activities of daily living in a satisfactory manner. The answer will undoubtedly be influenced by such variables as an individual's age, occupation, lifestyle and personal preference. Field rather than laboratory research will probably be needed in order to solve the problem, but research in this area has been inconclusive to date. Until more information is forthcoming, the decision on an appropriate fence will necessarily be somewhat arbitrary."

The same word 'arbitrary' is used by Ward (*loc. cit.*) in his summing up.

A hint of the way forward was, however, adumbrated by Suter:

> "One way to approach the problem of an appropriate fence would be to find the hearing level at which hearing-impaired subjects begin to perform differently from their normal-hearing controls."

and it was from this standpoint, albeit in a rather tentative way, that the figure of 19 dB H_{123} emerged from her study. This approach accords with ours but the difficulty is not finally dispelled until 'begin to perform differently' is translated into specific terms. This is what we have attempted in the present study.

Throughout this chapter the assumption is made that hearing ability can be more or less faithfully related to hearing threshold levels. There is no reason in principle, however, why a low fence should not be stated in other or supplementary ways. At the outset of this investigation it was envisaged that a measure related to frequency or temporal resolution might play such a part. If adequately sensitive and relevant tests of these functions were administered this might be feasible but it has to be admitted that this has not proved to be the case in the present study. Although superficially a higher correlation could be found using a combination of impairment measures (Table 43) than with hearing threshold level alone, this finding turned out to be a spurious side-effect of interdependence between the variables, confounded by non-linearity of the relations between them: interpreted literally these results implied that the worse the audiological impairment on the supplementary measure (CR-1 or TI-2) the better the performance (at constant HTL - but this is not a realistic condition). We contemplated undertaking a principal-components analysis to explore the possibility of identifying orthogonal dimensions to explain the data. We decided, however, that this endeavour would be unrewarding so far as a practical outcome is concerned.

7.5 *Relation to noise limits*

Although, as mentioned above, this question has often arisen in discussion of the low fence, the two matters should be clearly separated. Determination of a low fence is a necessary step, but in itself it cannot provide a unique answer to setting occupational noise limits, even if it were granted that the relation between noise exposure and hearing threshold level were precisely known. The missing 'ingredient' is the percent of population at risk, that is, liable to exceed the low fence. Determination of this percentage has nothing to do with the percentages used in connection with defining the HDTL: it is purely a political decision, and percentage is in effect an independent variable to be inserted into the equations.

It follows that substitution of a conventional low fence by an alternative measure, such as the HDTL advocated here, with a larger number of decibels attached to it, does not automatically imply any corresponding relaxation of noise limits - it simply changes (downwards) the percentage of exposed population that would be protected from exceeding the level in question. Clearly, there will be more people above the 'foot of the curve' (for whichever 'activity' one selects) than above the corresponding inability threshold which is some way up the curve - but the amount of disability in a given exposed population is in no way changed by redefining the threshold.

In reality the situation is not quite as simple as just described, however, because low fence, as we have seen, depends on a somewhat arbitrary, but hotly debated, criterion of disability. We suggest the following advantages of introducing the fence defined by HDTL:

1. It provides a concrete definition for start of disability.

2. The same numerical value appears to be applicable, within reasonably narrow limits, to represent the start of disability in different situations, background noises, etc.

3. It is simpler to define persons whose hearing deteriorates outside the limits of normal than persons who have 'slight', 'mild', 'minimal' or other adjectival degrees of difficulty with 'faint', 'conversational', 'everyday' or other adjectival categories of speech hearing.

We shall not enter into the question here of what constitutes a tolerable exceedence rate for hearing conservation purposes, save to comment on one aspect of this. The HDTL values of 30/38 dB adduced in Chapter 7.4 represent our best estimate of the joint inability threshold for several situations, and hence the disability threshold, referred to a young normal baseline. If we were to take the further step of defining an age related abnormality threshold (Figure 9) progressively higher HDTL values would be set for older populations. In the context of hearing conservation we have not taken this step, nor do we advocate it. In the first place we have far from sufficient data to deduce such a relationship (but a glance at the distributions of error scores in our otologically normal 58 year old group ON suggests that age would be a strong factor). There is a more cogent reason, however. This is the fact that the threshold shift due to noise exposure rises much faster in the early years of exposure than subsequently. Protection by noise limitation must therefore be primarily targetted on the young exposed population to ensure that the HDTL is not surpassed (by more than the politically determined percentage) during the years before the presbyacusic erosion of hearing catches up and overtakes in importance that of further noise exposure.

7.6 *Relation to other criteria*

On the hearing conservation side the pertinent base document in UK is British Standard 5330. This document makes no political judgement but rests on two value judgements plus a body of scientific knowledge about noise exposure *vs* threshold shift. The value judgements are these:

1. The risk of given noise exposure causing specified amounts of threshold shift is worked out in terms of a population assumed to be free from hearing deficits other than those related to age and noise exposure.

2. The low fence above which 'handicap' is deemed to exist is given as 30 dB H_{123}.

The first of these is under current consideration with a view to possible re-formulation. This would have an impact on the 'risk' values, but is not directly related to the subject of the present report and need not be discussed further here. The second, however, merits appraisal in the light of the present findings: it, too, determines the numerical values of 'risk' tabulated in the document.

It is relevant to recall the origin of the value 30 dB. It was arrived at from a starting point of the AAOO low fence of 25 dB $H_{0.512}$. BURNS *et al* (1977) presented data from a homogeneous population of noise-exposed steelworkers showing that, audiometrically, this was equivalent to 34 dB H_{123} (a conversion factor which could equally have been taken from the results of an earlier study, BURNS and ROBINSON, 1970). The change of frequencies was agreed upon in the light of mounting evidence (*circa* 1975) of the greater relevance of 3 kHz as compared with 0.5 kHz in the perception of speech in sensorineural hearing loss. Deliberations in committee caused the figure to be rounded down to 30 dB. The arguments for this adjustment are not documented but it can be attributed most aptly to the 'spirit of the times' and general advancement in the field of occupational hygiene. (This, in retrospect, was not a logical step: the existence or otherwise of a handicap is not related -- or only very indirectly related -- to standards of industrial welfare: an adjustment on those grounds belongs to the political arena).

It is little short of remarkable coincidence that the value of 30 dB is the same as the HDTL arrived at in this report, but one could say that BS 5330 would be consistent with the present findings if the words "handicap is deemed to exist" were simply replaced by "capability for speech reception is inferior to the limits of normal hearing".

The corollary of this is that our HDTL lies some 4 dB below the original AAOO low fence, alternatively that the latter is some 4 dB above the limit of young normal hearing. This relativity appears quite reasonable in the light of DAVIS's (1971) retrospective verbalization of the AAOO criterion:

> "The criterion ..... was the ability to understand everyday speech *adequately* (our emphasis). This does not mean monosyllables in the audiometric discrimination test, nor does it mean nonsense syllables in the psychoacoustic laboratory; the concept is everyday speech 'as she is spoke', and this implies the value of contextual cues and also the careless way that people speak. There is a great deal of redundancy if we are talking about everyday speech and not about the unexpected message, the unfamiliar proper name or the important telephone number."

"Adequate" clearly does not mean "excellent" or "perfectly normal". In fact, in another place DAVIS (1973) states that the AAOO rule

> "was anchored to the average hearing threshold level at which patients first *complain* of their handicap to a doctor rather than to the threshold level at which they first *notice* difficulty with faint speech, in church, and so on".

It is reasonable to suppose that people notice the difference when they reach a point beyond any of their normal-hearing peers (effectively our HDTL), but it is a matter for conjecture whether another 4 dB is enough to trigger complaints at the doctor's.

These comparisons should not be read to imply that we take any particular position on the rights or wrongs of such criteria for the furtherance of hearing conservation. We put forward the HDTL only as a benchmark because of its definitional properties, not necessarily as an action level.

On the hearing assessment side, the relevant documents in UK are those issued by the Department of Health and Social Security on statutory compensation for occupational hearing loss, and the publication issued by the British Association of Otolaryngologists (Anon., 1983) with a view to guidance in legal actions.

The DHSS scheme is based on the value of H_{123} with a notional low fence of 40 dB (although monetary compensation is not attracted below 50 dB, this point being considered as 20% disablement). The scientific provenance of the 40 dB baseline is obscure and the following are quotations from the White Paper Cmnd 5461 (Department of Health and Social Security, 1973) which preceded the introduction of the scheme:

"The [baseline] is the level at which a loss of faculty can be considered to occur, that is the point in the gradual development of deafness at which the loss of hearing results in disablement of at least one per cent." (It is not clear what 1% disablement means.)

"... [the baseline] represents a somewhat higher level of hearing loss than the level adopted in some overseas schemes and for other purposes, for example by the AAOO.... . In our [Industrial Injuries Advisory Council's] view a higher level is justified because it reduces the importance of the problem of temporary threshold shift."

We do not find in this much enlightenment on the true nature and level of the onset of disability.

The guidance document of the British Association of Otolaryngologists, apparently under the influence of Suter's findings, bases itself on H_{124} and identifies 20 dB as the starting point of disability, which equates to about 17 dB H_{123} for Suter's subjects or to 15.3 dB H_{123} for our group NI. If our SAN results are taken as the nearest equivalent to Suter's speech-in-noise data, there is no serious discrepancy with the 20 dB knee point read off Figure 13. However, such comparisons bring us back into the territory of ill-defined and condition-dependent 'cut-offs'.

7.7 *Onset of handicap*

Criticism has been levelled at some investigators' questionnaires, for example the Hearing Handicap Scale of HIGH *et al* (1964), on the grounds that they are heavily weighted towards 'sensitivity' questions, the result being a high correlation between scale score and hearing threshold level. The expectation of high correlation, in these circumstances, is a self-fulfilling prophecy, and there is a valid objection that 'handicap' as such is not tested.

However, similar highly significant correlation with hearing threshold level seems to be a common thread running through other self-report questionnaires, even in the case of the Hearing Measurement Scale developed by NOBLE (1978). This was deliberately structured to include several aspects of hearing handicap seemingly remote from simple auditory sensitivity. Noble found, not unexpectedly, a high correlation on Section I of his questionnaire, but more remarkable is the finding that the correlation was very little diluted (significance levels being unchanged) by including all seven Sections. Even those interrogating "Emotional response" and "Personal opinion" exhibited significant correlations with hearing threshold level at the higher frequencies.

Another common thread is that the correlation coefficients (values in the literature are typically in the range 0.35 to 0.65) are very similar between questionnaire score and either hearing threshold level or measures of speech hearing performance, in some cases being larger in the former case. This is not the situation that one would expect on the conceptual model that impairment generates loss of speech hearing which in turn engenders the state of handicap. Nevertheless our own results are also in the same genre as others.

Reference to Table 41 shows only modest correlation coefficients between test performance (p) and total questionnaire score (s) in the range 0.38–0.53 for the combined YN and NI groups, with similar values (0.35–0.55) for the sub-section of 'disability' questions (d) and substantially less (0.25–0.48) for the sub-section of 'handicap' questions (h). Against this, the correlation coefficients between questionnaire scores and hearing threshold level are larger in every case but one (see Table 50). Whatever the explanation of this may be, it permits treating at least a portion of the questionnaire results in the same manner as described in Chapter 7.4 with a view to determining an onset level of handicap in equivalent audiometric terms.

Table 50: Correlation coefficients for combined group YN + NI (n = 44) between self-assessments and hearing threshold level (left/right ear average) (×100)

	H_{123}	H_{346}	Best of the 5 p-correlations (Table 41)
Questionnaire Section I (Hearing in general)			
d_{22}	61	67	55
h_{23}	62	59	48
s_{24}	64	65	53
Questionnaire Section II (Hearing in particular situations)			
d_{25}	62	59	49
h_{26}	34	34	39
s_{27}	61	58	51

Since our concern in this chapter is with handicap, the relevant measures from the questionnaires are h_{23} and h_{26} and, as has already been seen, the latter proved to be insensitive for distinguishing normal from noise-impaired subjects. The handicap scores from Section I of the questionnaire are plotted against H_{123} in Figure 21, the frequency combination yielding the larger correlation coefficient (0.62), and against H_{346} in Figure 22. The data treatment and annotation of the diagrams are the same as for Figures 11–20.

The figures clearly show the anomalously low self-assessed handicap of the older normal group ON, whilst for the other groups there is apparently a uniform progression starting from the level of normal hearing. The intersection of the trend lines (broken) with the 2nd percentile score of the YN group occurs at the value 9 dB H_{123} (which is itself approximately the 2nd percentile hearing threshold level for this group), and 19 dB H_{346} respectively.

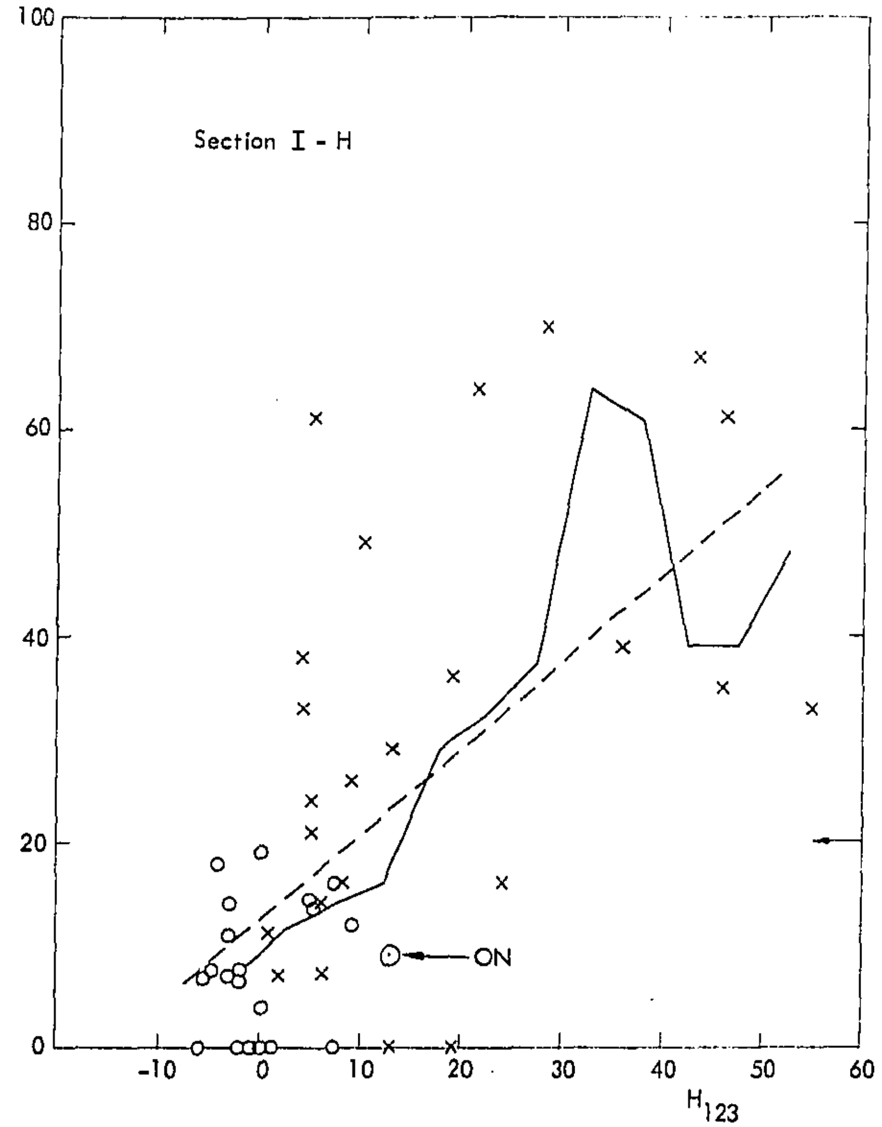

Figure 21: Scale scores (as percent of maximum possible) on Questionnaire Section I, 'handicap' questions, against hearing threshold levels $H_{123}^{L,R}$ (average of 1, 2, 3 kHz, both ears).

Key: o Group YN; x Group NI (individual values)
Group ON (median values)

Line connecting moving medians
Straight-line approximation

The arrow at right indicates the 2nd percentile scale score for Group YN.

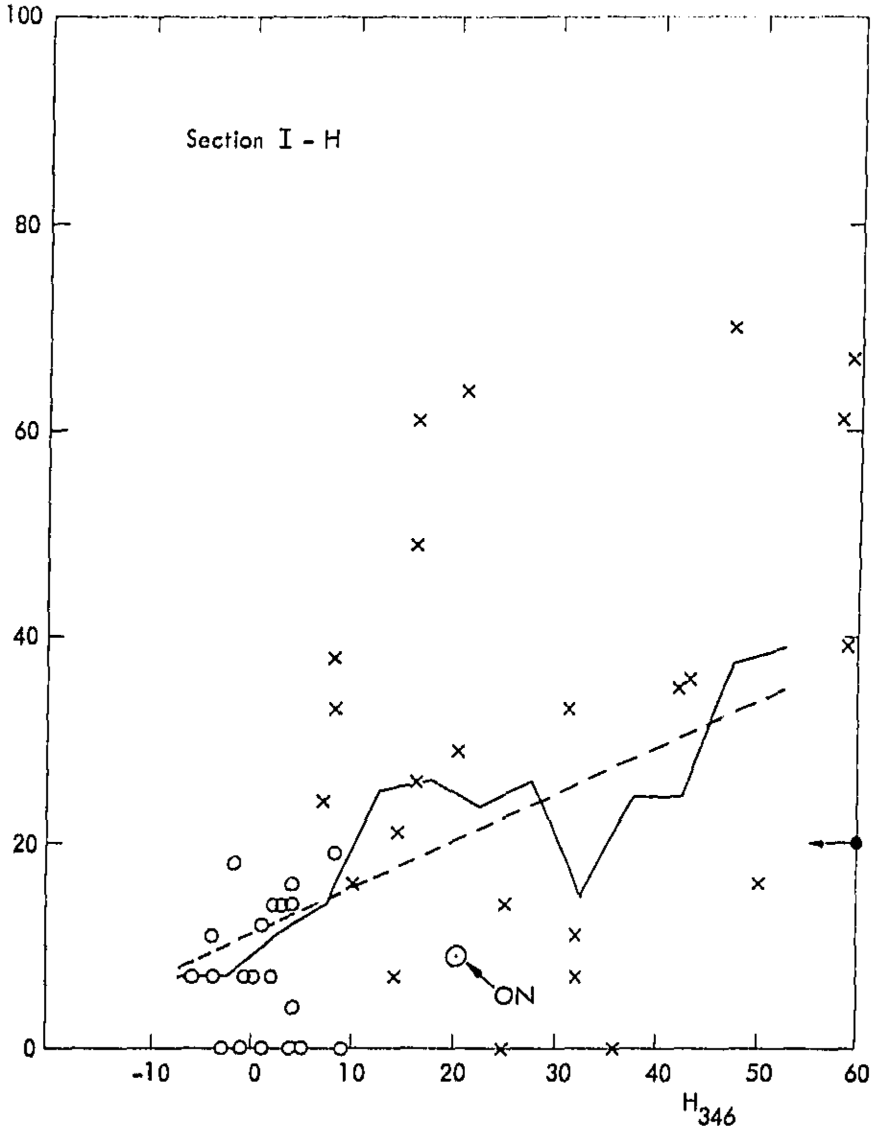

Figure 22: Scale scores (as percent of maximum possible) on Questionnaire Section I, 'handicap' questions, against hearing threshold levels H_{346}^{LR} (average of 3, 4, 6 kHz, both ears).

Key: see Figure 21.

Whilst it may be imprudent to read too much into the particular numerical values emerging from the diagrams in view of their being based on only one set of responses, there is a clear difference from the cases of test performance *vs* hearing threshold level shown in Figures 11-20 which all equate the limits of normal performance to considerably higher values of hearing threshold level. The four subjects in group NI with values of $H_{1.23}$ within normal limits ($\leq$ 10 dB) but rather large handicap scores (33-61%) were all within normal limits (some better than normal) on the measures CR-1, TI-2 and FS-2, so that explanations on the grounds of audiological impairment appear to be irrelevant. All but one of these four also gave better than average performance scores on the five listening tests; the other (subject 114) gave average or above-average scores (see Tables 23-26).

On the basis of Figure 21 we should conclude that there is no threshold for handicap - any deviation from normal threshold of hearing, no matter how little, evokes a response under self-assessment. This observation is reminiscent of the statement by MERLUZZI and HINCHCLIFFE (1973), made in reference to the effect of age:

> "Although a 'low fence' of 26 dB HL (ISO) would be applicable to a 70-year-old man, this value would be too high for younger people. For a 60-year-old person, a value of 18 dB HL (ISO) would be more appropriate, and for a 45-year-old person it would be less than 10 dB HL (ISO). Extrapolation of the curve to zero age gives a value of 1.4 dB HL (ISO) for the 'low fence'... It can be argued that *even a man with a 3 dB hearing loss* is receiving sound at an intensity half of what would normally be the case so that he *is already handicapped.*" (our emphasis).

7.8 *Concluding remarks*

The data obtained from the investigation can be considered in two different lights, either as revealing something about the responses of individuals or as yielding information of potential value in the area of hearing conservation where idiosyncratic responses must necessarily be submerged in pursuit of broader trends.

At the individual level the results are only useful in proportion to their absolute reliability, since random errors exert their full effect. In this respect the investigation proved to be reasonably successful. In an ideal experimental protocol, replication or replications would permit formal uncertainty auditing; in the given conditions the assertion is circumstantial. As regards the audiological measurements, the comparison of left and right ear measures (Table 35) is relevant (as well as the 'buried' replication of threshold measurements at 4 kHz); also the close correspondence of the YN and ON groups to established distribution patterns and magnitudes of hearing threshold level (Figure 8). The left/right similarity test fails, however, in respect of the TI and OF measures but any want of reliability here may be due in part to the rather abbreviated forms in which they were tested as much as to the performance of the test subjects. The high correlations between SAQ and hearing threshold level (given that only two arbitrary combinations of frequency, not necessarily the optimum, were used to characterize the latter), and between SAQ and SAN scores, suggest satisfactory reliability at the speech tests (Tables 38, 39). Similarly, high inter-section correlations between the parts of the questionnaires (especially Section I, Table 40) lend credibility to the consistency of the subjects' attempts at self-assessment.

When, therefore, one turns to the comparison of individuals' responses to the three component elements (*D*, *I* and *H*) of the investigation, as in Figures 11–22, and finds a very wide range of *relative* responses on these components, there can be no doubt that these are real. These diagrams show widely scattered results on performance (on all but the simplest listening test, SAQ), as well as on self-assessment. What is more, within the three simulations, some listeners seemed to be able to 'tune in' to one (or two) and fail at the other two (or one) (compare Tables 24, 25 and 26); also there were those who could perform well against a self-assessment of hearing difficulty, and vice versa. Two conclusions may be drawn:

(1) An individual assessment of hearing disability is to be viewed as something quite distinct from an assessment of perceived handicap. This can also be phrased the other way round: self-assessment is no guide to the actual hearing ability of an individual. There is no reason to doubt the self-assessment results on the grounds of internal inconsistency and no obvious reason from the point of view of motivation in the neutral conditions of these tests. These results do appear to warrant reservations about the value of self-assessment. However, these reservations are not about the procedure as such, for which a case can certainly be maintained in applications such as the medical management of individual cases, but only where it is offered as a surrogate for the actual testing of performance. There also appear to be important legal implications in the want of correspondence between self-report and test performance, but to pursue this aspect is out of place here.

(2) Where the object is to test individual disability, it is misleading to do this on the basis of speech audiometry alone (whether in quiet or otherwise). Nothing is clearer from our results than the fact that performance at either or both of these tests is no guide to reception of messages in more realistic situations. Moreover, performance in one such situation is no guide to performance in another. We have found this to be the case even within a very limited repertory of situations with the common elements of passive listening and speech material. It is hardly likely to be less true in the wider field of communication generally. Where this leads us as regards practical recommendations it is hard to say. The implementation of a quasi-realistic situation in controlled conditions, and any attempt at the standardization of such conditions, presents great difficulties, and a plurality of such situations is necessary to further complicate the matter. In this context, the role of extra-auditory input is also relevant. Our attempt to compare purely auditory and audio-visual performance, in simulations 3 and 1 respectively, failed to show much difference on the average (though not individually, some being better at one task than the other and vice versa). Acquired lip-reading skill will almost certainly not have been present in our subjects due to the small or moderate hearing losses involved, but some innate ability at lip-reading might have been expected to reduce the average error rate at simulation 1. This faculty may have been insufficiently exercised in the conditions of experiment due to pre-occupation with writing down the answers rather than watching the television screen as instructed.

Turning to the interpretation of the results on a 'population' basis, rather different considerations are involved. Firstly, there is the question of sampling. Our test groups were rather small in numbers and of differing sex ratios. Further, it was not practicable to consider demographic or socio-economic variables. In this respect the groups YN and ON were probably more nearly matched than NI, and in any case it is not clear how one could find control subjects matched to NI in all relevant respects except for noise exposure. The data must be understood with these reservations. However, there are some positive aspects. Firstly, the normal group YN appears to have been large enough to declare it audiologically typical. The same is true of group ON, small though the numbers are. All three groups expressed closely comparable experience of the situations interrogated in Section II of the questionnaire. No subject in any group failed at any of the tests and no difficulties were encountered in administering them or in deciphering the responses. All subjects were literate. There are no anomalies of the kind that group NI scored better than YN on any test (although there are large overlaps at the individual level). There was, however, likely to have been some difference in self-perception between groups ON and YN. The former was composed of persons who had no reason, except their age, to suppose that their hearing might be on the way to becoming impaired; NI subjects, on the other hand, were no doubt aware of this possibility in view of their noise history and because this was our reason for inviting them to hearing tests. A possible element of self-selection cannot be discounted in the latter case, and if this operated it would more likely have affected self-assessment than the other tests, in the direction of larger scores. It would seem unlikely to affect the deduced relations between performance and hearing threshold levels. *En passant* it is worth mentioning that the quality of audiometric performance as judged by excursion width and steadiness of the self-recorded traces was, though variable from person to person, not noticeably dissimilar between groups.

To sum up, we are reasonably confident of the estimates of HDTL (Table 49), but less sure about the audiometric equivalent of the handicap threshold (Figures 21, 22). The self-assessment of the ON group compared to that of the NI group is perhaps the least secure of the findings as regards magnitude, but it accords with the findings of others qualitatively. The highly variable and unpredictable performance of individuals, as well as their self-assessments, is such as to suggest that increasing the numbers would have made little difference to the results: correlation coefficients would become more significant but would probably remain numerically about where they are.

The analysis has focussed on the limit of normal response as the 2nd percentile (just over 2 standard deviations for a Gaussian distribution). The numerical results are determined by these criteria, and comparisons with other investigations are correspondingly sensitive to them. More extreme fractiles (apart from being impossible to determine without violent extrapolation) may be stretching the term 'normal limits' beyond reasonable bounds. On the other hand, a criterion such as the 10th percentile seems to err too far in the other direction, for an occurrence rate of 1 in 10 can hardly be said to be rare enough to neglect. We are therefore satisfied with the 2nd percentile as a reasonable limit, and its estimation for the various measures entailed only slight extrapolation of the data.

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APPENDIX A

TEST MATERIAL FOR SIMULATION OF A SOCIAL GATHERING

A.1 Text of introduction to the video tape

"The idea of this test is to see how well you can hear and write down somebody's name, address and telephone number under difficult listening conditions.

Each of the numbered entries will be presented as four separate items: the person's name, their address, the town and their telephone number. After each item has been spoken there will be a pause to allow you to write down on the form provided what you think was said. If you are unsure of the spelling of any of the names, spell the word the way it sounded to you. Always make some attempt to write down what you think was said, even if you are not confident or could not understand the whole word.

The numbers [superimposed] on the screen correspond to the item numbers on the form, so you can always find where to write your answer.

Each time an item is being spoken make sure that you look at the speaker's face, as this will help you to understand what is being said. To let you know when to look up at the TV screen, as shown on the form each of the items is preceded by an appropriate introductory phrase:

The next name is/and the address/The town is/and the 'phone number. So each entry will look and sound something like this:

The name is	J. Citizen
and the address	26 Chapel Road
The town is	Eastland
and the 'phone number	903 8711

In fact it will be more difficult for you to hear what is being said because we are going to introduce various noises into the room. To give you some practice under these conditions in a moment I will read two examples during which you should write down whatever you think was said. But first, do you have any questions? If so, please ask them now.

[Demonstration of 2 examples in noise.]

You probably didn't catch everything that was said. Don't worry about that - it is the purpose of the test to make it fairly hard for you. Here are two examples again, this time with sub-titles to indicate the correct words.

[Demonstration of the same 2 examples with sub-titles superimposed on picture.]

That is the end of the practice session. If you have any questions, please ask them now.

The test will start in a few seconds and you will see different speakers on the screen. Please get ready to start writing and remember to watch the screen each time the person is speaking. OK then, here goes."

A.2 *Speech material*

Practice items:

A	C. Hilton	15 Briarmere Walk	Chadderton	652 6597
B	A. Radford	35 Princess Road	Oldbury	429 8148

Test items:

Speaker JB

1	S. Moss	5 Humphrey Park	Urmston	865 5946
2	G. Day	53 Sansome Road	Shirley	744 8434
3	D. Rhodes	36 Leam Crescent	Solihull	743 0313
4	S. Godley	24 Ennerdale Avenue	Stanmore	907 9929
5	K. Bass	40 Haddon Grove	Sidcup	300 9920

Speaker MS

6	A. Richards	91 Ashtree Road	Tividale	552 6887
7	R. Tompkins	106 Overbury Avenue	Beckenham	658 1445
8	F. Barton	28 The Drive	Esher	398 1760
9	E. Waple	158 Wanstead Lane	Cranbrook	544 5869
10	J. Garrish	16 Hammer Road	Westvale	546 9787

Speaker KH

11	A. Stevens	70 Hall Lane	Ockerhill	556 3069
12	F. Murnane	69 Beacon Road	Sutton Coldfield	354 6890
13	T. Hussey	59 High Park Sail	Erskine	812 6050
14	R. Tough	123 First Avenue	East Molesey	941 1567
15	B. Cocking	48 Orchard Avenue	Bedfont	751 1048

Speaker DR

16	W. Wynn	30 Poulson Drive	Bootle	928 5134
17	A. Bickford	25 Hay Lane	Monkspath	745 5863
18	E. Willett	9 Redwood Estate	Cranford	897 1463
19	L. Nathan	39 Boreham Holt	Elstree	953 4232
20	R. Butterworth	12 Belmont Avenue	Springhead	652 1837

Pronunciation of telephone numbers:

556 3069	five five-six	three-oh six-nine
544 5869	five double-four	five-eight six-nine
300 9920	three double-oh	double-nine two-oh
658 1445	six five-eight	one-four four-five
etc.		

A.3 *Response form*

The form as presented to subjects is reproduced on the next page.

UNIVERSITY OF SOUTHAMPTON - INVESTIGATION OF HEARING HANDICAP

LISTENING IN SOCIAL SITUATIONS

NAME:______________________________ DATE:______________

	THE NAME IS	AND THE ADDRESS	THE TOWN IS	AND THE 'PHONE NUMBER
EXAMPLE:	J. CITIZEN	26 CHALET RD	EASTLAND	903 8711
PRACTICE	(PLEASE WRITE YOUR ANSWERS IN BLOCK CAPITALS)			
A				
B				
TEST				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

That is the end of this test, thank you.

APPENDIX B

TEST MATERIAL FOR SIMULATION OF PUBLIC ADDRESS ANNOUNCEMENTS IN A CONCOURSE

B.1 Text of introduction to the audio tape

"In a moment you will hear a typical announcement recorded at Waterloo railway station. Listen to it carefully and try to get used to understanding the important information.

[Demonstration]

Next we will play you a series of announcements. For each one there is a particular question [on the response sheet]. I will read the relevant question to you *before* each announcement so that you know what to listen for in particular. If you have any questions, please ask them now."

B.2 Transcript of announcements

Item 1: "The 17.52 to Guildford via Cobham will leave from Platform 10, calling at Surbiton, Hinchley Wood, Claygate, Oxshott, Cobham and Stoke d'Abernon, Effingham Junction, Horsley, Clandon, London Road and Guildford. The 17.52 to Guildford via Cobham is now standing at Platform 10."

Item 2: "The 17.50 to Portsmouth Harbour will leave from Platform 11, calling at Woking, Worplesdon, Guildford, Godalming, Haslemere, Petersfield, Rowlands Castle, Havant, Fratton, Portsmouth and Southsea, and Portsmouth Harbour. The 17.50 to Portsmouth Harbour is now standing at Platform 11."

Item 3: "The 18.02 to Dorking will leave from Platform 1, calling at Clapham Junction, Wimbledon, Worcester Park, Stoneleigh, Ewell West, Epsom, Ashtead, Leatherhead, Boxhill and West Humble, and Dorking. The 18.02 to Dorking is now standing at Platform 1."

Item 4: "We apologize to passengers travelling by the 18.10 to Salisbury and Bournemouth. The stock on the Bournemouth service is formed of 8 coaches only. This is due to the lack of suitable rolling stock."

Item 5: "The 17.54 to Eastleigh will leave from Platform 8, calling at Woking, Farnborough, Fleet, Winchfield, Hook, Basingstoke, Micheldever, Winchester, Shawford, and Eastleigh."

Item 6: "The 16.35 Intercity service to Bournemouth and Weymouth will leave from Platform 13, calling at Southampton and Bournemouth. The front 8 coaches furthest from the ticket barrier are for Branksome, Parkstone, Poole, Hamworthy, Holton Heath, Wareham, Dorchester South, and Weymouth. Change at Southampton for all stations to Pokesdown. Change at Wareham for bus connections to Swanage. The 16.35 Intercity service to Bournemouth and Weymouth is now standing at Platform 13."

Item 7: "The 16.12 to Basingstoke and Alton is a platform alteration and will now leave from Platform 11. We apologize to passengers travelling by this service for the inconvenience caused".

Item 8: "This is a special announcement for Jackie Cortez. Miss Jackie Cortez please call at the Police Station which is situated alongside Platform 15. This is a special announcement for Miss Jackie Cortez."

Item 9: "The 18.00 hrs to Portsmouth Harbour will leave from Platform 13, calling at West Byfleet, Woking, Worplesdon, Guildford, Farncombe, Godalming, Milford, Witley, Haslemere, Liphook, Liss, Petersfield, Rowlands Castle, Havant, Bedhampton, Fratton, Portsmouth and Southsea, and Portsmouth Harbour. The 18.00 hrs to Portsmouth Harbour is now standing at Platform 13."

Item 10: "The 17.58 to Alton will leave from Platform 6, calling at Woking, Brookwood, Ash Vale, Aldershot, Farnham, Bentley, and Alton. Passengers travelling to Ash Vale are requested to join the first 5 coaches further from the ticket barrier. The 17.58 to Alton is now standing at Platform 6."

B.3 Question sheet

The question sheet and model answers are reproduced on the next page.

UNIVERSITY OF SOUTHAMPTON - INVESTIGATION OF HEARING HANDICAP

UNEXPECTED ANNOUNCEMENTS IN A PUBLIC CONCOURSE

Name:___________________________ Date:_____________

In a moment you will hear a typical announcement recorded at Waterloo railway station. Listen to it carefully and try to get used to understanding the important information.

Next we will play you a series of announcements. For each one there is a particular question below. I will read the relevant question to you before each announcement so that you know what to listen for in particular. If you have any questions, please ask them now.

Item 1	From which platform will this train depart?	10
Item 2	Where should you change trains for Wanborough and Ash?	Guildford
Item 3	Does this train stop at Bookham?	No
Item 4	Why do British Rail apologize to passengers on this train? .. And why has the problem occurred?	Only 8 coaches Lack of suitable rolling stock
Item 5	Does this train stop at Winchfield?	Yes
Item 6	For which destinations should you change at Southampton? ...	All stations to Pokesdown
Item 7	What is the alteration to this service?	Departing from platform 11
Item 8	What is the special announcement for Miss Jackie Cortez? ...... (Please give all the relevant information)	Please go to the Police Station Alongside platform 15
Item 9	What is the departure time and destination of this train? ...	18.00 hours Portsmouth Harbour
Item 10	What are the special instructions for passengers to Ash Vale? ... (Please give all the relevant information)	Use the front 5 coaches Furthest from the ticket barrier

That is the end of this test, thank you.

APPENDIX C

TEST MATERIAL FOR TELEPHONE LISTENING IN NOISE

C.1 Text of introduction to the audio tape

"In this test you will listen to people's names, addresses and telephone numbers in the same format as you heard in the earlier test. To give you some practice under these conditions in a moment I will read two examples during which you should write down whatever you think was said.

[Demonstrations of 2 examples in noise.]

You probably didn't catch everything that was said. Don't worry about that - it is the purpose of the test to make it fairly hard for you.

Remember, if you are unsure of the spelling of any of the names, spell the word the way it sounded to you. Always make some attempt to write down what you think was said, even if you are not confident or could not understand the whole word.

That is the end of the practice session. If you have any questions, please ask them now.

The test will start in a few seconds, so please get ready to start writing. OK then, here goes."

C.2 Speech material

Practice items*:

A	C. Hilton	15 Briarmere Walk	Chadderton	652 6597
B	A. Radford	35 Princess Road	Oldbury	429 8148

*The same examples were used as in the first simulation (Appendix A).

Test items:

Speaker JB

1	L. Flood	74 Brook Lane	Welling	304 9942
2	D. Bedford	107 Sydney Road	Sutton	643 6094
3	A. Bowie	38 Delhi Avenue	Dalmuir West	952 8523
4	E. Parison	25 Hollington Crescent	New Malden	949 4092
5	D. Newcombe	18 Camden Avenue	Hayes	573 8047

Speaker MS

6	D. Penfold	39 Norman Road	Cheam	643 6609
7	H. Varley	32 Plymouth Street	Oldham	624 9940
8	M. Pendlebury	6 Parsonage Way	Cheadle	491 1433
9	A. Adnett	93 Peakdale Road	Draysden	370 7338
10	L. Griffiths	9 Kingswood Drive	Streetly	353 3977

Speaker KH

11	A. Kendrick	21 Wyburn Avenue	Barnet	440 5398
12	D. Robinson	1 Clayton Close	Bury	761 3250
13	L. Rudd	99 Reddish Lane	Denton	233 0955
14	R. Bray	31 Alexandra Road	Well End	953 2459
15	T. Finlayson	57 Kyle Court	Cambuslang	641 2485

Speaker DR

16	E. Dibsdale	119 Ashridge Drive	Watford	428 9779
17	M. Quinn	68 Shawcross Street	Stockport	477 2228
18	G. Penson	33 Heathcote Gardens	Romiley	427 4143
19	D. Casey	59 King Street	Burbank	336 5819
20	W. Ackland	106 Locket Road	Wealdstone	427 5728

C.3 Response form

The form as presented to subjects is reproduced on the next page.

UNIVERSITY OF SOUTHAMPTON - INVESTIGATION OF HEARING HANDICAP

LISTENING ON THE TELEPHONE

NAME:_______________________________ DATE:_______________

	THE NAME IS	AND THE ADDRESS	THE TOWN IS	AND THE 'PHONE NUMBER
EXAMPLE:	J. CITIZEN	26 CHAPEL RD	EASTLAND	903 8711
PRACTICE	(PLEASE WRITE YOUR ANSWERS IN BLOCK CAPITALS)			
A				
B				
TEST				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
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15				
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17				
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That is the end of this test, thank you.

APPENDIX D

WORD LISTS FOR THE SPEECH AUDIOMETRY

<u>List 1</u> SAQ 45	<u>List 3</u> SAQ 70	<u>List 5</u> SAQ 45	<u>List 7</u> SAQ 70
Ship	Thud	Fib	Badge
Rug	Witch	Thatch	Hutch
Fan	Wrap	Sum	Kill
Check	Jail	Heel	Thighs
Haze	Keys	Wide	Wave
Dice	Vice	Rake	Reap
Both	Get	Goes	Foam
Well	Shown	Shop	Goose
Jot	Hoof	Vet	Not
Move	Bomb	June	Shed

<u>List 2</u> SAQ 30	<u>List 4</u> SAN	<u>List 6</u> SAQ 30	<u>List 8</u> SAN
Fish	Fun	Fill	Bath
Duck	Will	Catch	Hum
Gap	Vat	Thumb	Dip
Cheese	Shape	Heap	Five
Rail	Wreath	Wise	Ways
Hive	Hide	Rave	Reach
Bone	Guess	Goat	Joke
Wedge	Comb	Shone	Noose
Moss	Choose	Bed	Got
Tooth	Job	Juice	Shell

Key: SAQ 30/45/70: speech level 30/45/70 dB(A), in quiet

SAN : speech level 70 dB(A), in 24 voice babble also at 70 dB(A)

APPENDIX E

QUESTIONNAIRES

E.1 Notes on the questionnaires

Each Section was in pencil-and-paper form, unpaced. Sections I and II were given consecutively, verbal instructions for each being repeated in printed form on the first sheet of these Sections.

Each of the nine question sheets of Section II was accompanied by a relevant photograph (not reproduced here), arranged in a loose-leaf folder, with question sheet and photograph on facing pages.

Section III consisted of three separate question sheets, presented to subjects one at a time after the completion of the corresponding simulation test (Appendices A, B, C), with verbal instructions in case the task was not self-explanatory.

E.2 Section I - Hearing in General

Please work through the questions below at your own speed and put ticks in the answer boxes that fit best. Even if your hearing is excellent (and you may answer that way to Question 1) remember that there are some occasions when almost anyone finds it a bit difficult to hear, so please try to answer every question. If some of them do not apply at all to you, or if you are quite unable to make a choice, then you may tick the "Not applicable" box.

1. Generally speaking, how would you describe your hearing? .... Excellent ☐
   - Good but not perfect ☐
   - Moderately good ☐
   - Not very good ☐
   - Bad ☐

---

2. Is your state of hearing much the same as it always was or is it getting worse? .... The same ☐
   - Slightly less good ☐
   - Noticeably worse ☐
   - Much worse ☐

---

3. Do you have to make a special effort to hear things? .... Never ☐
   - Sometimes ☐
   - Often ☐
   - Always ☐

---

4. Do you think other people notice that you have any problems with your hearing? .... No ☐
   - Possibly ☐
   - Yes ☐

   If this question is not applicable, please tick here .... ☐

---

5. Is your enjoyment of life affected by the state of your hearing? .... Not at all ☐

Slightly ☐

Quite a lot ☐

Severely ☐

If this question is not applicable, please tick here .... ☐

---

6. Do you feel that your hearing puts you at a disadvantage compared to others? .... Not at all ☐

Slightly ☐

Quite a lot ☐

Severely ☐

If this question is not applicable, please tick here .... ☐

---

7. When you hear an unexpected sound, do you instantly know the direction it comes from? ..... Always ☐

Usually ☐

Often not ☐

Never ☐

The next two questions are about particular sounds and how well you hear them

8. When watching your favourite TV programme or listening to the radio, do you like the volume higher than other members of the household? .... No ☐

Yes ☐

If you answered 'Yes' here, what is the reason? .... I need it louder to hear everything ☐

Just a matter of taste ☐

Any other reason? ....

....

....

---

9. How do you get on with hearing the sounds of daily life? ....

Such things as:
- the doorbell
- your pets
- birds singing
- water running
- kettle boiling
- phone bell in other room

Perfectly well ☐
Mostly quite well ☐
Sometimes miss things ☐
Quite often miss things ☐

If these or any other things affect you particularly, please write here what they are ....

....

The next few questions are about how well you hear speech

10. Do you have any difficulty in quiet surroundings with hearing what people are saying? ....

Never ☐
Sometimes ☐
Often ☐
Always ☐

---

11. In conversation with people that you don't hear very well, do you ask them to repeat what they said? ....

Never ☐
Sometimes ☐
Often ☐
Always ☐

If this question is not applicable, please tick here .... ☐

---

12. Broadly speaking, when you have any difficulty listening to what people are saying, is it because: ....

they don't speak loudly enough? ☐
even when loud enough you can't make out the words? ☐
other reason (please specify) ....

....

If this question is not applicable, please tick here .... ☐

The next two questions concern your work

13. Does the state of your hearing ever interfere with your work? ....

- Never ☐
- Sometimes ☐
- Often ☐
- Always ☐

If this question is not applicable, please tick here .... ☐

---

14. Do you work in an area where hearing protectors are made available or used? ....

- No ☐
- Yes ☐

If you answered 'Yes' here, do you yourself wear hearing protectors at work? ......

- Never ☐
- Sometimes ☐
- Usually ☐
- Always ☐

Does wearing a hearing protector cause you any additional problems with hearing sounds? ....

- No ☐
- Yes ☐
- Don't know ☐

---

15. If you get noises in the head or ringing in the ears after work, does this cause difficulties in your daily life? ....

- Not at all ☐
- A little ☐
- Quite a lot ☐
- Severely ☐

If this question is not applicable, please tick here .... ☐

E.3 Section II - Hearing in Particular Situations

We are going to describe some typical situations where you may have had some problem in hearing well. Each one is introduced separately and is described in a few words at the top of each page. There is also a picture for each situation to help you visualize the scene we are describing.

Please answer the questions by putting ticks in the boxes that best fit your experience. Even if you answer that the situation never happens to you (which is the first question on each page) we would prefer that you answer all the other questions rather than leave them blank. You can probably do this by using your imagination to put yourself in the kind of situation described.

You can go at your own speed and please remember when you start each page to examine the photograph which depicts the situation, read the description at the top of the question page carefully, and then carry on with the answers.

Please turn over now and begin with Situation A.

Situation A	You are listening to the sports results or similar factual information on the radio, with the volume control adjusted to your liking

Questions

1. This happens to me ...... never ☐ sometimes ☐ often ☐

2. I hear all the information well .... always ☐ usually ☐ sometimes ☐ never ☐

3. I have difficulty with ....
   - male voices...... ☐
   - female voices.... ☐
   - foreign accents.. ☐
   - dialect voices... ☐
   - voices relayed by telephone..... ☐
   - other (please specify)...........................

   If none of these apply, please tick here ... ☐

4. If there are distractions, my usual reaction is to ....
   - turn up the volume........... ☐
   - stop listening... ☐
   - other (please specify)...........................

   If none of these apply, please tick here ... ☐

5. It may be difficult to hear in this situation but this does not necessarily mean that it matters to you. But can you say how much it matters? .... Not at all ☐ A little ☐ Quite a lot ☐ Very much ☐

Situation B	You are at a noisy gathering in a pub or at a party. People are talking all around you and loud music is playing in the background. The person opposite you is trying to tell you some factual information - it might be the cricket score, how to get to a certain place, what they heard on the news, or something like that. You are trying to hear what they are saying.

Questions

1. This happens to me .... never ☐ sometimes ☐ often ☐

2. I can clearly hear the person opposite me ... always ☐ usually ☐ sometimes ☐ never ☐

3. What makes it particularly difficult? ....
   - the music.................. ☐
   - other conversations......... ☐
   - the general noise........... ☐
   - having to concentrate hard.. ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

4. When this situation is difficult, my usual reaction is to ....
   - ask the person to speak louder................ ☐
   - avoid such gatherings....... ☐
   - pretend I heard............. ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

5. It may be difficult to hear in this situation but this does not necessarily mean that it matters to you. But can you say how much it matters? .... Not at all ☐ A little ☐ Quite a lot ☐ Very much ☐

Situation C	You are in the concourse of a busy railway station or airport, full of people milling around you. Suddenly an announcement is called over the public address system with information which might or might not be important for you

Questions

1. This happens to me .... never ☐ sometimes ☐ often ☐

2. I hear the announcements clearly .... always ☐ usually ☐ sometimes ☐ never ☐

3. What makes it particularly difficult? ....
   - announcements too loud...... ☐
   - announcements not loud enough................ ☐
   - distorted sound quality..... ☐
   - the background noise........ ☐
   - the distractions............ ☐
   - catching the important words...................... ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

4. If I miss the announcement, my reaction is to ....
   - read the indicator board.... ☐
   - ask someone else........... ☐
   - get anxious................ ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

Situation D	You are concentrating on a quiet task at home - reading the paper, doing a crossword, writing a letter or something similar. The radio and TV are not on. Other members of the family are also in the room and everyone is quiet until, suddenly, one of them makes a casual remark

Questions

1. This happens to me .... never ☐ sometimes ☐ often ☐

2. I miss such remarks ...... never ☐ sometimes ☐ often ☐ always ☐

3. When I don't catch the remark properly, my usual reaction is to ....
   - guess what was said......... ☐
   - ask for it to be repeated... ☐
   - ignore it.................. ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

4. It may be difficult to hear in this situation but this does not necessarily mean that it matters to you. But can you say how much it matters? .... Not at all ☐ A little ☐ Quite a lot ☐ Very much ☐

Situation E	You are at a public meeting in a large hall. The principal speakers are on the platform and they are not using microphones.

Questions

1. This happens to me .... never ☐ sometimes ☐ often ☐

2. I would hear well wherever I sat .... always ☐ usually ☐ sometimes ☐ never ☐

3. I have difficulty if ....
   - several people speak at once..................... ☐
   - the speaker does not raise his voice............ ☐
   - I can't see who is speaking................. ☐
   - the hall is large & bare.... ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

4. If I find this kind of situation difficult, my usual reaction is to ....
   - sit near the front.......... ☐
   - ask the person next to me for help................. ☐
   - avoid such meetings......... ☐
   - other (please specify)...........................

   If none of these apply, please tick here ... ☐

Situation F	You are at a formal meeting seated round a large table.

Questions

1. This happens to me .... never ☐ sometimes ☐ often ☐

2. I hear everything that is said .... always ☐ usually ☐ sometimes ☐ never ☐

3. I have difficulty with ....
   - noise outside............... ☐
   - speakers who mumble......... ☐
   - papers rustling............. ☐
   - people whispering among themselves............ ☐
   - speakers who have their backs to me........... ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

4. If I find difficulty with this kind of situation, my usual reaction is to ....
   - sit near the chairman....... ☐
   - ask people to speak up...... ☐
   - find it tiring.............. ☐
   - avoid such meetings......... ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

Situation G	You are making a telephone call from a payphone in a noisy place such as a pub, a busy street or a railway station

Questions

1. This happens to me .... never ☐ sometimes ☐ often ☐

2. I hear most of what is said .... always ☐ usually ☐ sometimes ☐ never ☐

3. When I do not hear well, what are the main difficulties? ......
   - noise behind me............. ☐
   - an unfamiliar voice at the other end............ ☐
   - a bad line.................. ☐
   - the other person speaking too fast........... ☐
   - the other person speaking indistinctly....... ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

4. If I have difficulty in this situation, my usual reaction is to ....
   - ask the other person to speak up or speak more slowly................. ☐
   - ask for a repeat of words not heard............. ☐
   - shield my other ear......... ☐
   - try another line............ ☐
   - abandon the call altogether.................. ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

Situation H	You are at a cash counter such as a Post Office, a bank, or a ticket office, where the clerk sits behind a transparent grille or screen

<u>Questions</u>

1. This happens to me .... never ☐ sometimes ☐ often ☐

2. I hear the clerk clearly .. always ☐ usually ☐ sometimes ☐ never ☐

3. What is the main cause of difficulty? ....
   - the grille.................. ☐
   - noise behind me............. ☐
   - the clerk speaks too quietly................. ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

4. When I have difficulty hearing the clerk in this situation, my usual reaction is to ....
   - ask him/her to speak up or repeat what was said..... ☐
   - try to manage without hearing exactly what he or she said.............. ☐
   - other (please specify)..........................

   If none of these apply, please tick here .. ☐

Situation J	You are in one of the front seats of a car. It is night time, there is a lot of traffic about, and you are travelling in an unfamiliar area.

Questions

1. This happens to me .... never ☐ sometimes ☐ often ☐

2. In this situation, I am usually .... the driver ☐ a passenger ☐

3. I can clearly hear what another person alongside me in the front of the car says........ always ☐ usually ☐ sometimes ☐ never ☐

4. I have more difficulty hearing remarks made by other occupants of the car if ....
   - the radio is on............ ☐
   - any of the car windows is open............ ☐
   - the person speaking is in the rear seat......... ☐
   - other (please specify)..........................

   If none of these apply, please tick here ... ☐

5. (Answer <u>only</u> if you are <u>usually the driver</u>)

   Are you ever aware of danger or of being misdirected because you fail to hear your passenger giving you warnings or directions? .... never ☐ occasionally ☐ often ☐

6. (Answer <u>only</u> if you are <u>usually a passenger</u>)

   Does it happen that the driver asks you quickly for directions but you don't hear first time? ... never ☐ sometimes ☐ often ☐

E.4 Questionnaire - Section III: Reactions to Simulated Situations

Simulation 1 : Noisy gathering in the pub

Now please answer these questions

1. In the test you have just done which of these made it particularly difficult? ....
   - the music.................. ☐
   - the female voices.......... ☐
   - the background chatter...... ☐
   - having to concentrate hard.. ☐
   - writing down the answers.... ☐
   - other...............................

2. Did you find the test ....
   - easy....................... ☐
   - a bit difficult............ ☐
   - quite difficult............ ☐
   - almost impossible.......... ☐

3. What were your reactions during the test? ....
   - none in particular.......... ☐
   - only listened to the names and addresses - didn't watch the screen........... ☐
   - tried to lip read.......... ☐
   - it got easier as it went on. ☐
   - found it interesting........ ☐
   - disliked it................ ☐
   - wished it would stop........ ☐

Now please turn back to the photograph and description of Situation B and answer this question :

4. Did the test you have just done resemble the situation that you imagined when you were answering the questions about Situation B (the pub)?.....
   - very closely............... ☐
   - in some ways............... ☐
   - only vaguely............... ☐
   - not at all................. ☐
   - Any other comment?............................

Simulation 2 : Announcements at Waterloo Station

Now please answer these questions

1. In the test you have just done which of these made it particularly difficult? ....
   - announcements too loud...... ☐
   - announcements not loud enough................. ☐
   - distorted sound quality..... ☐
   - the background noise........ ☐
   - catching the important parts of the message........ ☐
   - having to concentrate....... ☐
   - writing down the answers.... ☐
   - other (please specify)...........................

2. Did you find the test ....
   - easy throughout............. ☐
   - difficult in parts.......... ☐
   - difficult throughout........ ☐
   - almost impossible........... ☐

3. What were your reactions during the test? ....
   - none in particular.......... ☐
   - it got easier as I got used to the voice........... ☐
   - other (please specify)...........................

Now please turn back to the photograph and description of Situation C and answer this question :

4. Did the test you have just done resemble the situation that you imagined when you were answering the questions about Situation C?................
   - very closely................ ☐
   - in some ways................ ☐
   - only vaguely................ ☐
   - not at all.................. ☐
   - Any other comment?...........................

Simulation 3 : Listening on the telephone

Now please answer these questions

1. In the test you have just done which of these made it particularly difficult? ....
   - the noise around me......... ☐
   - the male voices............. ☐
   - the female voices........... ☐
   - voices not loud enough...... ☐
   - having to concentrate....... ☐
   - writing down the answers.... ☐
   - other...............................

2. Did you find the test ....
   - easy........................ ☐
   - a bit difficult............. ☐
   - quite difficult............. ☐
   - almost impossible........... ☐

3. During the test I held the telephone in my .... left hand ☐ right hand ☐

   and wrote the answers with my.... right hand ☐ left hand ☐

4. When I don't have to write at the same time, I usually hold the telephone in my .... left hand ☐ right hand ☐

5. What were your reactions during the test? ....
   - none in particular.......... ☐
   - had to press the receiver hard against my ear......... ☐
   - found it tiring............. ☐
   - other...............................

Now please turn back to the photograph and description of Situation G and answer this question :

6. Did the test you have just done resemble the situation that you imagined when you were answering the questions about Situation G? ....
   - very closely................ ☐
   - in some ways................ ☐
   - only vaguely................ ☐
   - not at all.................. ☐
   - Any other comment?............................

APPENDIX F

REGISTRATION AND CONSENT FORM

Please complete the following general questionnaire and the consent form:

NAME: ______________________________

ADDRESS: ____

AGE LAST BIRTHDAY: __________ DATE OF BIRTH : __________________

OCCUPATION: ______________ SEX: __________

1 Have you ever received medical attention for your hearing? YES/NO

2 Do you or have you ever experienced noises in your ears or head (tinnitus) which last longer than 5 minutes? YES/NO

If yes, is this only after exposure to noise? YES/NO

3 Have you ever been exposed to high levels of noise at work? YES/NO

If yes, what kind of noise? ____________________

For how many hours per day? ________ days per year? _____

Years? _______

4 Have you ever been exposed to the noise of guns (including rifles and shotguns)? YES/NO

If yes, what weapons? ____________________________

Indicate the total number of rounds you fired:

1 - 10; 10-100; 100-1000; More than 1000

5 Have you ever been exposed to any other loud noise (e.g. at home or as part of your hobbies and recreation) or explosions? YES/NO

If yes, please specify ____________________________

6 Indicate with a tick if you have ever had any of the following treatments:

Quinine or other drugs for malaria?

Antibiotics by injection other than penicillin?

Diuretics (to make you pass more water)?

Aspirin in large or regular doses?

Any drugs which produced dizziness or ringing in the ears?

7 Have you in the past year had any problems with your ears or hearing, e.g. pains, discharges, or infections of the ear? YES/NO

8 Are you suffering, or have you in the last week suffered from a common cold or respiratory infection? YES/NO

CONSENT FORM

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

I, ______________________ of ______________________

consent to take part in the hearing handicap experiment

to be conducted by ______________________

during the period ______________ to ______________ 198

The purpose and nature of this experiment have been explained to me. I understand that the investigation is to be carried out solely for the purpose of research and I am willing to act as a volunteer for the purpose on the understanding that I shall be entitled to withdraw this consent at any time, without giving any reasons for withdrawal. I further certify that I have seen the questions concerning medical fitness for this experiment (questions 7 and 8 above) and confirm that to the best of my knowledge I do not suffer from any of the conditions listed.

Date: ______________ Signed: ______________

EXPERIMENTER'S CONFIRMATION

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

Date: ______________ Signed: ______________

(Researcher in charge of experiment)

APPENDIX G

INSTRUCTIONS FOR OPTIONAL AMENDMENT TO SELF-ASSESSMENTS

On completion of each sheet of the Questionnaire Section III, the relevant answer sheet of Section II (Appendix E.3, items B, C, G) was returned to the subject together with the following instructions:

"Here is the answer sheet that you filled in earlier.

Remember that when you were doing this we asked you to visualize situations of the kind described at the top of the page in a general way, not any particular situation.

But now that you have experienced something similar in the test you just listened to, you may like to take the opportunity to confirm or change your previous answers.

Please look through your own answer sheet now, and if you feel you need to alter (or add to) any of your answers use the coloured pen so that we know what alterations (if any) you make."

Coded (initials) Proof

Keyed

Proof

$ACC: C (7)

NEW

$AQN: (8)

ØX

NIS WORKSHEET

(Rev. 8/29/77)

$DOC: (40)

REPORT

$DKT: (10)

$RPT: (30)

EPA 55Ø/9-74-ØØ2

$CNT: (30)

EPA 68-Ø1-2229

$AUT: (30)

$COR: (42)

ERISMAN RESEARCH INST OF HYGIENE

$SPO: (42)

EPA. ONAC

$ADD: (100)

$REC: (30)

$RSO: (42)

$ETL: (250)

SOVIET NOISE RESEARCH LITERATURE: SIX REPORTS

$FTL: (250)

$SDT: (250)

INCLUDED IN THIS PUBLICATION ARE SIX REPORTS TRANLATED FROM THE ORIGINAL RUSSIAN AND GERMAN

$SDI: (250)

ARLINGTON, VA, EPA. ONAC, APR 1974, 37P.

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Term Check ______

$PNM: (30)

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$MFO: (42)

$MDN: (42)

$PBT: (42)

REPORTS,
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NOISE;
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NOISE ABATEMENT AND CONTROL;
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