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INSTITUTE OF SOUND AND VIBRATION RESEARCH
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A Baseline for the Assessment of Noise-Induced Hearing Loss: Contrasting thresholds-by-age for *otologically normal* persons and *typical* persons

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ABSTRACT

This document deals with two baselines for the assessment of Noise-induced Hearing Loss. It presents reviews of research studies that figured in the production of International Standard ISO 7029 dealing with screened populations of *otologically normal* persons. Also presented are reviews of research studies of ordinary populations screened to exclude persons with occupational noise exposure and ear disorders; such populations might be termed *typical*. For each baseline, medians are given for the hearing threshold levels of males and females according to age. Also examined is the spread of thresholds above and below the medians. Special attention is devoted to inter-quartile range, which includes thresholds for one-half of the appropriate populations, either *otologically normal* or *typical*.

KEY WORDS

hearing threshold levels, age-associated hearing loss, spread of hearing threshold levels, inter-quartile range, Noise-induced Hearing Loss

ABBREVIATIONS

AAHL	age-associated hearing loss
BS	British Standard
dB	decibel
dB HL	decibels Hearing Level (from an audiometer)
dB HTL	decibels Hearing Threshold Level (from a person)
EN	European Standard
HTL	Hearing Threshold Level
IHR/MRC	Institute of Hearing Research of the Medical Research Council
ISO	International Organization for Standardization
kHz	kilohertz
L	left
n	sample size
N	population size
NIHL	noise-induced hearing loss
PTA	pure tone audiometry
R	right
RETSPL	reference equivalent threshold sound pressure level (for calibration purposes)
TDH	Telephonics Dynamic Headphone

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1 INTRODUCTION

Medico-legal assessment in relation to a compensation claim for hearing damage requires an equitable baseline against which to compare the claimant's state of hearing. This baseline should match the claimant in every respect save for the cause of the potentially compensable hearing loss.

An International Standard (ISO 7029) exists for the **natural** deterioration of hearing acuity due to ageing but is specific to populations screened (to some degree) to ensure that the persons included are *otologically normal*; the definition given in ISO 7029 is open to varying interpretations. The present document briefly reviews the development of ISO 7029. The Standard, however, does not account for all the time-dependent hearing losses found in a *typical* legal claimant, and therefore must be regarded as an optimistic baseline.

The present document also presents and reviews a number of studies reporting the thresholds of *typical* males and female subjects, *viz*. ordinary individuals screened to exclude only those reporting ear disease and exposure to potentially harmful occupational noise.

2 THE DEVELOPMENT OF ISO 7029

2.1 Introduction

International Standard ISO 7029 (1984 and 2000) provides descriptive statistics of the hearing thresholds for *otologically normal* populations of various ages, from 18 years to 70 years inclusive. These statistics are calculated using formulae with given coefficients and parameters, specified for the range of audiometric frequencies from 125 Hz to 8 kHz. The results of the required calculations are:

a) the expected median value of hearing thresholds relative to the median hearing threshold at the age of 18 years (median threshold is assigned a value of zero at age 18 years); and
b) the expected statistical distribution above and below the median value.

Distinction is made between males and females since the difference is found to be of significance in the case of older age groups.

The standard is based on a thorough examination of published data on the change of hearing with age for populations of *otologically normal persons*, loosely defined by the following four requirements:

a) in a normal state of health,
b) free from all signs or symptoms of ear disease,
c) free from obstructing wax in the ear canals, and
d) having no history of undue exposure to noise.

Data calculated using the standard give a baseline for estimating the amount of any additional hearing loss caused by a specific harmful or injurious agent in a population. Such a comparison is valid if the population under study consists of persons who are *otologically normal* except for the effect of the specific noxious agent. For the purpose of the present document, noise exposure is an example of such a specific agent. For an individual with known noise exposure, the injurious effect of that exposure would be seen as a deviation from the frequency-dependent threshold statistics for the appropriate age and sex.

2.2 Research studies leading to ISO 7029

Hinchcliffe (1959)

Data from this study of *otologically normal persons* were included in the preparation of the sections of ISO 7029 (1984 and 2000) dealing with determination of median hearing thresholds for age and sex, and the deviations about the median.

This study was undertaken to document the effect of age upon hearing thresholds. The subjects, all adults, were selected from approximately 9 000 inhabitants of a representative rural area in Dumfriesshire, Scotland. All potential subjects were screened to exclude those with unfavourable otological factors including: scarred or perforated eardrum(s); fluid in the middle ear; inflammation of the ear canal; history of recurrent dizziness with nausea and vomiting; tinnitus; impacted earwax; and ear surgery. Some of these exclusions were applied to individuals, some to one ear of an individual. Those admitted to the study were broken into age groups of “clinically normal” ears as below:

Breakdown of the 645 clinically normal ears in each group.

age group	18-24	25-34	35-44	45-54	55-64	65-74
male	88	55	46	51	39	47
female	88	49	47	53	35	47
total	176	104	93	104	74	94

Manual pure-tone audiometry was performed on the clinically normal ears. In the higher frequencies, the median thresholds for clinically normal male ears were significantly higher (less acute) than the medians for females, even for the youngest male group. The research author opined that this discrepancy was due to the effects of “acoustic hazards”; there had been no exclusion for noise exposure during work or military service. This reviewer has not included the data for clinically-normal-but-noise-damaged ears of the male subjects. The female data are given below.

The median and quartile thresholds in relation to an arbitrary zero, for screened females in set age groups; the values are given to the nearest integer dB.

		age, years					
freq., Hz	centile	18-24	25-34	35-44	45-54	55-64	65-74
250	25	-3	-3	-2	0	2	5
	median	0	1	2	3	7	10
	75	3	5	6	8	12	16
500	25	-3	-2	-2	0	2	5
	median	0	1	2	4	7	10
	75	4	4	6	9	13	21
1k	25	-4	-2	-2	1	1	5
	median	0	1	2	5	6	13
	75	4	4	6	10	10	25
2k	25	-4	-4	-1	1	5	9
	median	0	0	3	6	9	15
	75	5	5	7	11	15	27
3k	25	-4	-3	0	5	9	10
	median	0	2	6	10	15	20
	75	5	7	10	18	20	41
4k	25	-4	0	2	7	9	12
	median	0	4	5	13	19	22
	75	4	9	10	19	26	46
6k	25	-7	-1	1	4	11	17
	median	0	4	6	11	22	34
	75	6	9	14	22	29	47
8k	25	-6	-5	-2	3	11	32
	median	0	3	7	8	25	42
	75	6	10	16	28	40	52

The research author observed that the median threshold of hearing of clinically normal female ears showed a decline with age for all frequencies; he opined that this trend probably represented “true presbyacusis”.

The reader should take care: the table values are not true HTLs in dB HL. The base hearing level for each frequency was set to be zero dB for the youngest female group. From this arbitrary zero, the analyses gave the better- and worse-hearing quartiles about the median threshold which grew worse (less acute) with increasing age.

Taylor, Pearson and Mair (1967)

Data from this study of otologically normal males and females were included in the preparation of sections of ISO 7029 (1984 and 2000) dealing with the determination of median hearing thresholds for age and sex, and the deviations about the median.

The authors intended to assess NIHL due to loom noise in a population of female jute weavers in Dundee Scotland. To accomplish this, an appropriate control population was needed to estimate hearing threshold changes due to AAHL. These authors felt it would be best to sample a predominantly female population not exposed to industrial noise, and living in the environs of Dundee. Female school teachers were judged suitable for their purpose.

Normal subjects were chosen from the teachers who consented to participate in the investigation. A subject was considered “normal” if, on examination, (1) neither eardrum was obscured by wax in the canal, (2) both eardrums appeared normal, (3) there was no reported history of ear disease, past or present, (4) there was no upper respiratory tract infection at the time of test, and (5) no history of excessive noise was given (*e.g.* industrial noise, use of firearms, explosives).

The subject pool comprised males and female teachers in various age bands, as given below:

	age group, yrs					
gender	18-24	25-34	35-44	45-54	55-64	totals
males	7	12	10	12	6	47
females	46	33	29	35	26	169

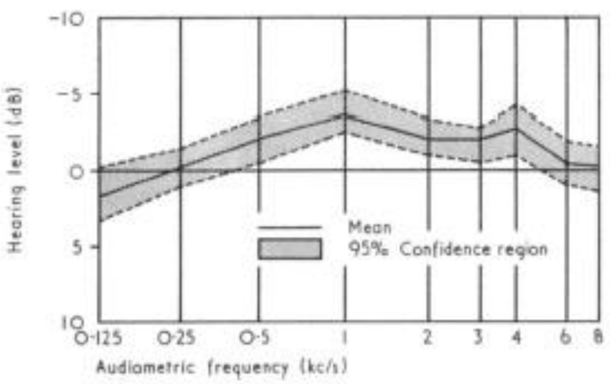
Manual pure-tone audiometry was performed over a range of conventional tone frequencies; the audiometer outputs (to TDH-39 earphones) were calibrated to values of audiometric zero specified in a British Standard of 1954.

The mean thresholds, by age groups, were reported only for the female teachers; the researchers felt that the number of male teachers was insufficient to yield reliable trends. The female means are given below.

Mean HTLs in dB HL for the female teachers

freq., kHz	age group, yrs 18-24	25-34	35-44	45-54	55-64
0.25	-0.5	0.3	0.6	2.7	2.9
0.5	-2.0	-0.4	0.0	2.3	3.0
1	-3.7	-2.4	-2.1	0.8	1.0
2	-2.0	-0.7	0.6	3.1	3.4
3	-2.2	-1.5	1.4	5.3	6.4
4	-2.7	-1.5	3.2	7.8	10.1
6	-0.5	0.8	7.1	16.1	20.0
8	0.0	1.5	9.1	20.6	25.8
no. of ears	92	66	58	70	52

The means for the youngest group, aged 18-24 years, may appear irregular, indeed strange, to the modern reader. See the figure below, reproduced from the source document, which gives the mean and confidence range for the youngest female teachers. The aspect of the figure is due to the audiometer calibration to meet the BS current at the time of test.



However, for each audiometric frequency, the dB differences with increasing age would have served in calculating age-related thresholds (for females) in ISO 7029 (1984 and 2000).

Hinchcliffe and Jones (1968)

Data from this study of otologically normal males and females were included in the preparation of sections of ISO 7029 (1984 and 2000) dealing with determination of median hearing thresholds for age and sex, and the deviations about the median.

The subjects selected for study comprised men and women from a predominantly black population residing in a poor suburban neighbourhood located just outside Kingston Jamaica. The subjects ranged in age from 35 to 74 years. The authors performed a clinical oto-laryngological examination, after which air-conduction audiometry was performed at 0.5, 1, 2, 4 and 8 kHz.

The only factory in the area was engaged in manufacturing light shoes, with adhesives used exclusively in their assembly; no nailing procedures were used. The authors concluded that the shoe-making process posed no threat to hearing. This was supported by there being no differences in the thresholds of their subjects who worked in the shoe factory and those who did not.

The median thresholds (after exclusion of ears with conductive hearing losses) for males and females are given below in dB HL (re ISO R 389, 1964).

Median hearing thresholds, in dB HL, for the male subjects with no undue noise exposure, and with no conductive hearing losses.

freq., kHz	ear	age group, years 35-44	45-54	55-64	65-74
0.5	R	1.1	2.6	3.6	7.9
	L	0.4	0.9	2.7	3.4
1	R	-0.1	0.9	3.3	3.5
	L	0.3	0.9	3.5	4.8
2	R	3.8	4.0	14.9	15.7
	L	4.0	5.6	11.1	13.9
4	R	11.4	13.5	23.8	28.0
	L	13.3	13.9	25.5	29.6
8	R	5.3	9.7	22.7	24.8
	L	1.7	3.0	21.6	19.8
number of ears	R	83	76	38	19
	L	83	76	39	19
TOTAL		166	152	77	38

Median hearing thresholds, in dB HL, for the female subjects with no undue noise exposure, and with no conductive hearing losses.

freq., kHz	ear	age group 35-44	45-54	55-64	65-74
0.5	R	3.6	6.6	9.9	11.6
	L	1.9	4.0	7.5	9.5
1	R	0.0	4.2	8.3	12.7
	L	0.7	3.0	7.4	12.0
2	R	4.3	8.4	14.9	20.0
	L	5.6	7.2	14.1	17.6
4	R	5.0	13.7	19.9	22.0
	L	6.5	13.6	23.4	25.5
8	R	4.5	11.2	19.3	33.1
	L	2.8	6.7	19.4	31.1
number of ears	R	123	95	75	35
	L	122	97	74	36
TOTAL		245	192	149	71

Spoor and Passchier-Vermeer (1969)

This work is cited in the bibliography of ISO 7029 (1984 and 2000), but was not used in the determination of median hearing thresholds for age and sex, or the deviations about the median.

These Dutch authors analysed hearing threshold data from research reports published between 1938 and 1963 to develop the spread of thresholds about the median, for different age groups of males and females. Their data pool included several thousand individuals in each gender group, all without known noise exposure.

The base hearing level for each frequency was set to be zero dB for the youngest age group of each sex. From this arbitrary zero, their analyses gave the better- and worse-hearing quartiles about the median threshold which grew worse (less acute) with increasing age.

The following two tables give the results of their analyses. The reader should take care. The table values give changes from the arbitrary zero. The table values are not true HTLs in dB HL, which would depend upon small-but-systematic errors calibrated into each combination of audiometer and earphone.

The median and quartile thresholds in relation to an arbitrary zero,
for males in set age groups.

		age, years					
freq., Hz	centile	20-29	30-39	40-49	50-59	60-69	70-79
250	25	-4	-3	-1	1	5	
	median	0	1	3	5	9	14
	75	4	5	7	10	14	
500	25	-4	-3	-1	1	5	
	median	0	1	3	6	10	16
	75	4	5	8	11	15	
1k	25	-4	-3	-1	1	5	
	median	0	1	3	6	10	17
	75	4	5	8	11	16	
2k	25	-4	-3	-1	5	12	
	median	0	2	6	11	19	30
	75	4	7	12	18	27	
3k	25	-5	-3	1	7	16	
	median	0	4	9	17	28	40
	75	6	11	18	27	39	
4k	25	-6	-1	5	14	23	
	median	0	6	13	23	34	48
	75	6	13	22	33	45	
6k	25	-6	0	8	17	29	
	median	0	7	16	27	40	55
	75	6	14	24	36	51	
8k	25	-6	-2	6	18	32	
	median	0	6	15	28	44	63
	75	6	14	24	39	56	

The median and quartile thresholds in relation to an arbitrary zero,
for females in set age groups.

freq., Hz	centile	age, years 20-29	30-39	40-49	50-59	60-69	70-79
250	25	-4	-3	-1	1	4	
	median	0	1	3	5	9	15
	75	3	5	7	10	14	
500	25	-4	-3	-1	1	5	
	median	0	1	3	6	10	16
	75	4	5	8	11	15	
1k	25	-3	-3	-1	1	5	
	median	0	1	3	6	10	16
	75	3	5	7	11	16	
2k	25	-3	-2	1	4	10	
	median	0	2	5	9	15	23
	75	4	6	10	15	21	
3k	25	-4	-3	0	5	11	
	median	0	2	6	12	19	28
	75	4	7	12	19	28	
4k	25	-4	-2	2	9	16	
	median	0	3	8	15	23	34
	75	4	8	14	22	31	
6k	25	-4	0	5	13	22	
	median	0	5	11	20	30	42
	75	4	10	17	28	39	
8k	25	-5	-3	3	10	23	
	median	0	3	10	19	33	51
	75	5	10	19	30	45	

Although the table values are **not** HTLs in dB HL, general trends may be discerned.

- At all frequencies, the medians increase with age for both males and females.
- For all frequencies, the inter-quartile range (25% to 75%) increases for both males and females.
- For the frequencies 2 kHz and higher, the median and interquartile ranges for males increase faster than for females.

Kell, Pearson and Taylor (1970)

Data from this study of otologically normal males and females were included in the preparation of sections of ISO 7029 (1984 and 2000) dealing with determination of median hearing thresholds for age and sex, and the deviations about the median.

In addition to the studies by Hinchcliffe (1959) and by Taylor, Pearson and Mair (1967), a third study was carried out, employing almost the entire population of the island of Westray in the Orkney archipelago off the north coast of Scotland. During the period of this survey (the summer of 1968), most inhabitants of Westray over the age of 15 years were examined on a voluntary basis.

At the time of the survey, the population of Westray (age 15 years and over) comprised 302 males and 300 females. With a few individuals unavailable for audiometric testing, or refusing to participate, 580 survey volunteers remained.

All potential subjects completed a questionnaire to give details of past noise exposure (including military service) and a medical history with details of head injuries, ear pathology (past and present) and use of potentially ototoxic medicines. An otological examination was made of the eardrum and canal of each potential subject: obstructive earwax was removed if possible.

A number of the potential subjects admitted noise exposure, or were found to have reason for medical exclusion. Of the islanders deemed suitable for the survey, the age distribution was:

sex	age, years							
	15-24	25-34	35-44	45-54	55-64	65-74	75+	total
male	43	39	19	36	33	17	14	201
female	36	39	42	45	49	28	23	262
							total	463

Manual pure-tone audiometry was performed on all subjects accepted into the study, being deemed to be *otologically normal*. The audiometer was calibrated to the audiometric zero given in a British Standard of 1954. The mean thresholds are given below for those individuals less than 75 years old, listed by age group and audiometric frequency.

Mean thresholds of the screened male subjects, in dB HL rounded to the nearest decibel.

age, years	number of ears	freq., kHz							
		0.25	0.5	1	2	3	4	6	8
15-24	86	2	0	-2	1	1	1	3	-1
25-34	76	2	-1	1	3	8	10	8	4
35-44	38	1	-1	-1	3	3	8	9	5
45-54	66	5	4	5	11	15	19	17	15
55-64	64	9	6	7	15	25	34	37	38
65-74	32	10	7	8	18	27	33	38	42

Mean thresholds of the screened female subjects, in dB HL rounded to the nearest decibel.

age, years	number of ears	freq., kHz							
		0.25	0.5	1	2	3	4	6	8
15-24	72	3	-1	-2	2	1	1	2	0
25-34	76	4	1	1	5	4	3	6	4
35-44	82	6	4	3	7	6	6	9	8
45-54	88	8	6	4	9	9	11	15	15
55-64	92	9	7	9	12	15	15	20	24
65-74	44	16	16	16	21	26	30	36	44

At the lower audiometric frequencies, the thresholds for the oldest group of females are somewhat higher (less acute) than those for males. Otherwise, the two genders show very similar thresholds.

2.2 ISO 7029 (1984 and 2000)

These two versions of the International Standard ISO 7029 are based upon an examination of the research literature on the change of hearing acuity with age for populations of *otologically normal persons*. Distinction was made between males and females, as the gender difference was found to be significant for older age groups.

An *otologically normal person* is defined in the Standard as a:

> "person in a normal state of health, who is free from all signs or symptoms of ear disease and from obstructing wax in the ear canals, and who has no history of undue exposure to noise."

The expected median values of hearing threshold for older age groups are given **relative** to the median hearing threshold at 18 years (assigned a value of zero dB). The spread of thresholds about the median are calculated using factors derived from the literature survey. A sample of the calculated values of median and spread are given below, for males and females, and for audiometric frequencies commonly used in the UK.

Hearing thresholds (relative to an arbitrary zero) for screened *otologically normal* males.

		age, years					
freq., Hz	centile	20	30	40	50	60	70
250	25	-4	-3	-2	-1	0	3
	median	0	0	2	3	5	8
	75	5	5	6	9	11	15
500	25	-3	-3	-2	-1	1	4
	median	0	1	2	4	6	9
	75	4	5	6	9	12	16
1k	25	-3	-3	-2	0	2	5
	median	0	1	2	4	7	11
	75	4	5	7	9	13	18
2k	25	-4	-3	-1	2	6	11
	median	0	1	3	7	12	19
	75	5	6	9	17	21	30
3k	25	-4	-3	0	5	11	19
	median	0	2	6	12	20	31
	75	5	7	13	21	32	46
4k	25	-4	-3	1	8	17	28
	median	0	2	8	16	28	43
	75	6	9	16	27	42	62
6k	25	-5	-3	2	9	19	32
	median	0	3	9	18	32	49
	75	7	10	18	30	48	70
8k	25	-6	-3	2	11	24	40
	median	0	3	11	23	39	60
	75	7	11	21	36	58	>80

Hearing thresholds (relative to an arbitrary zero) for screened *otologically normal* females.

freq., Hz	centile	age, years 20	30	40	50	60	70
250	25	-3	-3	-2	-1	1	3
	median	0	0	2	3	5	8
	75	4	5	6	8	11	15
500	25	-3	-3	-2	-1	1	4
	median	0	1	2	4	6	9
	75	4	5	6	9	12	16
1k	25	-3	-3	-2	0	2	5
	median	0	1	2	4	7	11
	75	4	5	7	9	13	18
2k	25	-4	-3	-1	1	4	9
	median	0	1	3	6	11	16
	75	5	6	8	13	18	26
3k	25	-4	-3	-1	2	6	12
	median	0	1	4	8	13	20
	75	5	6	10	15	22	31
4k	25	-4	-3	-1	32	8	14
	median	0	1	4	9	16	24
	75	5	7	11	17	26	37
6k	25	-5	-3	0	5	11	20
	median	0	2	6	12	21	32
	75	6	8	14	22	34	48
8k	25	-6	-4	0	6	14	25
	median	0	2	7	15	27	41
	75	7	10	17	27	42	60

A number of general observations may be made from the data given:

- for any given audiometric frequency, the median thresholds increase (grow worse, less acute) with increasing age of each gender;
- for any given frequency, the inter-quartile range grows wider with increasing age of each gender;
- for the frequencies below 2 kHz, the male and female medians and inter-quartile spreads are virtually identical; and
- for the frequencies 2 kHz and greater, the male medians increase faster (with age) than those of females; the male inter-quartile spreads increase faster than those of females.

2.3 Further research relating to ISO 7029

Robinson, Shipton and Hinchcliffe (1981)

This study was undertaken to clarify a number of aspects of International Standards regarding the audiometric zero used in the calibration of audiometers. The authors felt it advisable to return to first principles, making threshold measurements on a fairly large scale, and under carefully controlled conditions. To keep the project within manageable proportions, they decided to concentrate on the important central part of the audiometric frequency range from 0.5 to 6 kHz.

Fixed-frequency automatic-recording audiometry (on the Békésy principle) was chosen to eliminate, as much as possible, the random error and subjective uncertainties of audiometry. This left the requirement for test subjects defined with deceptive simplicity in ISO 389:1975 which was current at the time of testing (and also restated in ISO 7029): an otologically-normal subject is "*a person (within the inclusive age range 18 to 30 years) in a normal state of health who is free from all signs or symptoms of ear disease and from wax in the ear canal, and has no history of undue exposure to noise*". The authors' approach was to adopt a systematic method of classifying test subjects with respect to *otological normality*, and to explore the implications of criteria ranging from ultra-conservative to clearly less so with respect to the definition above.

The basic population was a subset of the staff of at the National Physical Laboratory aged between 18 years 0 months and 30 years 11 months. Before any testing was done, all potential subjects completed a 19-item questionnaire on their relevant medical, otological and environmental histories. There were otoscopic examinations of the eardrum and external ear canal, as well as tuning fork tests.

An otological abnormality scoring system was devised to quantify the normality (or otherwise) of potential test subjects.

Point system for otological abnormality score (OAS).

evidence		OAS
history (noise)	occupational	1 or 2*
	exposure to gunfire	2 or 3*
	exposure to explosions	3
	discotheques, other noisy recreations	0 or 1*
history (non-noise)	ear discharge	1
	persistent tinnitus	2
	episode(s) of unconsciousness	2
	family hearing disorder	1
	use of ototoxic drugs	2
	other 'ear trouble'	1
ear examination	scarring of drum(s)	2 or 4*
	retraction of drum(s)	6
	tuning fork: Rinne test unfavourable	5
	tuning fork: Bing test unfavourable	1
	binaural diplacusis	4
maximum		38

* depending on degree

After elimination of any potential subjects with a history of ear/mastoid surgery, current upper respiratory tract infection, or with an accumulation of wax in one or both ears canals, 62 were enrolled. In the opinion of the research authors, these 62 subjects “would generally be regarded as above average in terms of socioeconomic level and its likely concomitants in health terms”.

Number of subjects listed by OAS.

OAS	number of subjects
0	11
1	11
2	10
3	7
4	5
5	3
6	4
7	3
8	2
9	1
10	2
11	1
12	2
total	62

In respect of international standardisation, the authors opined that OAS = 0 would be an impossibly strict condition for an *otologically normal* population; an OAS range 0 to 3 resulted in a more manageable rejection rate.

The 62 testees gave HTLs in both ears for all frequencies; a full-range practice test was performed in the L ear first, followed by HTLs in the R with an L-repeat series. The HTLs improved with repeat testing; the authors suggested that this improvement was due to learning, indicating increasing confidence with the audiometric task. The authors reported the HTLs given as an average of the R and L-repeat values. As they suspected, the thresholds for subjects with OAS equal to 3 or less made a useful sample, with a tolerable rejection rate.

Mean thresholds of subjects grouped in OAS bands.

OAS bands	number of subjects	HTLs, dB HL average of R and L-repeat					
		frequency, kHz					
		0.5	1	2	3	4	6
0	11	-1.3	-4.3	-3.8	-4.1	-1.0	0.4
1	11	0.6	-1.1	-2.3	-3.2	-0.4	-0.1
2 - 3	17	0.1	-4.0	-3.8	-0.7	1.3	5.5
4 - 6	12	0.8	-1.8	-2.2	0.3	0.3	5.1
7 - 12	11	3.8	2.5	3.6	4.7	8.9	14.7
>12		—	—	—	—	—	—

Of significant interest here is the effect of increasing OAS upon the threshold values at all frequencies. Those subjects with OAS = 1 or 2 (very strict interpretation of *otological normality*) gave noticeably better (more acute) thresholds that those subjects with OAS = 7 to 12 (most certainly not *otological normal*).

Section 3 of the present document deals with *typical* populations, not rigorously screened for *otological normality.*

Coles, Lutman and Buffin (2000)

This paper presents guidelines which aim to assist in the diagnosis of noise-induced hearing loss (NIHL) in the medico-legal setting. The task is to distinguish between possibility and probability, the legal criterion being 'more likely than not'. It is argued that the amount of NIHL needed to qualify for that diagnosis is that which is reliably measurable and identifiable in the audiogram.

A probable diagnosis of NIHL is easy for younger individuals where 1) there is a history of unprotected noise exposure of high level and long duration, 2) an archetypal audiometric *notch* maximal at 3, 4, and/or 6 kHz, and 3) no evident complicating factor or diagnostic competitor.

However, in a considerable proportion of NIHL cases, especially after the age of about 50 years, the characteristic high-frequency notch is missing or distorted. This is usually due to the additional presence of high-frequency hearing impairment of other causation, notably that associated with natural ageing. In most cases, AAHL has the effect of converting a noise-induced audiometric *notch* into a downward "bulge" in the higher audiometric frequencies.

AAHL for *otologically normal* persons has been standardised in ISO 7029 (1984, 2000). For males and females aged 18 years, and for all audiometric test frequencies, these Standards represent the median hearing threshold level (HTL) as a value of zero dB for a population of highly-screened individuals. Since the publication of these ISO standards, it has become evident that threshold values greater than zero are appropriate for persons screened to exclude otological disorder and noise exposure. The authors provide tables of median thresholds and deviations for such persons, with all values in dB HL.

- The median table values for the youngest age (20 years) were altered from those of ISO 7029 to give the expected HTLs (in dB HL) of highly-screened *otologically normal* young persons.

- These *otologically normal* median HTLs were then subjected to ISO 7029 calculation procedures to yield values consistent with *otologically normal* AAHLs and dispersions (both in dB HL).

The authors' tables are reproduced below, with selected data for males and female thresholds separated by age and audiometric frequency; the spread about the median (50%) is given for the better- and worse-hearing quartiles.

Also, the reader should be aware that the listed thresholds for 6 kHz contain an adjustment of 6 dB to account for an incorrect Reference Equivalent Threshold Sound Pressure Level specified for calibrations of audiometers using the TDH-39 earphone. This earphone is the most common model used in UK audiometry, but reported thresholds (uncorrected) would indicate an apparent-but-exaggerated hearing deficit at 6 kHz, a noise-sensitive frequency.

HTLs in dB HL, for males screened to exclude otological disorder and noise exposure.

		age, years					
freq., kHz	centile	20	30	40	50	60	70
0.25	25	2	2	3	4	6	8
	median	8	8	9	11	13	16
	75	14	15	16	8	21	25
0.5	25	1	1	2	3	5	8
	median	5	6	7	9	11	14
	75	11	11	13	15	19	23
1	25	-2	-1	0	1	4	6
	median	2	3	4	6	9	13
	75	7	7	9	12	16	21
2	25	-1	0	1	4	8	13
	median	4	5	7	11	16	22
	75	9	11	14	19	25	34
3	25	-1	0	3	7	14	21
	median	4	6	9	15	23	34
	75	11	13	17	25	36	49
4	25	0	2	6	13	21	33
	median	6	8	14	22	34	49
	75	14	16	24	35	50	70
6	25	0	2	7	14	24	37
	median	7	10	16	25	39	56
	75	16	19	27	39	57	79
8	25	0	2	8	17	29	45
	median	8	11	18	30	46	67
	75	17	21	31	46	67	94

The authors assert these values to be "typical age-associated hearing loss (AAHL) data for men". The table values would be more accurately described as '*otologically normal* age-associated hearing loss (AAHL) data for men'. In the present document, the term *typical* is used to indicate persons **not** rigorously screened to verify them as *otologically normal*.

HTLs in dB HL, for females screened to exclude otological disorder and noise exposure.

freq., kHz	centile	age, years 20	30	40	50	60	70
0.25	25	2	3	4	5	6	9
	median	8	8	9	11	13	16
	75	14	14	16	18	21	24
0.5	25	1	1	2	3	5	8
	median	5	6	7	9	11	14
	75	11	11	13	15	19	23
1	25	-2	-1	0	1	4	6
	median	2	3	4	6	9	13
	75	7	7	9	12	16	21
2	25	-1	0	1	4	7	11
	median	4	4	6	10	14	20
	75	9	10	13	17	23	30
3	25	-1	0	2	5	8	15
	median	4	5	8	12	17	24
	75	10	11	15	20	27	36
4	25	0	1	4	7	12	19
	median	6	7	10	15	22	30
	75	13	15	19	25	34	45
6	25	1	2	5	10	17	25
	median	7	9	13	19	28	39
	75	15	17	23	31	43	57
8	25	0	2	5	12	20	31
	median	8	10	15	23	34	48
	75	17	20	26	37	51	70

The authors assert these values to be "typical age-associated hearing loss (AAHL) data for women". The table values would be more accurately described as '*otologically normal* age-associated hearing loss (AAHL) data for women'. In the present document, the term *typical* is used to indicate persons **not** rigorously screened to verify them as *otologically normal*.

Rodríguez Valiente *et al*. (2015)

Age-related hearing loss is a gradually on-going condition, and the boundary between normal and pathological hearing loss must be defined along a continuous scale. ISO 7029:2000 defines the distribution of normal hearing as a function of age; this study was undertaken to provide more data, to enhance the scope of ISO 7029.

Hearing threshold data were collected from volunteer subjects recruited from patients attending a hospital ENT department serving the province of Madrid in Spain. Inclusion criteria for the subjects followed the rather loose conditions defining *otological normality* in recent ISO standards: a normal state of health, free from all signs or symptoms of ear disease, free from obstructing wax in the ear canals, no history of undue noise exposure, no use of potentially ototoxic drugs, and no familial hearing loss.

The male and female participants were aged between 5 and 90 years old, and were divided into eight age groups at 10-year intervals:

10 year group (5 to 14 years old; n = 246);
20 year group (15 to 24 years old; n = 132);
30 year group (25 to 34 years old; n = 153);
40 year group (35 to 44 years old; n = 158);
50 year group (45 to 54 years old; n = 168);
60 year group (55 to 64 years old; n = 154);
70 year group (65 to 74 years old; n = 105); and
80 year group (75 to 90 years old; n = 59).

The youngest and oldest groups are not of interest for the present document; their threshold data will not be presented. Given on the following page are the HTLs determined by pure-tone manual audiometry over the octave test frequencies from 250 Hz to 8 kHz. Thresholds for 3 kHz and 6 kHz were not determined, although these frequencies are included in ISO 7029. In respect of considering whether a particular individual may exhibit NIHL, these new Spanish data will not be quite as useful as the authors hoped.

HTLs for male subject groups by age: upper quartile, median and lower quartile.

		age groups, years					
freq, Hz	centile	15-24	25-34	35-44	45-54	55-64	65-74
250	25	5	10	10	10	10	15
	median	10	15	10	15	15	15
	75	15	20	20	20	20	20
500	25	5	6	10	10	10	15
	median	10	10	10	15	15	15
	75	15	15	15	20	20	20
1k	25	0	5	5	10	10	15
	median	5	10	10	12	15	15
	75	10	15	11	20	20	20
2k	25	0	5	0	5	5	10
	median	5	5	5	10	10	15
	75	10	10	10	15	20	30
4k	25	0	5	10	10	15	20
	median	5	10	10	15	20	40
	75	10	15	16	20	30	45
8k	25	0	5	5	14	20	30
	median	5	10	10	20	30	45
	75	10	15	15	25	45	60
n		64	74	82	80	77	51

HTLs for female subject groups by age: upper quartile, median and lower quartile.

freq, Hz	centile	age groups, years 15-24	25-34	35-44	45-54	55-64	65-74
250	25	5	5	5	10	10	15
	median	10	10	10	15	15	15
	75	15	15	15	20	20	22
500	25	5	5	5	10	10	15
	median	10	10	10	15	15	20
	75	15	15	15	20	20	25
1k	25	0	5	5	10	10	10
	median	5	10	10	10	15	15
	75	10	10	15	20	20	25
2k	25	0	0	5	5	10	15
	median	0	5	5	10	15	20
	75	5	10	10	15	20	30
4k	25	0	5	5	10	15	20
	median	5	10	5	15	20	30
	75	10	15	10	20	25	40
8k	25	0	0	5	10	15	35
	median	5	5	10	15	25	45
	75	15	15	15	20	35	55
n		68	79	76	88	77	54

3 RESEARCH USING *TYPICAL* POPULATIONS

3.1 Introduction

The standard ISO 7029 does not account for all the time-dependent hearing losses found in an ordinary legal claimant who may not be "in a normal state of health", but rather suffering from chronic medical conditions commonly linked to increasing age. Therefore, the decline of hearing acuity due only to natural ageing must be regarded as optimistic baseline against which to compare an ordinary or *typical* legal claimant.

The present document presents and reviews a number of research studies reporting the median thresholds and dispersion ranges of *typical* males and female subjects, screened to exclude individuals reporting:

a) some otological disorder and
b) exposure to potentially harmful occupational noise.

3.2 The reviews

Berger, Royster and Thomas (1977)

In the absence of otological abnormalities, ear disease and high levels of occupational noise exposure, human hearing thresholds deteriorate with advancing years. This hearing loss affects high frequencies, with the losses accelerating with increasing age.

These authors felt that reported data for age-associated hearing loss comprises an uncomplicated aging effect (common to all individual males and females of humanity) but contaminated with *sociocusis*, the hearing damage associated with the noise of everyday living. *Sociocusis* would be regarded the result of military service, hunting, farming, transport, and the use of power tools and household machines. Such activities were considered quite ordinary for Americans employed in noisy occupations, and for those having lived relatively quiet life.

HTLs were determined for two sample populations from North Carolina in the United States. One sample population was enrolled from night-school students in a technical college in a rural setting; the sample comprised 121 males and 103 females, in the age range 16 to 59 years. Members of the other sample were visitors to an urban shopping mall: 213 males and 336 females, covering an age range of 15 to 79 years. There was no screening to exclude persons with a history of ear problems/disease; the only exclusion criterion was a lifetime exposure to industrial noise longer than 2 weeks; "this limited the subjects to clerks, salesmen, secretaries, housewives, students, bankers, and the like".

The reported results were mean HTLs of both ears, given in dB HL, for a range of audiometric frequencies. These means are reported in the tables below, separated into males and females, with age ranges appropriate to full-time employment. The study data did not contain a significant proportion of black subjects, so no attempt was made to contrast ageing data for black and white participants.

Male subjects by age: mean of R and L HTLs in dB HL

	age range, years				
freq., Hz	20-29	30-39	40-49	50-59	60-69
500	8.4	9.4	9.9	14.1	13.0
1k	5.2	7.0	8.0	12.9	11.5
2k	3.7	5.9	12.5	16.3	19.5
3k	5.7	10.9	20.2	26.4	32.2
4k	10.2	18.5	27.4	37.4	38.6
6k	16.1	21.1	32.5	49.2	45.9
sample n	86	54	58	24	15

Female subjects by age: mean of R and L HTLs in dB HL

	age range, years				
freq., Hz	20-29	30-39	40-49	50-59	60-69
500	8.2	9.9	11.0	12.7	13.6
1k	5.0	6.9	8.9	10.2	14.1
2k	3.1	5.2	9.3	9.7	23.1
3k	3.3	5.8	9.5	17.1	25.5
4k	4.4	8.3	12.4	18.2	29.2
6k	7.8	11.5	17.4	22.1	38.6
sample n	99	68	51	51	28

Several general trends may be seen. HTLs increase (grow worse) with age for all frequencies. For the noise-sensitive frequencies 3, 4 and 6 kHz, HTLs for males are consistently worse than those for females, suggesting that non-industrial noise exposure (including military service) is greater for males. These HTLs would be considered typical for Americans without noisy employment.

Robinson (1988)

Thresholds of hearing as a function of age and sex for persons screened for 'otological normality' have been standardised in ISO 7029. For the evaluation of hearing loss due to occupational noise exposure, it is not generally realistic to compare the HTLs to an age-matched 'otologically normal' baseline; the difference will include adventitious hearing loss as well as any noise-related component. Robinson offered thresholds for an unscreened population, derived from a critical analysis of published research material.

Seventeen hearing surveys, each employing little or no selection of subjects for *otological normality*, were critically reviewed to prepare a *typical* population in contrast to the highly screened population of ISO 7029. Given below are *typical* hearing thresholds for males and females, covering the age range 20 to 70 years; dispersion of thresholds about the median is given as the inter-quartile range. The threshold values in the tables are expressed relative to the median hearing at age 20 years for the *otologically normal* population; the reader may reproduce *typical* HTLs in dB HL by adding the entries found in the right-hand column of each table.

Hearing thresholds for males, relative to median *normal* hearing at age 20 years; for subject groups by age: upper quartile, median and lower quartile.

freq., Hz	centile	age groups, years 20	30	40	50	60	70	for HTLs add
500	25	0	1	1	3	5	9	2.1
	median	4	5	6	8	11	15	
	75	10	10	12	14	19	25	
1k	25	-1	-1	0	2	4	6	0.7
	median	2	3	4	6	10	15	
	75	5	8	10	12	18	28	
2k	25	-1	0	2	4	10	18	-0.8
	median	3	4	6	11	18	30	
	75	8	10	14	22	34	51	
3k	25	-1	1	4	9	18	32	0.7
	median	4	6	12	21	34	51	
	75	9	15	26	39	53	63	
4k	25	-1	3	8	14	25	40	0.9
	median	4	10	19	30	43	56	
	75	12	24	37	48	59	68	
6k	25	-2	0	5	13	25	41	6.2
	median	6	8	15	26	41	58	
	75	15	23	34	46	59	72	

Hearing thresholds for females, relative to median *normal* hearing at age 20 years; for subject groups by age: upper quartile, median and lower quartile.

freq., Hz	centile	age groups, years 20	30	40	50	60	70	for HTLs add
500	25	1	2	3	5	8	12	0.7
	median	5	6	8	11	14	20	
	75	10	12	14	17	22	30	
1k	25	-2	-1	1	2	5	8	-0.2
	median	2	3	5	6	10	16	
	75	4	6	10	12	18	27	
2k	25	-2	-1	1	4	7	13	-0.5
	median	2	4	6	9	14	22	
	75	6	8	11	16	24	36	
3k	25	-1	0	2	4	8	14	-0.2
	median	2	4	6	10	16	26	
	75	6	8	12	18	27	41	
4k	25	-3	-1	2	5	10	17	0.4
	median	1	4	7	12	19	31	
	75	6	9	13	21	32	48	
6k	25	-3	0	3	8	14	24	4.1
	median	2	6	10	15	24	39	
	75	9	12	18	27	39	57	

The data for females show that the medians and inter-quartile ranges for 500 Hz and 1 kHz become slightly greater than for males at age 60 and 70 years.

For the frequencies 1 to 8 kHz, the medians and inter-quartile ranges for males are somewhat greater than for females at the older ages. As the frequency becomes higher, the male/female discrepancy extends to lower ages.

Brant and Fozard (1990)

This study examined repeated measurements of hearing thresholds collected on a large and relatively homogeneous group of individuals ranging in age from 20-95 years. Participants were male volunteers in the Baltimore Longitudinal Study of Aging, an ongoing multi-disciplinary study of normal human aging begun in 1958. In any given year, 500-700 males were active in the study.

The males were generally well-educated (75% had completed a first degree at university), had sufficient economic means so that 82% considered themselves to be “financially comfortable”, were predominantly white (95%), and lived in the Baltimore-Washington DC metropolitan area.

No questionnaire or other assessment of noise exposure was given to the participants. The authors reasoned that the predominantly high educational and socio-economic status of these males, and the fact that most were engaged in white-collar jobs made it unlikely that very many were exposed to loud noises for long periods in their adult lives. Examination of medical histories given by the subjects ensured that no individual in the study had a prior history of significant hearing problems.

The subjects’ HTLs were determined by continuous-sweep-tone Békésy audiometry with frequencies ranging from 100 to 10 000 Hz; the test signal was presented using TDH-49P earphones. Participants were instructed to press a hand-held response button upon hearing a tone, to hold the button down as long as the tone was audible, and to release it when the signal was no longer heard. The audiogram traces were read to give HTLs at eleven frequencies (125, 250, 500, 750, 1 k, 1.5 k, 2 k, 3 k, 4 k, 6 k and 8 k hertz). The HTLs presented below are those given at the first testing session; HTLs for later sessions, after intervals of up to 15 years, are of no present interest.

Male subjects by age: mean of R and L HTLs in dB HL

	age, years					
freq., Hz	20	30	40	50	60	70
250	10.4	11.7	13.2	14.8	16.4	19.8
500	5.7	6.6	7.7	10.0	12.1	14.6
1k	4.8	7.4	11.6	11.0	15.6	20.3
2k	5.1	8.1	14.7	15.1	22.4	30.2
3k	4.8	13.5	20.5	25.8	33.8	42.3
4k	6.0	14.9	25.5	34.3	41.7	50.8
6k	6.1	17.9	30.0	39.2	46.4	57.3
8k	5.1	15.0	26.8	35.2	46.3	59.5
sample n	72	136	155	173	127	118

These male subjects did not undergo a rigorous selection process, although they had no history of ear disorder/disease, and were judged to be free of significant occupational noise exposure. The HTLs at each frequency, and for each age, are somewhat higher (less acute) than the male thresholds given in ISO 7029:1984. The males of this study should be considered *typical* rather than *otologically normal*.

Robinson (1991)

This author computed HTLs to aid in the estimation of noise-induced hearing loss for *otologically normal* populations and for *typical* unscreened populations, of males and females tabulated separately. Of interest here are the data for the *typical* unscreened populations without noise exposure; the "unscreened" descriptor is not defined.

For the purposes of this Health and Safety Executive report, hearing threshold levels are given as the average over both ears and over the audiometric frequencies 1, 2 and 3 kHz. The HTLs are expressed as dB HL relative to the audiometric zero current at the time. The thresholds are given below, as the median with upper and lower quartiles.

Thresholds, in dB HL, averaged over 1, 2 and 3 kHz for unscreened males.

	age, years				
centile	20	30	40	50	60
25	-1	1	3	6	12
median	3	4	8	13	21
75	7	10	15	22	32

values to the nearest dB

Thresholds, in dB HL, averaged over 1, 2 and 3 kHz for unscreened females.

	age, years				
centile	20	30	40	50	60
25	-1	0	2	4	8
median	2	4	6	9	13
75	5	7	10	14	21

values to the nearest dB

The reader will notice that the hearing of females is more acute than seen in males, with a smaller inter-quartile range.

The threshold average (over 1, 2, and 3 kHz) is not much used now to quantify NIHL. It harks back to impairment of hearing sufficient to cause difficulties with conversational speech, found in a British Standard of 1976.

Clark and Bohl (1992)

ISO 1999-1990 deals with occupational noise exposure and its effects on hearing; noise-induced permanent threshold shift is added to age-associated hearing loss. Annex A of the standard gives AAHL for highly-screened *otologically normal* persons; Annex B gives values of AAHL for an unscreened sample, considered to be representative of the population of an industrialised country, but without exposure to occupational noise.

These researchers went back to the original sources of the Annex B data. They found errors (mostly typographical errors in the reported thresholds, but also some missing minus signs amongst the thresholds) had been incorporated into the published Annex B. Corrected tables were offered, as seen below. The HTLs are for the better-hearing ears of the original two subject samples used to compile Annex B.

Corrected version of ISO 1999 Annex B for males; HTLs in dB HL

		age, years			
freq., Hz	centile	30	40	50	60
500	10	-1	0	1	2
	median	7	8	10	12
	90	15	19	21	26
1k	10	-5	-4	-3	-2
	median	0	3	5	6
	90	10	15	16	21
2k	10	-4	2	-2	0
	median	2	13	8	10
	90	13	41	28	43
3k	10	-1	2	5	9
	median	9	13	19	30
	90	30	41	51	62
4k	10	-1	4	8	12
	median	10	17	26	36
	90	38	50	54	68
6k	10	8	11	17	22
	median	18	24	31	46
	90	48	62	62	80

Corrected version of ISO 1999 Annex B for females; HTLs in dB HL

		age, years			
freq., Hz	centile	30	40	50	60
500	10	-1	0	1	4
	median	6	7	10	14
	90	15	19	21	29
1k	10	-6	-5	-4	-2
	median	1	2	4	7
	90	9	13	16	21
2k	10	-6	-4	-2	0
	median	0	2	6	8
	90	10	13	23	29
3k	10	-4	-2	0	6
	median	4	6	9	16
	90	13	18	26	27
4k	10	-5	-4	-1	4
	median	4	6	9	17
	10	16	18	26	43
6k	10	3	5	8	15
	median	12	15	20	29
	90	25	31	45	57

The authors concluded their brief article with: "These corrected values have been submitted to the working group which prepared the standard and to the secretariat of TC 43, and appropriate revisions to Annex B of the standard will be made." These authors' offering of corrected values did not appear in ISO 1999:2013. The 2013 edition, issued as BS ISO 1999:2013 includes three examples of HTLs for populations screened to exclude occupational noise. These populations are described by Hoffman *et al.* (2010, 2012), and two Scandinavian samples, Johansson and Arlinger (2002) and Engdahl *et al.* (2005); these three research reports are reviewed later in the present document.

Lawton (1998)

In compensation claims for hearing loss alleged to be due to occupational noise exposure, any medico-legal report should specify an equitable baseline against which to compare the state of the hearing of the Claimant. Some portion of the hearing loss of any Claimant will be attributable to the natural loss of hearing sensitivity due to ageing. The remainder **might** be due to other factors such as occupational noise, *sociocusis* or ear disease.

Age-related hearing loss has, for medico-legal purposes, been based upon the *otologically normal* population. However, such a baseline may be thought to be optimistic and unrealistic for hearing loss claims alleging damage due occupational noise.

Research was performed by the Institute of Hearing Research of the Medical Research Council, to describe the state of hearing of the British population within various age bands. The results of the UK National Study of Hearing are reported by Davis (1995), using subjects drawn from the electoral register in and around the cities of Cardiff, Glasgow, Nottingham and Southampton. Summaries are given of hearing loss due to age in ordinary males and females without noise exposure, but not selected for otological near-perfection. These *typical*-for-age thresholds might be considered an appropriate UK database for use in compensation claims for NIHL.

The report *Hearing in adults* (Davis, 1995) presents a large number of tables, giving HTLs (averaged over both ears) for various fractions of typical British males and females, at stated ages. Given below are the reported HTLs for *typical* males and females, without conductive hearing loss (that is, with no difference between air- and bone-conduction thresholds), and with no exposure to hazardous noise.

Familiar general trends may be seen in these reported data, seen below. For any particular audiometric test frequency, the HTLs increase with age, at the centiles given. For any particular audiometric test frequency, the spread of HTLs increase with age. For the higher frequencies, 3 kHz and above, the HTLs increase faster with age for males than for females.

Notes: The source document *Hearing in adults* (Davis, 1995) offered hearing data offered median threshold levels and spreads about the medians for manual workers. Although these 'manual' data have a degree of face validity for NIHL compensation claims, they were not chosen for consideration in Lawton (1998). Females were classified as manual workers on the basis of the occupation of their spouses, not their own employment. This sociological aspect of *Hearing in adults* was felt to compromise the data for females classified as manual workers. The data presented below deals with **all** males and **all** females screened to eliminate conductive hearing losses and a history of noise exposure.

HTLs, dB HL, for males screened to exclude individuals with
conductive hearing loss and a history of noise exposure.

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
250	25	4	3	7	9	8
	median	9	8	10	15	14
	75	12	11	14	18	18
500	25	1	1	3	5	10
	median	6	5	6	10	13
	75	10	8	11	15	18
1k	25	1	-1	3	5	8
	median	2	3	6	9	14
	75	8	4	10	17	18
2k	25	-1	1	3	3	12
	median	4	6	7	10	15
	75	7	9	12	16	28
3k	25	-3	5	6	12	17
	median	3	8	11	17	24
	75	10	19	18	31	36
4k	25	1	8	8	20	25
	median	7	14	13	25	31
	75	12	22	22	43	51
6k	25	7	14	20	22	33
	median	13	20	27	37	50
	75	19	31	33	58	68
8k	25	1	4	14	18	33
	median	6	10	19	32	49
	75	14	19	33	56	66
n with exclusions		90	45	48	50	34
N without exclusions		177	142	203	330	280

The bottom rows of the table above give n, the number of male subjects in the sub-set screened to eliminate conductive hearing loss and noise exposure, and N, the number of males (without exclusions) within the age range. The values of n and N indicate high rejection proportions, ranging from 0.49 to 0.88 for males.

HTLs, dB HL, for females screened to exclude individuals with conductive hearing loss and a history of noise exposure.

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
250	25	5	5	7	8	12
	median	8	8	10	12	17
	75	11	12	16	17	23
500	25	2	2	3	5	8
	median	5	6	7	10	14
	75	8	10	11	15	21
1k	25	1	1	3	5	7
	median	4	4	7	10	12
	75	8	8	11	14	18
2k	25	2	1	4	6	9
	median	5	5	8	12	16
	75	9	9	13	18	25
3k	25	2	2	4	8	14
	median	6	7	10	14	21
	75	10	11	16	21	32
4k	25	3	4	6	12	19
	median	7	8	13	18	26
	75	12	15	19	25	38
6k	25	9	13	14	22	30
	median	15	20	22	28	39
	75	20	26	29	39	54
8k	25	4	6	9	16	30
	median	9	12	15	28	47
	75	13	18	22	41	61
n with exclusions		158	110	135	157	92
N without exclusions		525	185	246	340	240

The bottom rows of the table above give n, the number of female subjects in the sub-set screened to eliminate conductive hearing loss and noise exposure, and N, the number of females (without exclusions) within the age range. The values of n and N indicate high rejection proportions, ranging from 0.41 to 0.70 for females.

Johansson and Arlinger (2002)

These authors undertook the task of gathering a reference database of HTLs in a population of individuals without hazardous noise exposure. Their ultimate purpose was to enable evaluation of hearing damage in members of the general population working in potentially injurious occupational noise.

Their reference database was intended to reflect the effects of non-occupational environment, heredity and disease that influence the general population, in addition to age. Therefore, subjects for the reference database were completely unscreened, save for the single exclusion of significant occupational noise exposure. This exclusion was made using a questionnaire intended to estimate the degree of noise exposure during present and former employments. A question asked each potential subject to state whether he or she could have a conversation with another person at a distance of one metre, in the presence of noise in the workplace. Those who answered “Yes, with normal voice level” or “Yes, with raised voice” were included in the survey. Those who answered “Yes, if I shout” or “No, not at all” were excluded.

The potential reference population was chosen randomly (by birthdate within each month) from the census records of the Swedish province of Östergötland, comprising 412 411 individuals. Over 1 800 persons were invited to participate; in the end, 603 ‘non-noise-exposed’ persons were selected for the reference population (266 males and 337 females). The breakdown-by-age of the study subjects is given below:

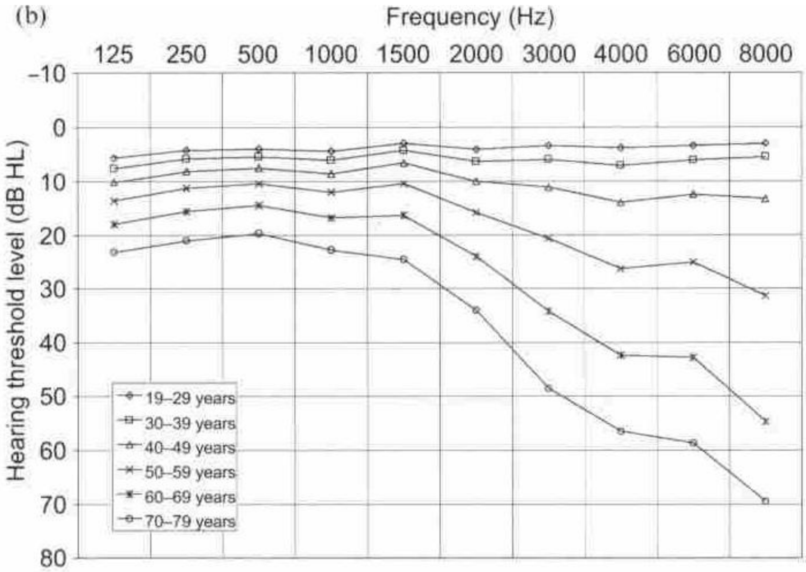
Numbers of subjects in the reference database, separated by sex and age band.

	age range, years					
	19-29	30-39	40-49	50-29	60-69	70-80
males	16	27	34	63	39	47
females	27	57	61	74	57	61

The numbers within each age range do not follow accurately what might be expected as a proportion of the Swedish population. For both males and females enrolled in the study, the youngest range is somewhat under-represented. For males in the study, the older ranges (age 50 and above) have higher numbers than would be expected as a proportion of the population.

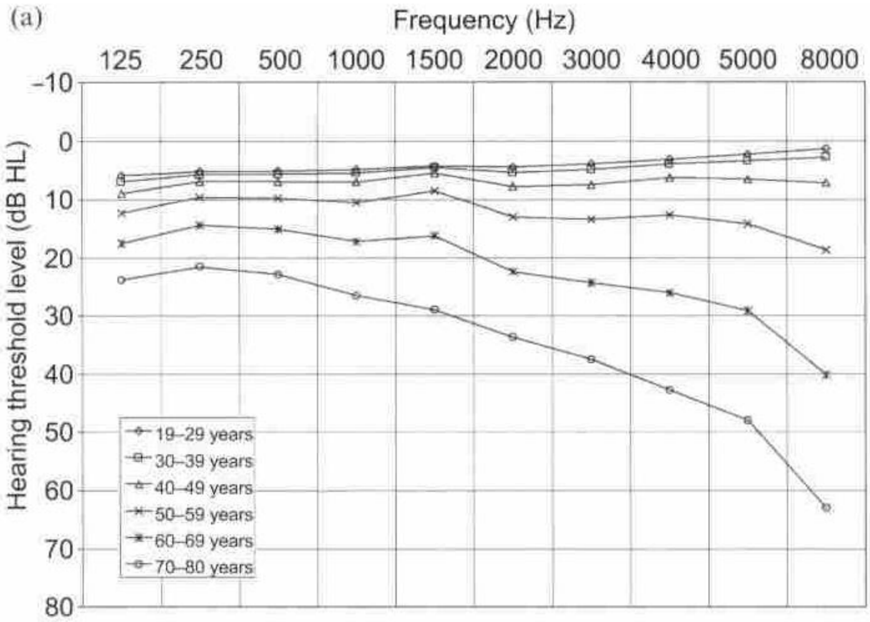
Each of the individuals enrolled in the reference sample performed manual air-conduction audiometry, using insert earphones. Thresholds were determined for both ears of each individual, at the frequencies 0.125, 0.25, 0.5, 1, 1.5, 2, 3, 4, 6 and 8 kHz. The authors presented their final results as group audiograms for males and females; these figures are reproduced below.

Median HTLs for male subjects, presented graphically by the authors, separated by frequency and age bands.



Considering the male group audiograms, the reader will note that the older male groups show downward 'bulges' at the frequencies 3 and 4 kHz. This could indicate that the exclusion for occupational noise was insufficiently stringent, enrolling those admitting *conversation with raised voice* in the presence of workplace noise. Alternatively, the audiometric bulges could be *sociocusis*, that component of overall hearing loss attributable to non-occupational noise exposure, for instance from motor cycles, firearms, or home use of power tools.

Median HTLs for female subjects, presented graphically by the authors, separated by frequency and age bands.



The reader will note that the female groups do not exhibit the downward ‘bulges’ (less acute hearing) at the frequencies 3 and 4 kHz, as seen in the older males groups. Perhaps these Swedish women enjoyed quieter lives than did their male counterparts in this study.

The median thresholds for those audiometric frequencies commonly used in the UK can be read from the figures; the values are given below, separated by sex and age band.

Median HTLs for male subjects, separated by frequency and age band; threshold values given to the nearest dB.

	age, years					
freq., kHz	19-29	30-39	40-49	50-59	60-69	70-79
0.25	4	6	8	12	15	21
0.5	4	5	7	11	14	20
1	5	6	8	10	16	23
2	5	6	10	16	24	34
3	4	6	11	21	34	48
4	4	7	14	27	42	57
6	4	7	13	26	42	58
8	3	6	14	32	55	69

Median HTLs for female subjects, separated by frequency and age band; threshold values given to the nearest dB.

	age, years					
freq., kHz	19-29	30-39	40-49	50-59	60-69	70-79
0.25	5	5	7	10	14	22
0.5	5	5	7	10	15	23
1	5	5	7	10	17	26
2	5	5	8	13	22	34
3	4	5	7	13	24	38
4	3	4	6	13	26	43
6	2	3	6	14	29	48
8	2	3	7	18	40	63

Johansson and Arlinger (2004)

These authors gave a reference data base of HTLs for an adult population in Sweden, screened to eliminate individuals with known ear pathology and those exposed to hazardous occupational noise. Those persons accepted into the survey gave HTLs for the conventional audiometric test frequencies over the range 0.125 to 8 kHz. This data base was reported in Johansson and Arlinger (2002).

It is known that NIHL initially appears as a threshold shift in the frequency region 3 to 6 kHz in pure-tone audiometry. These frequencies are obviously of most interest when evaluating hearing loss due to occupational noise exposure.

The data from 2002 were re-worked to give an additional reference data base for the pure-tone average for the noise-sensitive frequencies 3, 4, and 6 kHz. This high-frequency average was determined from each individual's HTLs, with the benefit that test-retest accuracy was somewhat better when considering the average of HTLs at several frequencies compared to a single frequency.

The distribution of the high-frequency averages is reproduced below, for male and female subjects of increasing age. The values have been rounded to the nearest dB.

3, 4, 6 kHz average HTLs, dB HL: Males screened to eliminate ear-related disorders/diseases and a history of noise exposure.

	age, years				
centile	25	35	45	55	65
10	2	3	6	12	21
median	6	9	16	27	43
90	17	26	39	54	68

3, 4, 6 kHz average HTLs, dB HL: Females screened to eliminate ear-related disorders/diseases and a history of noise exposure.

	age, years				
centile	25	35	45	55	65
10	0	1	3	7	13
median	6	6	9	17	31
90	12	15	22	36	53

As seen before, the HTLs for females are lower (more acute) than those for males of the same age. For both sexes, the spread of HTLs increases with age, with the males exhibiting the greater inter-decile range between 10% and 90%.

Engdahl *et al.* (2005)

The likelihood that an individual's hearing loss has developed due to occupational noise exposure may be estimated by comparing that individual's HTLs with the thresholds of a suitable reference population, separated for different age groups and gender. Any conclusion regarding potential NIHL will depend heavily on the threshold distribution of the reference population and how it has been selected.

These investigators present reference HTL data of a population in Norway, with a sample screened for various criteria, and compared to unscreened population data. Invitations were sent by mail to all men and woman in the county of Nord-Trøndelag. This county is representative of Norway in terms of economy, occupations and income sources, age distribution, morbidity, and mortality. However, the county has only 5 towns (none with more than 12 000 inhabitants). Principal occupations were farming, forestry, trade and commerce, and service industries. Those invited to participate were aged 20 years or more, and included in the Norwegian public address registry. In total, there were 94 196 potential subjects. The population of Nord-Trøndelag was considered suitable for epidemiological studies, being stable and homogeneous (less than 3% non-Caucasian). Invitations were sent out for hearing tests, along with a questionnaire about occupational and leisure noise exposure, ear-related disorders and diseases, and symptoms of hearing loss. In all, over 82 000 people were invited to participate in this mass-population survey.

Computer-controlled pure-tone audiometry was administered to 40 541 males and 40 728 females; aged 20 to 89 years during the period 1995 to 1997, using instruments equipped with TDH-39P earphones and MX 41/AR cushions.

These authors set out to establish an appropriate reference sample of HTLs from males and females of various age ranges, against which to compare persons with known noise exposure. To this end, the authors reported audiometric data for samples screened to eliminate ear-related disorders and diseases, and exposure to significant occupational and leisure noise. The median, and upper and lower quartiles of HTLs for these *typical* (but not necessarily *otologically normal*) subjects are given in the tables below. These *typical* subjects, 4 435 males and 14 984 females, ranged from 20 to 79 years. Data acquired from older persons are not reported here.

HTLs, dB HL averaged over R and L ears: Males screened to eliminate ear-related disorders/diseases and a history of noise exposure.

freq., Hz	centile	age, years 20-29	30-39	40-49	50-59	60-69	70-79
250	25	7.5	10.0	10.0	12.5	15.0	17.5
	median	12.5	12.5	15.0	17.5	20.0	22.5
	75	17.5	17.5	20.0	22.5	25.0	30.0
500	25	2.5	2.5	5.0	5.0	7.5	10.0
	median	5.0	7.5	7.5	7.5	12.5	17.5
	75	10.0	10.0	12.5	12.5	17.5	25.0
1k	25	0.0	2.5	2.5	5.0	7.5	12.5
	median	2.5	5.0	5.0	7.5	12.5	20.0
	75	7.5	7.5	10.0	12.5	17.5	30.0
2k	25	-2.5	0.0	2.5	5.0	10.0	20.0
	median	2.5	5.0	7.5	10.0	17.5	32.5
	75	7.5	10.0	12.5	17.5	30.0	47.5
3k	25	-2.5	2.5	5.0	7.5	17.5	32.5
	median	2.5	5.0	10.0	15.0	30.0	47.5
	75	7.5	12.5	17.5	25.0	47.5	60.0
4k	25	-2.5	2.5	7.5	15.0	27.5	42.5
	median	5.0	10.0	15.0	22.5	40.0	57.5
	75	10.0	15.0	25.0	37.5	57.5	70.0
6k	25	5.0	10.0	12.5	20.0	35.0	*51.6**
	median	10.0	15.0	20.0	30.0	50.0	65.0
	75	17.5	22.5	30.0	42.5	65.0	77.5
8k	25	2.5	5.0	10.0	17.5	37.5	57.5
	median	7.5	10.0	17.5	27.5	52.5	70.0
	75	12.5	17.5	27.5	45.0	67.5	80.0
n with exclusions		650	619	997	807	586	594
N without exclusions		2967	4072	5041	4318	3444	2850

** Unlikely value given in source reference.*

Note: The values of n and N indicate high rejection proportions, ranging from 0.78 to 0.85.

HTLs, dB HL averaged over R and L ears: Females screened to eliminate ear-related disorders/diseases and a history of noise exposure.

freq, Hz	centile	age, years 20-29	30-39	40-49	50-59	60-69	70-79
250	25	10.0	10.0	12.5	15.0	17.5	20.0
	median	12.5	15.0	15.0	17.5	22.5	25.0
	75	17.5	20.0	20.0	25.0	27.5	32.5
500	25	2.5	5.0	5.0	7.5	10.0	15.0
	median	7.5	7.5	10.0	12.5	15.0	22.5
	75	10.0	12.5	12.5	17.5	22.5	30.0
1k	25	0.0	2.5	2.5	5.0	7.5	15.0
	median	2.5	5.0	7.5	10.0	12.5	22.5
	75	7.5	7.5	10.0	15.0	20.0	32.5
2k	25	0.0	0.0	2.5	5.0	10.0	20.0
	median	2.5	5.0	7.5	10.0	17.5	30.0
	75	7.5	10.0	12.5	17.5	27.5	40.0
3k	25	-2.5	0.0	2.5	5.0	12.5	22.5
	median	0.0	2.5	5.0	10.0	20.0	32.5
	75	5.0	7.5	12.5	17.5	27.5	45.0
4k	25	-2.5	0.0	2.5	7.5	15.0	27.5
	median	2.5	5.0	7.5	15.0	22.5	40.0
	75	7.5	10.0	15.0	22.5	35.0	52.5
6k	25	5.0	7.5	10.0	17.5	22.5	37.5
	median	10.0	12.5	17.5	22.5	32.5	52.5
	75	17.5	20.0	22.5	32.5	47.5	67.5
8k	25	2.5	5.0	10.0	15.0	27.5	47.5
	median	7.5	10.0	15.0	22.5	40.0	62.5
	75	12.5	15.0	22.5	35.0	55.0	75.0
n with exclusions		1840	2389	2983	2518	2223	2269
N without exclusions		3587	4633	5537	4703	3669	3345

Note: The values of n and N indicate rejection proportions ranging from 0.32 to 0.48.

While screening had little effect on the median HTLs of young adults, there was a substantial effect when screening men above 40 years of age for a history of noise exposure. Screening for known ear-related disorders and diseases resulted in small effects on the HTLs. The median thresholds of the screened samples (given above) exceeded the age- and sex-specific thresholds specified by ISO 7029. Indeed, the median thresholds of the unscreened samples (not reported here) exceeded the age- and sex-specific thresholds specified in ISO 7029. One may conclude that the ISO 7029 data are an optimistic base-line for the hearing of most ordinary people.

Hoffman *et al.* (2010 and 2012)

For their publication of 2010, these authors extracted HTLs (for age, sex and frequency) from a national survey in the USA (National Health and Nutrition Examination Survey, 1999–2004) for presentation in a format suitable to replace Annex B in ISO 1999:1990. Their proposed new Annex comprises thresholds from 4 218 adults to represent a “typical unscreened population of an industrialised country”; see the review for Clark and Bohl

(1992) included in the present document. The publication of 2012 draws upon a later American national survey (National Health and Nutrition Examination Survey, 2005–2006) which included 252 older participants.

Audiometric thresholds were obtained using TDH-39 headphones, with pure-tone signals from a specially programmed automated test intended to mimic conventional manual audiometry. The automated threshold search followed the 'up by 5 dB, down by 10 dB' method. Threshold was defined as the level at which a subject responded at least 50% of the time (two-of-three or three-of-five trials).

The better-ear results for the participants of both national surveys are reproduced in the tables below. These tables give thresholds in dB HL, separated by audiometric frequency, spread within the samples (10%, 50% median, 90%), and age groups.

HTLs, dB HL: Males screened to eliminate a history of noise exposure.

		age range, years				
freq., Hz	centile	25-34	35-44	45-54	55-64	65-74
500	10	-1	-1	1	2	4
	median	7	8	10	11	15
	90	16	19	20	23	28
1k	10	-2	-1	1	1	4
	median	4	6	9	11	14
	90	14	17	18	23	31
2k	10	-5	-3	0	3	6
	median	4	6	10	14	21
	90	14	20	24	38	54
3k	10	-5	-1	3	7	13
	median	4	9	15	25	37
	90	17	29	45	57	66
4k	10	-2	2	6	13	20
	median	7	13	22	35	49
	90	23	39	57	65	73
6k	10	0	4	9	16	26
	median	11	17	25	40	56
	90	27	41	64	74	84
8k	10	-2	2	7	13	30
	median	8	14	23	42	60
	90	21	41	61	78	86
publication date		2010				2012

HTLs, dB HL: Females screened to eliminate a history of noise exposure.

freq., Hz	centile	age range, years 25-34	35-44	45-54	55-64	65-74
500	10	0	-1	1	4	5
	median	7	7	9	13	17
	90	17	19	21	27	32
1k	10	-3	-2	-1	1	3
	median	4	5	7	10	13
	90	12	15	19	26	33
2k	10	-4	-2	-1	1	4
	median	4	5	7	11	17
	90	12	16	21	28	35
3k	10	-6	-2	-2	2	8
	median	2	4	7	12	20
	90	11	15	21	33	42
4k	10	-5	-2	0	4	10
	median	4	7	10	16	27
	90	14	19	26	40	48
6k	10	0	3	4	9	17
	median	10	12	17	24	37
	90	22	27	34	49	61
8k	10	-2	1	4	10	16
	median	7	10	16	26	48
	90	17	25	39	58	74
publication date		2010				2012

The texts of these two articles give little indication of the degree/rigour of subject screening in the source studies of US groups (National Health and Nutrition Examination Surveys, 1999–2004 and 2005–2006). The authors' intention to eliminate a history of noise exposure refers back to ISO 1999-1990 and Clark and Bohl (1992).

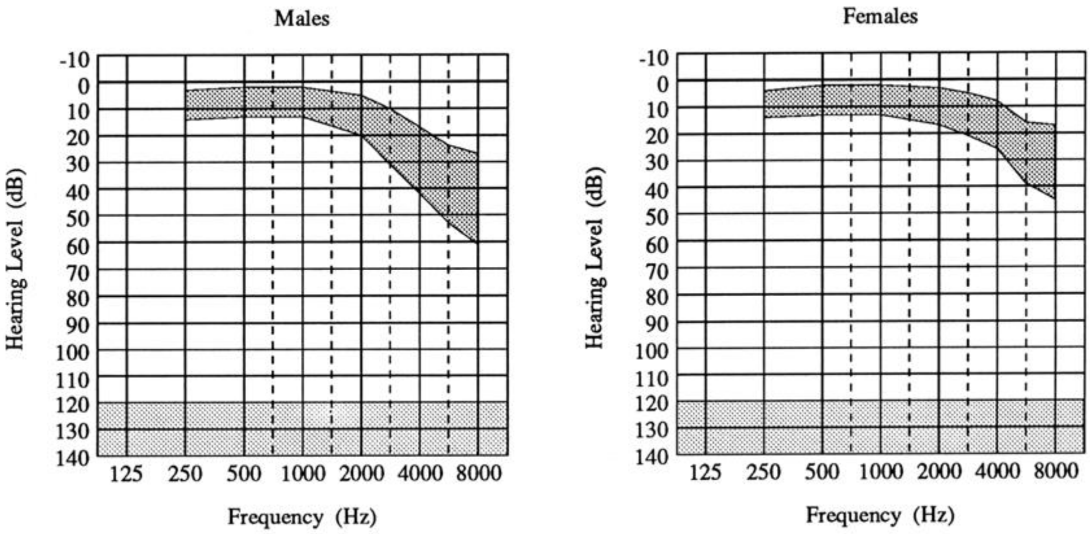
4 SUMMARY AND CONCLUSIONS

4.1 General Considerations

Summary data in this chapter are restricted to particular audiometric frequencies. The mid-frequency 1 kHz is sometimes used as a convenient ‘anchor’ against which to consider the other thresholds in an audiogram; this audiometric frequency is rarely involved in occupational hearing damage. NIHL is widely recognised as affecting the audiometric frequencies 3, 4 and/or 6 kHz; data are given for these noise-susceptible frequencies. The highest audiometric frequency 8 kHz usually exhibits a degree of hearing recovery in cases of NIHL, and thus gives the audiogram its notched aspect.

The inter-quartile ranges of thresholds should be especially useful in a medico-legal assessment relating to a compensation claim for hearing damage. In Civil Court compensation claims, the judgement hangs on the concept ‘more likely than not’. The inter-quartile range of thresholds indicates the middle 50% of thresholds expected of persons of a given age, or within a given age range. Above the inter-quartile range would be the 25% of thresholds better (more acute) than those within the inter-quartile range. Likewise, thresholds below the inter-quartile range would be the worse 25% of expected thresholds.

Consider the two audiogram forms given below, extracted from Lawton (1998).



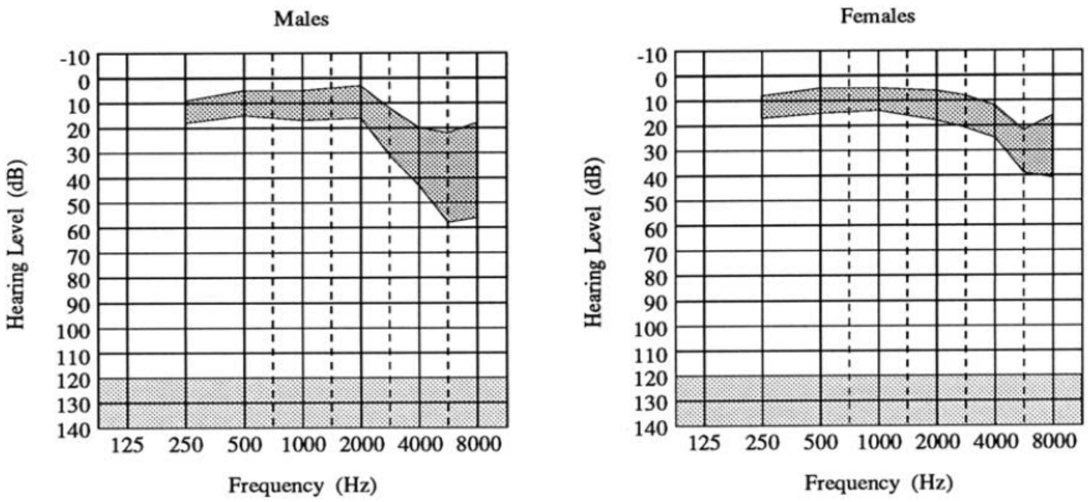
These two audiogram forms give data from ISO 7029 for *otologically normal* males and females, aged 60 years. The horizontal axis is audiometric test frequency in Hertz. The vertical axis is audiometer output in decibels Hearing Level; note that audiometric zero line is near the top of the chart, with increasing audiometer output in dB HL going downward for increasingly loud tones (necessary for listeners with increasing hearing losses).

On each audiogram, the inter-quartile range is shown as the shaded area. The upper boundary of the shaded area is the 25th centile of the threshold distribution, indicating a quarter of the population have thresholds lower (more acute) than the 25th centile. Likewise, the lower boundary is the 75th centile, with three quarters of the population having lower (better) thresholds for the indicated gender and age of the population. Half of the population of screened *otologically normal* males or females, aged 60 years, would give thresholds falling within the shaded area of the appropriate audiogram chart.

Age-related hearing loss has, for purely medical and audiological purposes, been based upon the hearing of the *otologically normal* population, screened for near-perfection. However, it is doubtful whether any older hearing loss claimant would be considered *otologically normal*, even without his or her occupational noise exposure. Most people accumulate hearing risk factors with increasing age.

In the medico-legal context of hearing damage claims, it must be kept in mind that *otological normality* should be demonstrated or proved, not accepted by default. Judgement by a medical examiner that a hearing loss claimant is 'clinically normal' (not ill) is not the same as classification of that claimant as *otologically normal* (near perfect). It is unlikely that any hearing loss claimant has been sufficiently questioned or examined to be verified as a member of the *otologically normal* population. It is 'more likely than not' that any hearing loss claimant is a member of the *typical* population.

The two audiogram forms given below were extracted from Lawton (1998) and based upon data from Davis (1995). The shaded areas represent the middle 50% of *typical* males and females in the age range 51 - 60 years, with **neither** conductive hearing loss nor noise exposure. (Recall that the previous figures gave the shaded middle half of thresholds expected of *otologically normal* persons at age 60 years.)



Thresholds for 3, 4 and/or 6 kHz falling within the shaded area would indicate values expected for half of the *typical* population within the age range 51 - 60 years. Thresholds for 3, 4 and/or 6 kHz falling below the shaded area would lend support to an allegation of NIHL if other necessary conditions were met, the most important being a history of unprotected exposure to potentially injurious noise.

4.2 *Normal* -v- *Typical* Populations

The following tables reproduce hearing data (median thresholds and inter-quartile ranges) for the audiometric frequencies 1 kHz to 8 kHz. The present author's intention is to facilitate easy comparison of the data from Coles, Lutman and Buffin (2000), representing medians and inter-quartile ranges in dB HTL (adjusted from the arbitrary data from ISO 7029 for *otologically normal* persons), and data from two research studies of *typical* persons.

The *typical* data are drawn from two population surveys: Davis, AC (1995) and Engdahl B *et al*. (2005). The 2005 study described a mass population hearing study of over 80 000 Norwegians living in a rural county; the study sample was considered homogeneous with less than 3% non-Caucasians. The UK National Study of Hearing (with results reported by Davis) was a more modest survey of approximately 2 600 persons living in the urban areas of Cardiff, Glasgow, Nottingham and Southampton. At the time of this study, the UK population was roughly 6% 'non-white'.

The following pages give a number of tables for audiometric frequencies, gender, and data sources; the tables are laid out thusly:

1 kHz (to 8kHz**) male (**or female**)**

CLB guidelines: Coles, Lutman and Buffin (2000) for *otologically normal* persons

		age, yrs				
freq., Hz	centile	20	30	40	50	60

Engdahl B *et al*. (2005) for *typical* persons

		age range, yrs				
freq., Hz	centile	20-29	30-39	40-49	50-59	60-69

National Study of Hearing (NSH): Davis, AC (1995) for *typical* persons

		age range, years				
freq., Hz	centile	18-30	31-40	41-50	51-60	61-70

Entries for the studies of *typical* persons give subject numbers subject to **exclusions** for ear disease and occupational noise exposure. The ages or age groups were not reported consistently across the three reports cited.

1 kHz male

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
1k	25	-2	-1	0	1	4
	median	2	3	4	6	9
	75	7	7	9	12	16

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
1k	25	0.0	2.5	2.5	5.0	7.5
	median	2.5	5.0	5.0	7.5	12.5
	75	7.5	7.5	10.0	12.5	17.5
n with exclusions		650	619	997	807	586

NSH

freq., Hz	centile	age range, yrs 18-30	31-40	41-50	51-60	61-70
1k	25	1	-1	3	5	8
	median	2	3	6	9	14
	75	8	4	10	17	18
n with exclusions		90	45	48	50	34

2 kHz male

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
2k	25	-1	0	1	4	8
	median	4	5	7	11	16
	75	9	11	14	19	25

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
2k	25	-2.5	0.0	2.5	5.0	10.0
	median	2.5	5.0	7.5	10.0	17.5
	75	7.5	10.0	12.5	17.5	30.0
n with exclusions		650	619	997	807	586

NSH

freq., Hz	centile	age range, yrs 18-30	31-40	41-50	51-60	61-70
2k	25	-1	1	3	3	12
	median	4	6	7	10	15
	75	7	9	12	16	28
n with exclusions		90	45	48	50	34

3 kHz male

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
3k	25	-1	0	3	7	14
	median	4	6	9	15	23
	75	11	13	17	25	36

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
3k	25	-2.5	2.5	5.0	7.5	17.5
	median	2.5	5.0	10.0	15.0	30.0
	75	7.5	12.5	17.5	25.0	47.5
n with exclusions		650	619	997	807	586

NSH

freq., Hz	centile	age range, yrs 18-30	31-40	41-50	51-60	61-70
3k	25	-3	5	6	12	17
	median	3	8	11	17	24
	75	10	19	18	31	36
n with exclusions		90	45	48	50	34

4 kHz male

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
4k	25	0	2	6	13	21
	median	6	8	14	22	34
	75	14	16	24	35	50

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
4k	25	-2.5	2.5	7.5	15.0	27.5
	median	5.0	10.0	15.0	22.5	40.0
	75	10.0	15.0	25.0	37.5	57.5
n with exclusions		650	619	997	807	586

NSH

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
4k	25	1	8	8	20	25
	median	7	14	13	25	31
	75	12	22	22	43	51
n with exclusions		90	45	48	50	34

6 kHz male

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
6k	25	0	2	7	14	24
	median	7	10	16	25	39
	75	16	19	27	39	57

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
6k	25	5.0	10.0	12.5	20.0	35.0
	median	10.0	15.0	20.0	30.0	50.0
	75	17.5	22.5	30.0	42.5	65.0
n with exclusions		650	619	997	807	586

NSH

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
6k	25	7	14	20	22	33
	median	13	20	27	37	50
	75	19	31	33	58	68
n with exclusions		90	45	48	50	34

8 kHz male

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
8k	25	0	2	8	17	29
	median	8	11	18	30	46
	75	17	21	31	46	67

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
8k	25	2.5	5.0	10.0	17.5	37.5
	median	7.5	10.0	17.5	27.5	52.5
	75	12.5	17.5	27.5	45.0	67.5
n with exclusions		650	619	997	807	586

NSH

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
8k	25	1	4	14	18	33
	median	6	10	19	32	49
	75	14	19	33	56	66
n with exclusions		90	45	48	50	34

1 kHz female

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
1k	25	-2	-1	0	1	4
	median	2	3	4	6	9
	75	7	7	9	12	16

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
1k	25	0.0	2.5	2.5	5.0	7.5
	median	2.5	5.0	7.5	10.0	12.5
	75	7.5	7.5	10.0	15.0	20.0
n with exclusions		1840	2389	2983	2518	2223

NSH

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
1k	25	1	1	3	5	7
	median	4	4	7	10	12
	75	8	8	11	14	18
n with exclusions		158	110	135	157	92

2 kHz female

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
2k	25	-1	0	1	4	7
	median	4	4	6	10	14
	75	9	10	13	17	23

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
2k	25	0.0	0.0	2.5	5.0	10.0
	median	2.5	5.0	7.5	10.0	17.5
	75	7.5	10.0	12.5	17.5	27.5
n with exclusions		1840	2389	2983	2518	2223

NSH

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
2k	25	2	1	4	6	9
	median	5	5	8	12	16
	75	9	9	13	18	25
n with exclusions		158	110	135	157	92

3 kHz female

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
3k	25	-1	0	2	5	8
	median	4	5	8	12	17
	75	10	11	15	20	27

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
3k	25	-2.5	0.0	2.5	5.0	12.5
	median	0.0	2.5	5.0	10.0	20.0
	75	5.0	7.5	12.5	17.5	27.5
n with exclusions		1840	2389	2983	2518	2223

NSH

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
3k	25	2	2	4	8	14
	median	6	7	10	14	21
	75	10	11	16	21	32
n with exclusions		158	110	135	157	92

4 kHz female

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
4k	25	0	1	4	7	12
	median	6	7	10	15	22
	75	13	15	19	25	34

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
4k	25	-2.5	0.0	2.5	7.5	15.0
	median	2.5	5.0	7.5	15.0	22.5
	75	7.5	10.0	15.0	22.5	35.0
n with exclusions		1840	2389	2983	2518	2223

NSH

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
4k	25	3	4	6	12	19
	median	7	8	13	18	26
	75	12	15	19	25	38
n with exclusions		158	110	135	157	92

6 kHz female

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
6k	25	1	2	5	10	17
	median	7	9	13	19	28
	75	15	17	23	31	43

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
6k	25	5.0	7.5	10.0	17.5	22.5
	median	10.0	12.5	17.5	22.5	32.5
	75	17.5	20.0	22.5	32.5	47.5
n with exclusions		1840	2389	2983	2518	2223

NSH

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
6k	25	9	13	14	22	30
	median	15	20	22	28	39
	75	20	26	29	39	54
n with exclusions		158	110	135	157	92

8 kHz female

CLB guidelines

freq., Hz	centile	age, yrs 20	30	40	50	60
8k	25	0	2	5	12	20
	median	8	10	15	23	34
	75	17	20	26	37	51

Engdahl

freq., Hz	centile	age range, yrs 20-29	30-39	40-49	50-59	60-69
8k	25	2.5	5.0	10.0	15.0	27.5
	median	7.5	10.0	15.0	22.5	40.0
	75	12.5	15.0	22.5	35.0	55.0
n with exclusions		1840	2389	2983	2518	2223

NSH

freq., Hz	centile	age range, years 18-30	31-40	41-50	51-60	61-70
8k	25	4	6	9	16	30
	median	9	12	15	28	47
	75	13	18	22	41	61
n with exclusions		158	110	135	157	92

The reader will have noted that, for the frequencies 1 and 2 kHz, the data for *otologically normal* (CLB guidelines) and *typical* (Engdahl and NSH) persons, both males and females, are quite similar across the age range. For the frequencies 3 kHz and higher, subjective comparisons of the datasets yield few consistent trends.

A new question now emerges: Which dataset for *typical* persons would be most appropriate for the assessment of hearing damage compensation claims? Here the choice is between different populations (Norwegian rural -v- UK urban/suburban) with different sample sizes (very large -v- modest, respectively). In most cases, the larger sample would be assumed to offer better accuracy and precision.

In the specific case under consideration here, the underlying populations are neither fundamentally dissimilar nor exactly alike. Close inspection shows that differences exist between the descriptive statistics for Engdahl *et al* (2005) and the National Study of Hearing (Davis, 1995). Such differences are non-systematic, that is, showing neither population to have uniformly lower median thresholds and smaller interquartile ranges.

The only general guide may be drawn from Robinson, Shipton and Hinchcliffe (1981) reviewed above in section 2.3:

> Persons rigorously screened to ensure *otological normality* gave noticeably better (more acute) thresholds for the audiometric frequencies 1 to 6 kHz than did subjects with adverse clinical signs or unfavourable factors in their individual noise and medical histories.

Reasoning that, as most people accumulate hearing risk factors with increasing age, older hearing loss claimants would not be considered *otologically normal*, even without his or her occupational noise exposure. The alternative choice is to compare hearing loss claimants against a *typical* population.

5 RECOMMENDATION

The likelihood that an individual's hearing loss has developed due to occupational noise exposure may be estimated by comparing that individual's HTLs with the thresholds of a suitable reference population, separated for different age groups and gender.

The median thresholds of the screened samples of *typical* persons exceeded the age- and sex-specific thresholds specified by ISO 7029 for an *otologically normal* population. This indicates that the ISO 7029 data are an optimistic baseline for the hearing of ordinary persons.

The UK National Study of Hearing should appeal to UK Courts. This study by the IHR/MRC determined Hearing Threshold Levels for British persons with **no** conductive hearing loss, and **no** exposure to significant occupational noise. The results were reported for males and females in certain age bands. These *typical*-for-age thresholds should be considered as the obvious database against which to compare hearing thresholds of UK workers alleging noise-induced hearing loss.

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DEFINITIONS of terms used in audiology

These definitions are drawn from Lawton and Robinson (1999).

acoustic trauma

Instantaneous injury to, or destruction of, a component or components of the auditory system resulting from exposure to a very high transient sound pressure, e.g. from explosion or weapons fire. The term is **not to be confused** with noise-induced hearing loss from chronic exposure.

audiometer

An electroacoustical instrument, equipped (for air conduction) with earphones and headband, which provides pure tones at specified frequencies and known sound pressure levels, used to determine hearing threshold levels, one ear at a time.

(a) Manual audiometer: one in which the signal presentations, the selection of frequency and hearing level, as well as the noting of the subject's responses, are performed manually by the audiometrician.

(b) Automatic-recording audiometer (also called self-recording audiometer): one in which the signal presentations and the changes of hearing level and frequency are implemented automatically at set rates; only the direction of hearing level change is under the subject's control. Recording of the subject's responses is also done automatically. An automatic-recording audiometer may have facilities for presenting fixed frequencies or a continuously-variable (sweep) frequency, or both; it may also provide continuous as well as pulsed tone outputs.

(c) Computer-controlled audiometer: one in which the test procedure is controlled by a computer or microprocessor. Often, the hearing threshold levels are calculated by a pre-set programme, for display or print-out.

audiometric frequencies

The series of frequencies conventionally employed in pure-tone audiometry. The series comprises the preferred frequencies at one-octave intervals from 125 to 8 000 Hz, usually supplemented by 3 000 and 6 000 Hz.

audiometric zero

For pure-tone air-conduction audiometry: a set of sound pressure levels of pure tones at audiometric frequencies, intended to typify the threshold of hearing of young otologically normal persons. For each frequency, the value is expressed by the sound pressure level measured in an acoustic coupler or artificial ear when the earphone, driven by a specific electrical signal, is placed on it.

This value is known as the reference equivalent threshold sound pressure level (RETSPL) for the frequency in question. The specific electrical signal is such that the sound pressure level it generates under the earphone when placed on the average human ear corresponds to the modal value of the thresholds of hearing of a group of young otologically normal persons of both sexes within a specified age range.

The term audiometric zero is also taken to mean the 0 dB HL line on audiogram charts.

Békésy audiometry

A form of automatic-recording pure-tone audiometry employing a continuous frequency sweep (glide tone). Use of the eponymous term should be confined to its original meaning to distinguish Békésy audiometry from fixed-frequency automatic-recording audiometry, sometimes called self-recording audiometry.

decibel (dB)

The unit for measuring the relative magnitude of a quantity based on a logarithmic scale. Commonly used to specify sound pressure level; A-weighted sound pressure level; hearing level; and hearing threshold level.

frequency

The rate of oscillation of an acoustic or vibratory signal, symbol *f*. The unit is the hertz (Hz), one complete oscillation per second. High frequencies can conveniently be expressed in kilohertz (kHz).

hearing level (HL)

Of a pure tone generated by a specified type of transducer for a specified frequency and manner of application, the sound pressure level (or the vibratory force level) of the tone, produced by the transducer in a specified calibration device (artificial ear, acoustic coupler or mechanical coupler) minus the appropriate reference equivalent threshold sound pressure level (or reference equivalent threshold force level). Thus, dial settings in hearing level of a correctly-calibrated audiometer indicate decibels relative to audiometric zero.

hearing loss

The amount in decibels by which an individual's hearing threshold level changes for the worse, commonly understood to refer to the combined loss from all causes. The term may also be applied to that part of the overall loss which is attributable to a known influence (for example, noise-induced hearing loss) or a combination of contributing causes (for example, age-associated hearing loss). The related term *threshold shift* implies before-and-after comparison, whereas hearing loss commonly assumes a notional starting point such as audiometric zero.

In a qualitative sense, hearing loss is used loosely to mean a symptom of hearing disorder, and is often modified by descriptors, e.g. conductive, sensorineural, etc.

hearing threshold level (HTL)

Of a given ear, for a pure tone of specified frequency, the threshold of hearing at that frequency, expressed as hearing level in dB HL. Note that hearing threshold level is a property of the ear under test whereas hearing level refers only to the sound (or vibration) generated by an audiometer.

median

Of a statistical distribution ranked in magnitude, that value (true or notional) which divides the total number of observations in half. The median acknowledges the existence of outliers but is not influenced by their numerical values.

notch, noise notch

Of a pure-tone audiogram, a colloquial term for a sharply elevated (worse) threshold level over a narrow frequency range, flanked by lower (better) thresholds. A notch is often associated with noise-induced hearing loss.

otological normality

An ideal definition of otological normality would be the notional state of complete freedom from derangement, both of form and function, of the auditory system. Natural biological variability and ageing are not exclusions. In practice, normality is based upon a specified set of exclusion criteria, applied with greater or lesser rigour, to a total population.

In the principal audiological Standards, an *otologically normal person* is defined as:

> A person in a normal state of health, who is free from all signs or symptoms of ear disease and from obstructing wax in the ear canals, and who has no history of undue exposure to noise.

For the purpose of specifying calibration levels for audiometric instruments (audiometric zero), the otologically normal population is restricted to the age range 18-30 years. Recent extensions of the Standards (*e.g.* to higher frequencies and to speech audiometry) have introduced a narrower age range (18-25 years) and additional exclusion criteria, *viz.* history of familial hearing loss and known exposure to potentially ototoxic drugs.

pure-tone audiometry

A technique for determining a person's hearing threshold levels for pure tones by behavioural means, usually understood to employ a manual technique as described under **audiometer (a)**. Sound may be applied monaurally by means of an earphone (termed air-conduction audiometry), or vibrations may be applied to the skull by a bone vibrator (termed bone-conduction audiometry).

sound pressure level

The sound pressure level of a sound in air, in decibels (dB), is equal to 20 times the logarithm to the base 10 of the ratio of the root-mean-square sound pressure to the reference sound pressure (20 micropascals). This reference sound pressure is zero dB on the scale of sound pressure level.

threshold of hearing

The minimum level of a sound which is just audible in given conditions on a specified fraction of trials (conventionally 50%). The term is often understood to imply quiet listening conditions, that is, it represents the irreducible, absolute threshold.