

# **Guideline for diagnosing occupational noise-induced hearing loss**

## **Part 3: Audiometric standards**

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**Amended November 2012**

## Summary and Recommendations

This document considers standards relating to audiometric assessment of clients presenting with a history of noise exposure.

### 1. Acoustical test environment

Maximum permissible ambient sound pressure levels or noise levels (MPANL) in the test area shall meet the requirements of ISO 8253-1 Acoustics – Audiometric test methods, Part 1: Basic pure-tone air and bone conduction threshold audiometry for hearing threshold levels down to 0 dB HL.

The ability to accurately determine bone conduction thresholds to a hearing level of 5 dB HL is required. The maximum permissible background sound pressure levels to test to threshold levels of 5 dB for air and bone conduction with a +5 dB uncertainty over the range 500 to 8k Hz are provided in *Table 1* below. All test environments used for diagnostic audiology should meet the ambient noise requirements for bone conduction testing and hence test environments should comply with the ambient noise levels specified in the right hand column in *Table 1*.

Table 1: Maximum permissible ambient noise levels,  $L_{s,max}$ , for air and bone conduction audiometry for hearing thresholds to 5 dB, with 5 dB uncertainty over the range 500 to 8000 Hz, using typical supra-aural earphones such as the Telephonics TDH39 with MX 41/AR cushions or the Beyer DT48 (adapted from ISO 8253-1 Table 2 and Table 4).

Octave band centre frequency (Hz)	Maximum permissible background sound pressure levels	
	$L_{s,max}$ (dB re 20 $\mu$ Pa)	
	Test tone frequency range (Hz)	
	Air conduction audiometry	Bone conduction audiometry
	500 to 8,000	500 to 8,000
125	55	34
250	46	24
500	31	21
1,000	33	20
2,000	40	19
4,000	47	15
8,000	46	22

Reassessment of ambient noise levels should be performed at 5-year intervals, with the proviso that if conditions (eg ventilation noise, changes to the structure of the booth or the building) change, earlier reassessment should be carried out.

### 2. Calibration

Formal calibration of all audiometric test equipment shall be carried out on an annual basis for equipment that moves between testing locations or biennially for equipment kept in a fixed testing location. Calibration will be undertaken by an accredited testing laboratory with full documented traceability to National Standards. Formal calibration shall be carried out in accordance with the relevant ISO and IEC standards (IEC 60318, IEC 60645 & ISO 389).

Daily listening checks are very important. A brief listening check should be carried out on a daily basis.

### **3. Training and qualifications of person undertaking audiometry**

The current guidelines pertain to diagnostic audiometry for the purpose of diagnosing NIHL, and hence the person undertaking audiometry requires a high level of training and skill. Audiologists have the highest level of training and hence are the preferred professional for audiometric testing.

### **4. Audiometric test procedures**

- 4.1. Rather than leaving earphones in place during bone conduction testing, it is preferable that testers use audiometric testing facilities that allow accurate bone conduction audiometry down to at least 5 dB HL without the test ear being occluded
- 4.2. Immittance audiometry (tympanometry and acoustic reflex testing) is recommended as a cross-check procedure for pure tone audiometry to determine if there is a conductive component to the hearing loss.
- 4.3. Because of the errors that potentially can affect air and bone conduction thresholds, and the possibility of incorrectly identifying middle ear pathology using tympanometry alone (without acoustic reflexes), speech audiometry and acoustic reflex testing are recommended as core elements of the diagnostic audiometry test battery.

### 1. Scope

Audiometry provides critical evidence in noise-induced hearing loss (NIHL) diagnosis and the quality of audiometry has a direct impact on the accuracy of the diagnosis. This document reviews the evidence base and consensus practices of various bodies for audiometry and provides best practice guidelines for obtaining a valid audiogram. It includes a review of the qualifications and experience required of those who take the audiogram and the conditions under which diagnostic audiometry should be taken.

### 2. Application

This document is intended to be a resource for use by otorhinolaryngologists / ear nose and throat specialists (ORLs/ENTs), general practitioners, audiologists, ACC staff and other related parties.

### 3. Relevant audiometric standards

The following standards are relevant to the measurement of separate ear, pure-tone thresholds via diagnostic pure-tone audiometry. The focus of this document is diagnostic audiometry, rather than screening or monitoring audiometry, although several standards that relate to workplace screening audiometry are listed here (AS/NZS 1269.4, ISO 6189:1983).

Relevant documents from the American National Standards Institute (ANSI) are listed; however, Standards New Zealand is affiliated with the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), and local calibration labs use ISO/IEC standards. Hence the ISO and IEC standards are the most relevant.

The ISO 8253-1 standard specifies maximum permissible ambient noise levels for audiometric test rooms, as does the ANSI/ASA S3.1-1999 (R 2008) standard.

#### *Australian/New Zealand*

- i. AS ISO 8253.1-2009 Audiometric test methods, Part 1: Basic pure tone air and bone conduction threshold audiometry
- ii. AS/NZS 1269.4-2005 Occupational noise management, Part 4: Auditory assessment
- iii. AS/NZS1270-2002 Acoustics – Hearing protectors.

#### *International*

- i. IEC 60318-3 ed1.0 (1998-08) Electroacoustics – Simulators of human head and ear – Part 3: Acoustic coupler for the calibration of supra-aural earphones used in audiometry
- ii. IEC 60318-5 ed1.0 (2006-08) Electroacoustics – Simulators of human head and ear – Part 5: 2 cm<sup>3</sup> coupler for the measurement of hearing aids and earphones coupled to the ear by means of ear inserts
- iii. IEC 60318-6 ed1.0 (2007-11) Electroacoustics – Simulators of human head and ear – Part 6: Mechanical coupler for the measurement on bone vibrators
- iv. IEC 60645-1 ed2.0:2001 Electroacoustics – Audiological equipment – Part 1: Pure-tone audiometers
- v. IEC 60645-5 (2004-11) Electroacoustics – Audiometric equipment – Part 5: Instruments for the measurement of aural acoustic impedance/admittance

- vi. ISO 389-1:1998 Acoustics – Reference zero for the calibration of audiometric equipment – Part 1: Reference equivalent sound pressure levels for pure tones and supra-aural earphones
- vii. ISO 389-2:1994 Acoustics – Reference zero for the calibration of audiometric equipment – Part 2: Reference equivalent threshold sound pressure levels for pure tones and insert earphones
- viii. ISO 389-3:1994 Acoustics – Reference zero for the calibration of audiometric equipment – Part 3: Reference equivalent threshold force levels for pure tones and bone vibrators. This Standard includes: ISO 389-3/COR1:1995 Tech. Corr. 1
- ix. ISO 389-4:1994 Acoustics – Reference zero for the calibration of audiometric equipment – Part 4: Reference levels for narrow-band masking noise
- x. ISO 1999:1990 Acoustics – Determination of occupational noise exposure and estimation of noise-induced hearing impairment
- xi. ISO 6189:1983 Acoustics – Pure tone air conduction threshold audiometry for hearing conservation purposes
- xii. ISO 7029:2000 Acoustics – Statistical distribution of hearing thresholds as a function of age
- xiii. ISO 8253-1:1989 Acoustics – Audiometric test methods – Part 1: Basic pure tone air and bone conduction threshold audiometry
- xiv. ISO/IEC 17025:2005 General requirements for the competence of testing and calibration laboratories.

#### *North American*

- i. ANSI/ASA S3.21-2004 (R 2009) American National Standard methods for manual pure-tone threshold audiometry (*Revision of ANSI S3.21-1978*)
- ii. ANSI/ASA S3.1-1999 (R 2008) American National Standard maximum permissible ambient noise levels for audiometric test rooms
- iii. ANSI S3.6-2004 American National Standard specification for audiometers (*Revision of ANSI S3.6-1996*)
- iv. ANSI S3.39-1987 (R 2007) American National Standard specifications for instruments to measure aural acoustic impedance and admittance (aural acoustic immittance).

#### 4. Definitions

<i>air conduction audiometry</i>	Hearing measurement via transducers that deliver sound acoustically to the ear canal, via supra-aural, insert or circumaural earphones
<i>ambient noise levels</i>	Sound level in the test environment when no test sound is being presented, measured in dB SPL [re 20 microPascals ( $\mu\text{Pa}$ )] using a sound level meter
<i>audiogram</i>	Graphical representation of hearing sensitivity for pure tones, with detection thresholds plotted in decibels hearing level versus audiometric test frequency (thresholds are reported in dB HL as a function of frequency in Hz)
<i>dB HL</i>	Sound level corresponding to pure-tone detection threshold determined using pure-tone audiometry, specified in decibels relative to the median hearing thresholds of otologically normal young adults (as defined by the ISO 389 standards that specify reference equivalent threshold levels for different audiometric transducers)
<i>bone conduction audiometry</i>	Hearing measurement via a bone conductor, usually placed behind the ear on the mastoid bone, that delivers sound to the inner ear via mechanical vibration of the skull
<i>conductive hearing loss</i>	Hearing loss due to external or middle ear pathology, resulting in normal bone conduction and elevated air conduction hearing thresholds
<i>immittance audiometry</i>	Includes tympanometry (see definition below) and acoustic reflex measurement; the acoustic reflex is the reflexive contraction of the middle ear stapedius muscle in response to loud sound delivered to the same (ipsilateral) or opposite (contralateral) ear
<i>mixed hearing loss</i>	Hearing loss due to a combination of conductive (external and/or middle ear) and inner ear pathology, resulting in elevated bone and air conduction thresholds, with a gap of at least 15 dB between air and bone conduction sensitivity (bone better than air)
<i>NIHL</i>	Noise-induced hearing loss, sensorineural hearing loss associated with a significant noise exposure history that has a degree and a configuration consistent with noise damage
<i>otoscopy</i>	Visual examination of the external and middle ear conducted using an otoscope that has a light and magnifying lens to facilitate visualisation of the eardrum
<i>video otoscopy</i>	Otoscopy that includes the ability to digitally capture a photographic image of the external ear and tympanic membrane
<i>pure tone audiometry</i>	Measurement of hearing sensitivity across a range of test frequencies using a standardised test method that specifies the procedure for threshold determination, the range of test frequencies and presentation levels, and the way thresholds are presented graphically, including the symbols used
<i>sensorineural hearing loss</i>	Hearing loss caused by inner ear pathology, resulting in elevated air conduction thresholds, with equivalent air and bone conduction hearing (air-bone gap less than 15 dB)
<i>tympanometry</i>	Measurement of energy flow through the middle ear (middle ear admittance), allowing the objective assessment of middle ear status and detection of ear diseases such as otitis media

#### 5. Limitations

This paper considers the diagnosis of noise-induced hearing loss using pure-tone audiometry and other audiometric tests, such as immittance and speech audiometry, that provide a cross-check of pure-tone audiometry results. Immittance audiometry includes tympanometry and stapedius muscle acoustic reflex testing. Immittance audiometry

assesses middle ear status and hence is an important test for verifying the presence or absence of an air-bone gap obtained on pure tone audiometry. Speech recognition testing in quiet and in noise should be used to verify the pure tone audiometry results, and to estimate the functional impact of the hearing loss. These diagnostic measures are routinely included in an audiological test battery for diagnosis of noise-induced sensorineural hearing loss. Medical procedures such as micro-otoscopy are also used by ORLs when making a diagnosis of NIHL; these procedures are not addressed in this document.

## 6. Search strategy

Keywords were used to search Google, Google Scholar and Medline plus the databases of the ISO, IEC and ANSI standards organisations and the websites of professional organisations in otolaryngology (see organisations listed below). Relevant results from these searches are listed in the Appendix, with extracts of selected material applicable to this document.

### *Keywords*

ambient noise levels	maximum permissible background noise levels audiometry
audiometry	pure tone technique guidelines standards testing environment procedures quality assurance calibration noise masking air-bone gap
audiometric testing	tester qualification tester training competency guidelines
otolaryngology	training audiometry professional organisation

*Selected professional organisations in otolaryngology*

Organisation	Website	Relevant results of keyword search "audiometry"
American Academy of Otolaryngology-Head and Neck Surgery	<a href="http://www.entnet.org">www.entnet.org</a>	Certificate Program for Otolaryngology Personnel (CPOP) Curriculum <a href="http://www.entnet.org/ConferencesAndEvents/cpopCurriculum.cfm">www.entnet.org/ConferencesAndEvents/cpopCurriculum.cfm</a>
American Board of Otolaryngology	<a href="http://www.aboto.org/">www.aboto.org/</a>	Nil*
American Otological Society	<a href="http://www.americanotologicalsociety.org/">www.americanotologicalsociety.org/</a>	None relevant to audiometric test procedures
Australian Society of Otolaryngology Head and Neck Surgery	<a href="http://www.asohns.org.au">www.asohns.org.au</a>	Surgical Education & Training in Otolaryngology Head & Neck Surgery Module Document & OHNS Training Syllabus <a href="http://www.asohns.org.au/search?SearchableText=audiometry">http://www.asohns.org.au/search?SearchableText=audiometry</a>
Canadian Society of Otolaryngology – Head and Neck Surgery	<a href="http://www.csohns.com">www.csohns.com</a>	Nil*
European Academy of Otorhinolaryngology, Head and Neck Surgery	<a href="http://www.eaorl-hns.org/">www.eaorl-hns.org/</a>	Nil*
International Federation of ORL Societies (IFOS)	<a href="http://www.ifosworld.org/content/resource/AMGATE_7328_1_TICH_R3681146586920/">www.ifosworld.org/content/resource/AMGATE_7328_1_TICH_R3681146586920/</a>	Nil*
New Zealand Society of Otolaryngology, Head and Neck Surgery	<a href="http://www.orl.org.nz">www.orl.org.nz</a>	Nil
Society for Physician Assistants in Otorhinolaryngology Head and Neck Surgery	<a href="http://www.entpa.org/">www.entpa.org/</a>	Nil*
Society of Otolaryngology and Head and Neck Nurses	<a href="http://www.sohnnurse.com/">www.sohnnurse.com/</a>	see publication <i>Core Curriculum for Otorhinolaryngology and Head-Neck Nursing</i> , 2nd edition <a href="http://www.sohnnurse.com/pub_core.asp">www.sohnnurse.com/pub_core.asp</a>

\* These websites did not have a search engine and were searched manually



## 7. Specifications for pure-tone audiometry

Specific subsections are listed below. For each subsection, the Appendix contains additional background information obtained using the specified search strategy.

- 7.1. Acoustical test environment
- 7.2. Calibration
- 7.3. Training and qualifications of person undertaking audiometry
- 7.4. Audiometric test procedures
- 7.5. Reliability of air and bone conduction audiometry
- 7.6. Additional audiometric procedures for diagnosis of NIHL
- 7.7. Audiometric patterns and the progression of hearing loss
- 7.8. Quality assurance

### 7.1. Acoustical test environment

This section addresses maximum acceptable ambient noise levels for air and bone conduction audiometry. Ambient noise levels are also referred to as background noise levels. It is important to ensure the ambient noise in the test environment is satisfactory for audiometric testing. If ambient noise levels do not meet specific requirements, audiometric test results will be unreliable due to masking of test signals. Thresholds will be elevated by background noise, particularly in the low frequencies, and will vary if the level of background noise fluctuates. The methodology described here for establishing acceptable background noise levels is based on National Acoustic Laboratories (NAL) Report No. 133 (Williams, 2010).

Audiometric testing must include frequencies up to and including 8 kHz in order to sufficiently characterise the high frequency hearing loss or typical 'notch' observable in the audiogram in the 4,000-6,000 Hz frequency region in NIHL (McBride & Williams, 2001). The recommended frequency ranges are 250-8,000 Hz and 500-4,000 Hz for air and bone conduction testing respectively (Sataloff & Sataloff, 1987, pp. 61-74). Ambient noise levels are specified here for frequencies up to 8,000 Hz for air conduction and 4,000 Hz for bone conduction. In order to allow accurate testing at these frequencies, maximum ambient noise levels should not be exceeded.

#### *Calculation of acceptable ambient noise levels*

Ambient noise levels are indicated here for hearing threshold level determination down to a minimum test level of 0 dB HL. An uncertainty of 5 dB has been assumed. Table 1 summarises these levels. Also included here is the methodology for different threshold criteria if required.

Maximum permissible ambient sound pressure levels or noise levels (MPANL) in the test area shall meet the requirements of ISO 8253-1 (2010) Acoustics – Audiometric test methods, Part 1: Basic pure tone air and bone conduction threshold audiometry for hearing threshold levels down to 0 dB HL. This is to ensure there will be no uncertainty with the measured audiometric threshold levels introduced through the influence of

unwanted external noise sources. Ambient noise levels above those prescribed in the standard will lead to uncertainties and errors in measurement.

If it is acceptable to measure hearing thresholds to a level other than 0 dB HL for air and bone conduction audiometry, this shift in threshold can simply be added to the MPANL values in Table 1. For example, if a level of 15 dB HL is satisfactory, 15 dB is simply added to each of the octave bands to obtain the adjusted MPANLs.

**Table 1: Maximum permissible ambient noise levels,  $L_{s,max}$ , for air and bone conduction audiometry for hearing thresholds down to 0 dB using typical supra-aural earphones such as the Telephonics TDH39 with MX 41/AR cushions or the Beyer DT48 and with a maximum of  $\pm 5$  dB uncertainty (adapted from ISO 8253-1 Table 2 and Table 4)**

Octave band centre frequency (Hz)	Maximum permissible background sound pressure levels				
	$L_{s,max}$ (dB re 20 $\mu$ Pa)				
	Test tone frequency range (Hz)				
	Air conduction audiometry			Bone conduction audiometry	
	125-8,000	250-8000	500-8,000	125-8,000	500-8,000
125	23	30	42	17	21
250	18	18	33	11	11
500	18	18	18	8	8
1,000	20	20	20	7	7
2,000	27	27	27	6	6
4,000	34	34	34	2	2
8,000	33	33	33	n/a	n/a

Notes: 1. Using the above values provides an uncertainty of 5 dB due to ambient noise

2. The parameter  $L_{s,max}$  should be measured with the sound level meter on "S" (slow) time weighting

### *Supra-aural versus insert earphones*

If the specified MPANLs cannot be achieved in the test area, acceptable background noise levels may be achieved for the listener through the use of insert earphones such as the Etymotic ER-3A earphones. The attenuation characteristics of insert earphones when used in such a manner are provided by the manufacturer and are outlined in Table 2.

The octave band attenuation data is added to the MABSPL to estimate the adjusted MPANL under the headset. An example of MPANL calculation using noise attenuation values for ER-3A inserts is shown in Table 3.

Table 3 shows the calculation of acceptable ambient noise levels for ER-3A inserts with the attenuation characteristics provided in Table 2, with the aim of testing down to threshold levels of 0 dB HL from 250 to 8,000 Hz with an uncertainty of 5 dB.

**Table 2: Attenuation characteristics in octave bands for Etymotic ER-3A inserts (as per ISO/DIS 8253-1: 2008) SD=standard deviation**

Octave centre frequency (Hz)	125	250	500	1,000	2,000	4,000	8,000
Attenuation (dB) (mean <i>minus</i> SD)	33	36	38	37	33	40	43

*Supra-aural earphones mounted in noise-excluding earmuffs*

If a headset is used that consists of earphones (TDH39) mounted within a typical commercial noise-excluding earmuff, the attenuation of the headset used for audiometry must be determined in accordance with the requirements of the combined Australian/New Zealand Standard AS/NZS 1270: Acoustics – Hearing protectors.

To calculate the acceptable ambient noise levels when using a headset other than those specified in ISO 389-1 (e.g. Telephonics TDH39 with MX 41/AR cushions or Beyer DT48 earphones), the process is to simply add the **extra** attenuation provided by the alternate headset to that provided by the typical specified headset. Alternatively, if the attenuation values are less, the values are subtracted.

This procedure was followed by Murray et al (2000), who placed TDH39 earphones set in MX41/AR cushions inside Bilsom 847 circumaural cushions. Higher maximum acceptable background noise levels were obtained for this combination than for other combinations previously assessed, particularly for frequencies up to 1,000 Hz.

No Australian/New Zealand or International Standard has been published to cover calibration of audiometers with circumaural headsets, and hence insert earphones are preferred to circumaural earphones.

**Table 3: Table summarising the calculation required to estimate the maximum permissible background sound pressure levels ( $L_{S,max}$ ) in octave bands using ER-3A inserts for air conduction hearing threshold measurements down to 0 dB from 125-8,000 Hz, with a maximum uncertainty of 5 dB**

Octave band centre frequency (Hz)	Max background using typical supra-aural H/S* ( $L_{S,max}$ dB)	Typical attenuation of supra-aural H/S** (dB)	Mean attenuation for ER-3A† (dB)	Difference between ER-3A and typical supra-aural† (dB)	Max b/g when using ER-3A® ( $L_{S,max}$ dB)
	A	B	C	(C – B)	A + (C – B) + 8
125	23	3	33	30	61
250	18	5	36	31	57
500	18	7	38	31	57
1,000	20	15	37	22	50
2,000	27	26	33	7	42
4,000	34	32	40	8	50
8,000	33	24	43	19	60

Notes: \* Value derived from ISO 8253-1, Table 2

\*\* Value from ISO 8253-1, Table 3

† Obtained from supplier data, as tested to AS/NZS1270

‡ Difference between the attenuation of the ER-3A inserts and the typical supra-aural headset

● Maximum background using the proposed headsets = (maximum ambient levels using typical supra-aural earphones + the extra attenuation provided by the proposed headset with an uncertainty of + 5 dB in the final audiogram. If an uncertainty of +5 dB is too large and an uncertainty of only +2 dB must be met, do not add the extra 8 dB to the background noise level in this step)

*Acceptable ambient noise levels for accurate BC testing down to 5 dB HL*

Bone conduction testing is not performed if hearing is within the normal range (15 dB HL or better). Air-bone gaps of 10, 15 and 20 dB should be expected for a significant proportion of pure-tone threshold measurements, and these do not always indicate middle ear dysfunction (Studebaker, 1967; Margolis, 2010). An air-bone gap of 15 dB is

considered clinically significant. Hence, if the air conduction threshold is 20 dB HL, the ability to accurately determine bone conduction thresholds to a hearing level of 5 dB HL is required.

The maximum permissible background sound pressure levels to test to threshold levels of 5 dB for air and bone conduction with a +5 dB uncertainty over the range 500-8,000 Hz are provided in Table 4 below. All test environments used for diagnostic audiology should meet the ambient noise requirements for bone conduction testing and hence test environments should comply with the ambient noise levels specified in the right-hand column in Table 4.

**Table 4: Maximum permissible ambient noise levels,  $L_{s,max}$ , for air and bone conduction audiometry for hearing thresholds to 5 dB, with 5 dB uncertainty over the range 500-8,000 Hz, using typical supra-aural earphones such as the Telephonics TDH39 with MX 41/AR cushions or the Beyer DT48 (adapted from ISO 8253-1 Table 2 and Table 4)**

Octave band centre frequency (Hz)	Maximum permissible background sound pressure levels	
	$L_{s,max}$ (dB re 20 $\mu$ Pa)	
	Test tone frequency range (Hz)	
	Air conduction audiometry	Bone conduction audiometry
	500- 8,000	500 - 8,000
125	55	33
250	46	24
500	31	31
1,000	33	20
2,000	40	19*
4,000	47	15*
8,000	46	22*

#### *Time Interval for Repeat Testing of Ambient Noise Levels*

The calibration requirements for ISO 8253 - 1 are described in Section 12.2. There it mentions three levels of calibration for equipment and presumably fixed test locations. The maximum time between complete calibrations (Stage C) is noted to be five years if no other work has been done on the instrumentation in the meantime. Other routine calibration checks (Stages A and B) are carried out along the way. It is reasonable to assume that the ambient noise check period for fixed facilities should be taken to be similar to this specified time, with earlier checks required if conditions have varied.

Standard 1269.4 requires reassessment of ambient noise levels every three years (Appendix B, page 26) for fixed facilities, but re-evaluation is required when there are changes that could affect the levels.

Given that hearing assessments for ACC are typically carried out in clinic facilities rather than in mobile test environments sited in potentially noisy work sites, the 5-year period referred to in ISO 8253-1 would seem to be the more appropriate period for regular reassessment of ambient noise levels, with the proviso that if conditions (eg ventilation

noise, external noise levels in the surrounding area, changes to the structure of the booth or the building) change, earlier reassessment must be carried out.

## 7.2. Calibration

Accurate calibration of sound levels and frequencies delivered by the audiometer is essential for accurate pure-tone audiometry. Calibration of test equipment shall be carried out at regular intervals by an accredited calibration laboratory. Audiometric standards specify that pure-tone audiometric testing shall only be carried out using calibrated audiometric test equipment, using a specified procedure. Calibration shall be carried out with the specific headphones or type of inserts supplied for use with the audiometer. If a different set of headphones or type of inserts are to be used, the equipment shall be recalibrated for those particular headphones or type of inserts.

In the case of audiometric equipment or instrumentation that remains in a fixed location and is not transported, this interval shall be every two years. In the case of portable equipment that varies location, this interval shall be at least yearly. For equipment that is relocated on a regular basis, for example weekly, it may be necessary to have calibration checks more often than yearly.

Calibration procedures are described in detail in the relevant audiometric standards. Stephens (2003) provides a recent overview of calibration procedures in his chapter "Acoustics, measurement of sound and calibration" in the *Textbook of Audiological Medicine*, edited by Linda Luxon. Reference sound pressure levels that correspond to the median hearing threshold of otologically normal adults (0 dB HL) for different audiometric transducers are specified in the ISO 389 standards (Smith et al, 1999).

Audiometers shall be of Type 1, as specified by IEC 60645-1. A Type 1 pure-tone audiometer has a range of transducer types, including supra-aural and insert earphones and a bone vibrator. Test frequencies available on the audiometer range from 125 to 8,000 Hz for air conduction and from 250 to 6,000 Hz for bone conduction. Air conduction maximum hearing levels for a Type 1 audiometer are 70 dB at 125 Hz, 90 dB at 250 Hz, 120 dB at 500-4,000 Hz, and 110 dB at 6,000 and 8,000 Hz, and bone conduction maximum hearing levels are 45 dB at 250 Hz, 50 dB at 6,000 Hz, 60 dB at 500, 750 and 4,000 Hz, and 70 dB at 1,000-3,000 Hz (Frank, 1997).

### *Formal calibration requirements and schedule*

Formal calibration of all audiometric test equipment shall be carried out annually for equipment that moves between testing locations or biennially for equipment kept in a fixed testing location. Calibration will be undertaken by an accredited testing laboratory with fully documented traceability to National Standards. Formal calibration shall be carried out in accordance with the relevant ISO and IEC standards (IEC 60318, IEC 60645 and ISO 389). The need for annual calibration of audiometric equipment is widely recognised in the literature (e.g. Meyer-Bisch, 1993), but New Zealand calibration laboratory data support the extension of this to a two-yearly requirement for equipment

that is not moved around, based on the stability of modern audiometers. Older audiometric equipment that is still in current use may require annual calibration even when it is in a fixed testing location. Since it is difficult to document which equipment is portable and/or relocated on a regular basis, annual calibration is recommended for equipment used for diagnostic pure-tone audiometry for diagnosis of NIHL. Audiometric equipment that demonstrates clinically significant instability from one calibration date to the next should be replaced.

#### *Informal calibration requirements and schedule*

A survey of audiometers being used for hearing conservation purposes undertaken by Pfeiffer (1980) revealed many equipment faults. Although modern digital audiometers are likely to be more reliable than those developed in the 1970s, the transducers used for audiometry are susceptible to damage from mishandling. Audiometer manufacturers specify that care should be taken when handling transducers as dropping them may alter the calibration (e.g. Interacoustics AS216

[http://www.audiometrics.net/sitebuildercontent/sitebuilderfiles/operation\\_manual\\_az26.pdf](http://www.audiometrics.net/sitebuildercontent/sitebuilderfiles/operation_manual_az26.pdf)).

Daily listening checks are very important. A brief listening check should be carried out on a daily basis. The purpose of the daily listening check is to detect changes in stimulus level, distortion in signals, tone switching transients and other unwanted sounds due to faulty earphones, faulty switches and other audiometer faults. A subjective check should also be carried out on a minimum of a weekly basis to ensure the audiometer can still perform at the required level. The subjective test involves testing someone with known hearing thresholds to ensure the audiogram has not changed. Faulty equipment, or equipment producing a 10 dB or more change in hearing thresholds based on the subjective test, should be sent to an approved calibration facility for service and/or recalibration.

Procedures for daily and weekly audiometer checks are described in detail in Section 12 of the British Society of Audiology's (2004) recommended procedure for pure-tone air and bone conduction threshold audiometry ([www.thebsa.org.uk/docs/bsapta.doc](http://www.thebsa.org.uk/docs/bsapta.doc)). Additional information on calibration requirements is reported in the Appendix.

### **7.3. Training and qualifications of person undertaking audiometry**

Pure-tone audiometry includes reference, monitoring (both screening audiometry procedures) and diagnostic audiometric procedures. Reference, monitoring and screening audiometry are terms usually used in the context of occupational noise management programmes in industry, for the purposes of identifying and preventing NIHL. The reference audiogram is a baseline audiogram obtained at the start of a person's employment as a reference for future audiograms, in order to determine if a hearing loss develops. The monitoring audiogram is used to determine if hearing thresholds have changed as a result of noise exposure in the workplace.

The current guidelines pertain to diagnostic audiometry for the purpose of diagnosing NIHL, and hence the person undertaking audiometry requires a high level of training and skill. In New Zealand, the recognised qualification for people undertaking diagnostic audiometric procedures is a two-year master's qualification in audiology, with a one-year postgraduate clinical practicum year. Other individuals with varying levels of training also currently perform audiometric testing in New Zealand. The person conducting the audiometry should be appropriately trained and supervised. Audiometrists with appropriate training and supervision or audiologists meeting the requirements for membership of the New Zealand Audiological Society can conduct pure-tone air and bone conduction audiometry. Interpretation of audiometric results is performed by audiologists and otolaryngologists.

Competency requirements for audiometrists are specified in Appendix E of AS/NZS 1269.4:2005 Occupational noise management, Part 4: Auditory assessment. Appendix E of AS/NZS 1269.4:2005 specifies that:

"Audiometric test procedures shall be carried out by a person or group who, through a combination of training, qualifications and experience, have acquired the knowledge and skills to perform the procedures, interpret the results and present them in a manner that will enable the people in the workplace to make appropriate decisions.

In particular, a person or group carrying out assessments shall be able to demonstrate a comprehensive understanding of:

- (a) the anatomy and physiology of the auditory pathway;
- (b) the mechanisms of hearing;
- (c) the correct usage and limitations of audiometers, audiometric test spaces and audiometric testing;
- (d) an audiogram and its relationship to the detection and understanding of human speech;
- (e) correct audiometric test technique, appropriate headphone placement and test subject instruction;
- (f) how to record the results of an audiometric test;
- (g) audiometric test result interpretation and how to explain the results to the test subject;
- (h) hearing damage due to noise exposure, its pattern, progress, cause and prevention;
- (i) when and how to advise a test subject who requires referral for audiological, medical or rehabilitative purposes;
- (j) the correct selection, usage and limitations of personal hearing protectors;
- (k) requirements of relevant legislation concerning audiometric testing;
- (l) the management of test results particularly those relating to confidentiality of audiograms;
- (m) the basic physics of sound; and
- (n) awareness of ototoxic agents."

The competency requirements listed above do not specify an understanding of the theoretical basis and clinical application of masking. Masking is used to ensure hearing thresholds accurately reflect the test ear, rather than a cross-heard response from the non-test ear. Masking is one of the most difficult elements of audiometric testing. As noted by Valente (2009, p. 115), mastery of this technique requires extensive supervised clinical practice as well as academic knowledge.

The Australian Society for Otolaryngology Head and Neck Surgery Training Syllabus and the American Academy of Otolaryngology-Head and Neck Surgery Certificate Program for Otolaryngology Personnel both specify training for otolaryngologists in air and bone conduction audiometry, but do not provide specific details. No specific guidelines for training in pure tone audiometry are provided by the New Zealand Society of Otolaryngology, Head and Neck Surgery. The Certificate Program for Otolaryngology Personnel (CPOP) developed by the American Academy of Otolaryngology-Head and Neck Surgery involves self-study, intensive training and an examination process to ensure competency in audiometric testing.

ISO 8253-1:1989 Acoustics – Audiometric test methods – Part 1: Basic pure tone air and bone conduction threshold audiometry specifies that a qualified tester is “someone who has followed an appropriate course of instruction in the theory and practice of audiometric testing”. This qualification may be specified by national authorities or other suitable organisations. In ISO 8253, it is assumed that tests will be carried out by, or be under the supervision of, only a qualified tester. Accurate audiometry is critical for the correct diagnosis of NIHL and hence the training and qualifications of the person performing audiometry are critical. Audiologists have the highest level of training and so are the preferred professionals for audiometric testing.

#### **7.4. Audiometric test procedures**

The procedures for diagnostic air and bone conduction audiometry are specified in the following standards:

- AS ISO 8253.1-2009 Audiometric test methods, Part 1: Basic pure tone air and bone conduction threshold audiometry
- ISO 8253-1:1989 Acoustics – Audiometric test methods – Part 1: Basic pure tone air and bone conduction threshold audiometry. (Note that this standard has been in the process of revision and voting on the final draft of the 2010 version closed on 28 August 2010)
- ANSI/ASA S3.21-2004 (R 2009) American National Standard methods for manual pure-tone threshold audiometry (*Revision of ANSI S3.21-1978*).

There is international consensus about the test procedure for audiometry and test frequencies, but there are variations in masking procedures, symbols and hearing loss categories. The internationally accepted test method for diagnostic pure-tone audiometry is the modified Hughson-Westlake procedure described by Carhart and Jerger (1959), also



referred to as the “down 10-up 5” method. The same method is used for pure-tone threshold determination for air and bone conduction audiometry, but the range of frequencies and presentation levels is restricted (usually to 500-4,000 Hz) for bone conduction audiometry.

### *Masking*

Masking using narrowband noise in the non-test ear is sometimes required to ensure that hearing thresholds reflect hearing sensitivity in the test ear, rather than a cross-heard response from the non-test ear. Masking is routinely applied when there is a significant (usually defined as 15 dB) air-bone gap, or when there is a substantial ear difference, leading to the possibility of false air conduction thresholds due to cross hearing from the other cochlea.

Masking procedures should follow standard audiological practice (Sataloff & Sataloff, 1987; Goldstein & Newman, 1985; Valente, 2009). The plateau method has been used for many years as the preferred masking technique for audiometry. The plateau method (first described by Hood, 1960) requires the level of masking in the non-test ear to steadily increase until a specified stable plateau is obtained for the test ear threshold. More recently, a more efficient “optimised” masking method has been described (Turner, 2004). In the optimised method, the initial masker is set relative to the threshold of the test ear. This is a major difference from the plateau method. The initial masking level is set relative to the test ear rather than the non-test ear, as occurs in the traditional plateau method. According to Turner (2004, p. 22), the new method is optimised as it attempts to use the maximum possible masking without overmasking, by referencing the masking level to the threshold of the test ear, not the non-test ear. Overmasking is avoided by setting the masking level 10 dB below the air conduction threshold of the test ear. Fernandes and Russo (2009) compared plateau and optimised masking methods and found no significant differences in masked thresholds overall; however, there were some examples of audiograms where the plateau method was recommended as more accurate. Accurate and reliable masking requires considerably more training than is required for pure-tone audiometry.

### *Documentation*

Test frequencies and symbols for air and bone conduction audiometry are specified in ISO 8253-1:1989. Symbols for masked air conduction and unmasked and masked bone conduction used routinely in New Zealand differ from those specified in the ISO or ANSI standards. Symbols used in New Zealand for unmasked audiometry match those used internationally (O = right air conduction, x = left air conduction, < = right bone conduction, > = left bone conduction). Masked symbols used in New Zealand differ, however (● = masked right air conduction, ✕ = masked left air conduction, ◁ = right masked bone conduction, ▷ = left masked bone conduction). Because of international variations in the use of audiometric symbols, it is essential that symbols are specified on

audiometric documentation. Documentation should include details of the tester, equipment model and calibration, test environment and date.

### *Classification of hearing loss*

There are variations in the labels assigned to different degrees of hearing loss (e.g. Kutz et al, 2010), which contributes to inconsistency in reporting audiometric findings. The hearing loss categories described by Goodman (1965) and modified by Clark (1981), which are listed in Table 5, have been adopted by the American Speech-Language-Hearing Association (ASHA) and the New Zealand Audiological Society.

**Table 5: Recommended criteria for classifying degree of hearing loss, adapted from Clark (1981)**

<b>dB HL range</b>	<b>Hearing loss category</b>
-10-15	Normal hearing
16-25	Slight hearing loss
26-40	Mild hearing loss
41-55	Moderate hearing loss
56-70	Moderately severe hearing loss
71-90	Severe hearing loss
>90	Profound hearing loss

### *Bone conduction*

As for air conduction, bone conduction threshold accuracy depends on consistency of transducer placement, test technique and test conditions. In addition, there are two well-established potential errors in bone conduction audiometry (the occlusion effect and acoustic radiation); these have been noted by the British Society of Audiology in their recommended procedure for pure-tone air and bone conduction threshold audiometry. At test frequencies below 3,000 Hz it is recommended that the test ear is **not** occluded as this may produce the “occlusion effect”, in which low frequency bone conduction thresholds are improved when the ear is plugged. The occlusion effect can create a false low frequency air-bone gap (apparent conductive hearing loss). This can occur when testers use an insert earphone to occlude the test ear during bone conduction testing. This is done to avoid ambient noise masking the bone conduction thresholds when the test room does not meet the specifications for testing with ears uncovered or with supra-aural earphones in place. Acoustic radiation from the bone vibrator at high frequencies can result in bone conduction thresholds appearing better than they are because the acoustically radiated sound is heard via air conduction at softer levels than via bone conduction.

## **7.5. Reliability of air and bone conduction audiometry**

Factors affecting reliability of audiometry include transducer placement, test technique including instructions, fluctuating background noise and step size. Test reliability can be

improved by repeat testing (Hartley et al, 1973; Macrae, 1988; 1994), smaller step sizes (Jerlvall & Arlinger, 1986; Macrae, 1988; Marshall et al, 1996), clear instructions (Dancer et al, 1976) and careful transducer placement. Bone conductor and supra-aural earphones should have a coupling force that is consistent with the specifications in the audiometer standard; this is checked as part of the equipment calibration procedure. Insert ear plugs should be deeply inserted to ensure stable and repeatable placement. Test-retest reliability of 5 dB is accepted as the clinical standard (Hartley et al, 1973). When appropriate procedures are followed to ensure test reliability, changes in thresholds of 10 dB or greater between tests are regarded as clinically significant (Macrae, 1994). There are a number of sources of error for both air and bone conduction audiometry and hence comprehensive audiometric training and evaluation of audiometric skills are essential for ensuring accurate pure-tone audiometry.

#### *Air-bone gap*

The sources of variability for air conduction and bone conduction are independent, and consequently air-bone gaps can occur in patients with normal middle-ear function. Differences of 10 dB or more (both positive and negative) between air and bone thresholds are quite common (Margolis, 2010). Milne (1977) found that the air-bone gap at 1,000 Hz recorded in 487 adults aged 62-90 years exceeded 10 dB in 17% of cases. Thus, the presence of an air-bone gap should be interpreted in the light of other information such as the history, otoscopy and immittance audiometry (tympanometry and acoustic reflexes) used to verify conductive pathology. When an air-bone gap is detected that is restricted to the high or low frequencies, procedures should be undertaken to ensure this is not a false air-bone gap. False air-bone gaps may be due to the occlusion effect in the low frequencies and acoustic radiation in the high frequencies, although the latter has been questioned by Margolis (2010).

#### *Occlusion effect*

The occlusion effect is the increase in low frequency sound pressure level in the ear canal for bone-conducted sound that occurs when the ear canal is blocked. For bone conduction testing, the earphones are normally removed from the head and hence the ear canals are not normally blocked, unless masking is required, in which case a supra-aural or insert earphone may remain or be placed on or in the non-test ear. ISO 8253-1 notes that "the ear being tested by bone conduction should be unoccluded" and that if the ear is occluded "it shall be noted on the audiogram". The maximum permissible noise levels for bone conduction audiometry are lower than those for air conduction audiometry if the ears are uncovered as there is no attenuation provided by an earphone cushion or earplug (Hinchcliffe & Littler, 1961).

Testers sometimes choose to leave earphones in place on the test ear for bone conduction audiometry in order to reduce ambient noise effects on bone conduction thresholds. If this occurs, it should be noted on the audiogram as specified in ISO 8263-1, and care should be taken to ensure the occlusion effect does not produce a false air-bone gap.

According to Goldstein and Hayes (1965, p. 137), "The increase in sound pressure arises from the ear canal walls...which vibrate from the bone conduction signal and from vibrations which are transmitted by the condyloid process of the mandible, adjacent to the exterior portion of the ear canal. The jaw, because of inertia, vibrates out of phase relative to the movements of the skull and therefore sets up the sound pressure in the ear canal. This sound dissipates into the larger volume of the surrounding air, when the ear is unoccluded but becomes an effective supplement to audition when the ear is occluded".

Rather than leaving earphones in place during bone conduction testing, it is preferable that testers use audiometric testing facilities that allow accurate bone conduction audiometry down to at least 5 dB HL without the test ear being occluded (see Table 4). If this is not possible, any air-bone gaps at 500 Hz in particular should be cross-checked using other measures of conductive pathology (immittance and micro-otoscopy). The occlusion effect can create inaccurate air-bone gaps and so care is required when interpreting air-bone gap results if bone conduction testing is performed with the test ear occluded.

#### *Acoustic radiation*

Failure to occlude the ear canal at high test frequencies can lead to more sensitive bone conduction thresholds, resulting in a false air-bone gap in the audiometric results. Bone conductors tend to emit more sound (acoustic radiation) than vibration at frequencies above 2,000 Hz (Lightfoot, 1979; Bell et al, 1980; Shipton et al, 1980). When testing at 3,000 and 4,000 Hz, it may be necessary to insert an ear plug (e.g. E.A.R. plug such as those used for hearing protection purposes) into the test ear canal or cover the test ear with a supra-aural earphone, so that a false air-bone gap is not obtained due to acoustic radiation. The earplug or earphone attenuates the air-borne radiation from the bone conductor and so should eliminate a false air-bone gap due to acoustic radiation if this is the cause. Recently Margolis (2010) has disputed whether acoustic radiation is a significant factor contributing to high frequency air-bone gaps in people with no other evidence of middle ear abnormality. Margolis notes that the 4,000 Hz air-bone gaps are seen relatively commonly in the absence of conductive pathology and suggests that this may reflect an error in the reference threshold level specified in the audiometric standard for bone conduction at this frequency.

#### *Inner ear disorders*

There are a number reports in the literature of apparent conductive hearing loss associated with labyrinthine abnormalities such as superior semicircular canal dehiscence (Merchant et al, 2007), lateral and posterior canal dehiscence, Paget disease, enlarged vestibular aqueduct and other inner ear malformations (see review by Merchant & Rosowski, 2008). In each case, surgical and other investigations failed to reveal any abnormality of the middle ear. Merchant and Rosowski (2008) hypothesise that the air-bone gap in these cases results from a "pathologic third window on the vestibular side of the cochlea" (p. 284) that allows for some of the energy from the air conduction signal to be shunted away from the cochlear partition, whereas the compression of inner ear fluids caused by bone -

conducted sound is enhanced because the third window increases the pressure difference between the two sides of the cochlear partition by lowering the impedance on the scala vestibuli side. A low frequency air-bone gap with bone conduction thresholds better than 0 dB is characteristic of third-window lesions, especially in dehiscence of the semicircular canals. Acoustic reflexes are typically absent in true middle ear disease but are generally present in third-window lesions. Merchant and Rosowski recommend imaging studies, acoustic reflex testing and assessment of bone conduction thresholds at levels less than 0 dB HL in suspected cases of third-window lesions.

#### **7.6. Additional audiometric procedures for diagnosis of NIHL**

Air conduction audiometry needs to be accompanied by bone conduction audiometry to ascertain whether the hearing loss is sensorineural rather than conductive, but, as noted above, an air-bone gap suggestive of outer or middle ear pathology may be an artefact of the testing procedure, or associated with inner ear pathology. The Committee on Hearing and Equilibrium (1995) guidelines for the evaluation of results of treatment of conductive hearing recommend that, in order to delineate the presence of conductive hearing loss, air conduction pure-tone thresholds should be recorded at octave intervals from 500 to 8,000 Hz and at 3,000 Hz and by bone conduction at octave intervals from 500 to 4,000 Hz and at 3,000 Hz. The 3,000 Hz test frequency would not normally be included in bone conduction audiometry but is included in these guidelines that are focused on surgical outcomes "to reflect the importance of higher frequencies in the understanding of speech" (p.186).

As noted in section 7.5, different factors can affect the reliability of air and bone conduction audiometry (e.g. placement effects) and so it is possible to obtain an air-bone gap that does not reflect outer or middle ear conductive pathology. Immittance audiometry (tympanometry and acoustic reflex testing) is recommended as a cross-check procedure for pure-tone audiometry to determine if there is a conductive component to the hearing loss. NIHL would not normally be associated with conductive hearing loss unless there are multiple underlying causes of hearing loss. Tympanometry alone has reasonably good sensitivity and specificity for detection of middle ear pathology (Fishpool et al, 2009), but this is improved by the inclusion of acoustic reflex testing (Nozza et al, 1992). Hence the inclusion of at least one acoustic reflex threshold test is recommended to improve the detection of conductive pathology. Acoustic reflex testing should always be performed when evaluating patients with an air-bone gap despite having an intact tympanic membrane and an aerated middle ear. Acoustic reflex testing can also be used to screen for retrocochlear pathology (Prasher & Cohen, 1993; Emanuel, 2009).

Speech perception in quiet is routinely tested to verify the pure-tone audiogram. The 50% speech recognition point (also referred to as the "speech recognition threshold" or SRT) is widely used to cross-check pure-tone thresholds. Speech scores in quiet correlate well with the traditional three frequency pure-tone average (500 Hz, 1,000 Hz, 2,000 Hz) and hence speech scores in quiet may not be sensitive to the effects of high frequency hearing loss (Smoorenburg, 1992). Speech perception in noise correlates with 2,000-4,000 Hz

audiometric thresholds in adults with NIHL (ASHA, 1981; Smoorenburg, 1992; Barrenas & Holgers, 2000) and hence speech recognition testing in noise is recommended as a cross-check of the audiogram and to estimate the degree of functional disability caused by the NIHL. The ASHA Taskforce on the Definition of Hearing Handicap (ASHA, 1981) reviewed studies comparing speech perception in noise and pure-tone audiometry and concluded that pure-tone thresholds at 1,000-4,000 Hz have the strongest relationship with speech scores. Two studies by Suter reviewed by ASHA (1981) show differences in speech perception in noise and "hearing handicap" for people with average hearing loss at 1,000, 2,000 and 4,000 Hz greater than 22 dB HL. Although pure-tone thresholds and speech scores are correlated, speech perception in noise can vary widely in NIHL (Kramer, 2008) and hence should be measured. Busis (1991) recommends that speech perception in noise be assessed using realistic materials such as sentences. Standardised audiological tests of speech perception that incorporate a range of speech materials are available.

Phoneme, rather than whole word, scoring is recommended for speech audiometry. Phonemic scoring involves measuring speech perception performance as the percentage of vowels and consonants recognised. As noted by Boothroyd (2008), this has several benefits:

- It increases the number of test items and therefore improves test-retest reliability.
- It is possible to obtain reasonably reliable scores from very short lists and the time saved can be used for testing at several levels.
- Phoneme scores are less influenced by vocabulary than whole-word scores.

Because of the errors that potentially can affect air and bone conduction thresholds, and the possibility of incorrectly identifying middle ear pathology using tympanometry alone (without acoustic reflexes), speech audiometry and acoustic reflex testing are recommended as core elements of the diagnostic audiometry test battery. The person performing audiometry for the purposes of diagnosing NIHL requires competency beyond basic pure-tone audiometry and tympanometry in order to be able to perform and interpret these additional audiometric test procedures.

### **7.7. Audiometric patterns in NIHL**

A recent review by Nondahl et al (2009) indicates that the presence/absence of a notch may be an unreliable indicator of noise-induced hearing loss. Thus the absence of a notch in the high frequency audiogram does not exclude the possibility of NIHL. In these cases, the degree of low versus high frequency hearing loss and audiogram slope may be key indicators of NIHL. Control of ambient noise levels is critical for accurate determination of these aspects of the audiometric configuration.

Chung (1980, p. 29) describes 27 cases of NIHL with a double notch, one in the low and one in the high frequency region, and concludes that "It is misleading to construe hearing loss as being of NIHL type on the basis of the high frequency notch alone".

Perez et al (2000) studied audiometric patterns of 143 patients (286 ears) exposed to

explosions, and observed a range of audiometric configurations including the following: slope (46%), dip (41%), flat (12%), 6,000 Hz dip (19%). Albera et al (1994) examined audiogram shape in 315 subjects with hearing loss who were occupationally exposed to noise. In 60% of cases thresholds were poorer at 4,000 and 6,000 Hz compared with 8,000 Hz but for the remaining 40% of cases the threshold at 8,000 Hz was worse. This pattern was more common in older cases but was also found in a small percentage of some younger subjects. Thus it is not possible to reliably diagnose NIHL solely on the basis of the shape of the audiogram. It is recommended that a detailed history is obtained in all cases and in some cases serial audiometry may be required.

If the diagnosis of a "noise notch" is unclear after reference to the document Noise-induced hearing loss of occupational origin: a guide for medical practitioners, produced by the Department of Labour in 1994, further expert assistance and serial audiometry may be required to establish whether the audiogram reflects NIHL and/or a combination of NIHL and other factors such as ageing or synergistic drugs and chemicals.

### **7.8. Quality assurance**

Hinchcliffe (1997) notes that inadequate training, bias, poor history taking, use or non-use of specific tests, and differences in test interpretation can lead to considerable variation across medical examiners. Hinchcliffe mentions noise-induced hearing loss as an area where these issues are problematic for medical specialists and highlights the need for more training. King et al's (1992) text *Assessment of Hearing Disability: guidelines for medicolegal practice* includes a section on quality assurance, as well as sections on sources of error, calibration and procedural requirements for audiometry, and training requirements.

An effective quality assurance programme will reduce variation across examiners. Individual testers and testing organisations should satisfy the requirements for testing and calibration laboratories as described in International Standard ISO/IEC 17025:2005 General requirements for the competence of testing and calibration laboratories. This standard specifies the requirements for any accredited testing organisation for quality control of all test procedures and results, including quality systems, document control, calibration and traceability, record management, corrective actions, test equipment, training, and technical requirements.

The ISO/IEC 17025:2005 framework should be used for monitoring quality of pure-tone audiometry for diagnosis of NIHL. Quality indicators would include evidence of formal and informal calibration procedures, documentation, adherence to audiometric test procedures specified in international standards, acceptable test-retest reliability for repeat audiograms, and evidence of training and monitoring of tester competence. ISO/IEC17025 is not a difficult standard to implement. It functions as a consolidation of points mentioned previously in a systematic manner and when used appropriately ensures correct procedures are rigorously followed so that all aspects of a quality system

are in place. Much of what is discussed in ISO/IEC 17025 should be commonplace across testing locations.

Spreeuwers et al (2008) conducted a quality improvement study over a 15-month period comparing the diagnosis and reporting of NIHL versus occupational adjustment disorder. A range of quality indicators was developed. Questionnaire results for these indicators showed greater variability between physicians and poorer quality for diagnosing and reporting NIHL than for occupational adjustment disorder. This Dutch study showed a need for quality improvement in the areas of the medical history, audiometric measurement, clinical diagnosis and reporting. Spreeuwers et al's findings (2008) highlight the potential benefits of applying a quality assurance framework to the diagnosis of NIHL.



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## APPENDIX: Relevant results of keyword searches

### Section 7.1. Acoustical test environment

**Keywords:** audiometry ambient noise levels

**Franks (2001) *Hearing measurement***

[http://www.who.int/occupational\\_health/publications/noise8.pdf](http://www.who.int/occupational_health/publications/noise8.pdf)

**Table 8.1. Comparable American National Standards Institutes and International Standards audiometric standards.**

Topic Area	ANSI Standard	ISO Standard
Audiometer Calibration	S3.6-1996 Specifications for Audiometers	ISO 8253 Audiometric Test Methods - Part 1 (1989): Basic Pure Tone and Bone Conduction Audiometry; Part 2 (1991): Sound Field Audiometry; Part 3 (199x): Speech Audiometry ISO 389-1985: Acoustics - Standard reference zero for the calibration of pure tone air conduction audiometers and Addendums 1, 2, and 3 IEC 60645-Part 1 (1987) Pure Tone Audiometers: Part 2 (199x) Equipment for speech audiometry, Part 3 (199x) Specifications of reference audiometric test signals of short duration, Part 4 (199x) Equipment for extended high frequency audiometry
Test Room Noise Levels	S3.1-1991 Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms	ISO 8253(1) 1989 Audiometric Test Methods - Part 1: Basic Pure Tone Air and Bone Conduction Audiometry ISO 6189-1983 Acoustics-Pure Tone Air Conduction Threshold Audiometry for Hearing Conservation Purposes
Sound Level Meters	S1.4-1983 (1990) American National Standard Specification for Sound Level Meters; S1.4A-1985 Amendment to ANSI S1.4-1983; S1.25 American National Standard for Personal Noise Dosimeters; S1.43-1997 American National Standard Specification for Integrating-Averaging Sound Level Meters	IEC 60651 (1979) IEC 60804 (1985)
Estimation of Noise-Induced Hearing Loss	S3.44-1997	ISO-1999 (1992)

**Table 8.2. Maximum permissible background noise level during audiometric testing: Accordance with ANSI S3.1-1991, OSHA table D-2 (1981), and OSHA table D-1 (1983). Levels shown are octave-band sound pressure levels (dB re 20  $\mu$ Pa) for ears covered with standard MX41/AR cushions.**

Octave-Band Center Frequency	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
ANSI S3.1-1991 (Rounded to the nearest whole decibel)	22	30	34	42	45
OSHA Table D-2	27	30	32	42	45
OSHA Table D-1	40	40	47	57	62

- Also displayed in Table 8.2 are the maximum permissible ambient levels specified by the OSHA [Occupational Safety and Health Administration, 1983] Hearing Conservation Amendment (OSHA 1983). The OSHA levels are much higher, being based on audiometers calibrated to much older American Standards Association standards. OSHA had initially proposed that these higher levels from Table D-1 of the Hearing Conservation Amendment be used for two years until industry came into compliance with the Hearing Conservation Amendment, afterwards switching to the levels from ANSI S3.1-1991 with a 5 dB adjustment at 500 Hz (OSHA 1981).
- Audiometry that relies on OSHA's specifications will be unable to test to levels below 15 dB HTL (Franks, Engel, and Themann 1992).

### ***Noise-reducing earphone enclosures***

- NIOSH recommends that noise-reducing earphone enclosures not be used. OSHA will issue a de minimus citation when they are used in a test booth with ambient noise levels that meet the OSHA maximum allowable ambient noise levels or a serious citation when they are used in place of a test booth that meets OSHA's ambient noise limits.
- In spite of all the reasons against using noise-reducing earphone enclosures, they are fairly common. Since these devices essentially place the standard earphone/cushion inside an earmuff, it would seem that they ought to reduce ambient noise levels, making a quieter situation for testing. Unfortunately, they don't effectively reduce ambient noise and they affect calibration (shown by studies).



***Documenting ambient noise levels***

- For a fixed facility, it should be adequate to measure the test room ambient noise levels annually. For mobile facilities, ambient noise levels should be taken daily or whenever the facility is relocated, whichever is most frequent.
- The noise levels should be kept as part of the record keeping system and should also be recorded on each audiogram.
- Sometimes, it may be necessary to perform audiometry even when the test room ambient noise levels are higher than specified by the standards. At such times, it will not be possible to test to audiometric zero at the frequencies for which the noise levels are too high. The audiometrist should make certain to annotate each audiogram with a statement that the minimum test hearing level could not have been zero. For example, if the octave-band ambient noise level at 1,000 Hz was 40 dB SPL instead of the 30 dB SPL specified by the standard, the note would say that hearing thresholds of less than 10 dB HL at 1,000 Hz were unreliable.

<b>Keywords: audiometry technique guidelines</b>
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**American Speech-Language-Hearing Association. Guidelines for manual pure-tone threshold audiometry. Rockville, Maryland: ASHA, 2005.**

<http://hearinglossprevention.org/Documents/ASHA%20Guidelines%20for%20Manual%20Pure%20Tone%20Threshold%20Audiometry.pdf>

***Test environment***

- The test environment shall meet at all times the specifications detailed in Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms (ANSI S3.1-1999; American National Standards Institute, 2003)
- The use of sound-isolated rooms or booths is viewed as a standard practice. In the interest of comfort, the test room and audiologist work area should provide for proper control of temperature, air exchange, and humidity

<b>Keywords: background noise levels audiometry</b>
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**Eckel A. *Selecting an Audiometric Room***

<http://www.eckelusa.com/news/59-selecting-an-audiometric-room.html>

The basic purpose of a sound room in audiometric testing is to provide the proper acoustical environment so that tests can be conducted without interference from outside noise. A room of this type should afford adequate ventilation and lighting so that the subject will be comfortable while his hearing is being evaluated. Not only does the room supply environmental control but it eliminates distraction from changes on the visual horizon which may invalidate an audiogram as readily as acoustical interference.



Hearing test rooms should be located in as quiet a place as possible. Preferably they should be within practical access but away from outside walls, elevators, heating and plumbing noises, waiting rooms and busy hallways. If the highest noise levels in a test room do not exceed the levels listed in Table 1, test room noises will not affect test results.

To obtain these internal room ambients one must know what the outside ambient is going to be. This can be obtained with a noise survey by octave bands of the area where the room is to be located. Once this is done, a room should be selected which will provide ample noise reduction to bring the internal noise down to those prescribed by the standard (Table 1).

### **Background Noise Levels**

The American Standards Assn., in its pamphlet on criteria for background noise levels in audiometer rooms, has printed a very useful chart for depicting the outside background noise levels allowable for the use of different types of sound rooms i.e. regular duty single wall rooms and double walled rooms. This chart shows the relationship between outside ambient levels and the amount of performance required to bring down the internal noise levels to the acceptable levels for testing without interference.

<b>Keywords: audiometric testing environment</b>
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**WorkSafe BC. *Hearing Loss Prevention Section – Administration procedures: industrial audiometry*. British Columbia: WorkSafe BC (undated).**

[http://hearingconservation.healthandsafetycentre.org/pdfs/hearing/AdminProcedures\\_Audiometry.pdf](http://hearingconservation.healthandsafetycentre.org/pdfs/hearing/AdminProcedures_Audiometry.pdf)

### **Minimum requirements for an approved testing facility**

- Testing space must be a self-contained room or area of at least 50 square feet. Maximum number of booths per testing space is 2.
- Sound-treated rooms must be used to ensure maximum background noise levels are not exceeded according to the ANSI-1999.
- Certificates of currently authorised Industrial Audiometry Technicians must be posted in the testing room.
- Maintenance of facility approval requires proof of annual audiometer calibration, conducted by a service provider acceptable to the Hearing Loss Prevention Section.

**Keywords: maximum permissible ambient noise levels**

**Frank T, Durrant JD, Lovrinic JM. Maximum permissible ambient noise levels for audiometric test rooms. *American Journal of Audiology* 1993;2:33-37**

<http://aja.asha.org/cgi/content/citation/2/1/33>

The MPANLs are specified in both octave and one-third-octave band intervals for the two testing conditions and the three test frequency ranges conventionally employed for audiometry. The MPANLs for each test condition and test frequency range are shown in Table 1 for octave and in Table 2 for one-third octave band intervals. The octave band MPANLs for each test frequency range are also shown in Figure 1 for the ears-not-covered condition and in Figure 2 for ears-covered, along with the MPANLs previously specified in ANSI S3.1-1977 (for comparison).

**TABLE 1. Maximum permissible ambient noise levels in octave band intervals centered at 125-8,000 Hz for ears-covered and ears-not-covered test conditions and test frequency ranges 125-8,000 Hz, 250-8,000 Hz, and 500-8,000 Hz as specified in ANSI S3.1-1991. Tabled values in dB (re: 20  $\mu$ Pa) rounded to the nearest 0.5 dB.**

Octave Band Inter- vals	Ears Covered			Ears Not Covered		
	125- 8000 Hz	250- 8000 Hz	500- 8000 Hz	125- 8000 Hz	250- 8000 Hz	500- 8000 Hz
125	34.0	36.5	47.5	28.0	32.5	42.5
250	22.5	22.5	33.5	18.5	18.5	28.5
500	19.5	19.5	19.5	14.5	14.5	14.5
750	21.5	21.5	21.5	12.5	12.5	12.5
1000	26.5	26.5	26.5	14.0	14.0	14.0
1500	26.5	26.5	26.5	10.5	10.5	10.5
2000	28.0	28.0	28.0	8.5	8.5	8.5
3000	33.5	33.5	33.5	8.5	8.5	8.5
4000	34.5	34.5	34.5	9.0	9.0	9.0
6000	38.0	38.0	38.0	14.0	14.0	14.0
8000	43.5	43.5	43.5	20.5	20.5	20.5

**TABLE 2. Maximum permissible ambient noise levels in one-third-octave band intervals centered at 125-8000 Hz for ears-covered and ears-not-covered test conditions and test frequency ranges 125-8,000 Hz, 250-8,000 Hz, and 500-8,000 Hz as specified in ANSI S3.1-1991. Tabled values in (dB re: 20  $\mu$ Pa) rounded to the nearest 0.5 dB.**

1/3 Octave Band Inter- vals	Ears Covered			Ears Not Covered		
	125- 8000 Hz	250- 8000 Hz	500- 8000 Hz	125- 8000 Hz	250- 8000 Hz	500- 8000 Hz
125	29.0	31.5	42.5	23.0	27.5	37.5
250	17.5	17.5	28.5	13.5	13.5	23.5
500	14.5	14.5	14.5	9.5	9.5	9.5
800	16.5	16.5	16.5	7.5	7.5	7.5
1000	21.5	21.5	21.5	9.0	9.0	9.0
1600	21.5	21.5	21.5	5.5	5.5	5.5
2000	23.0	23.0	23.0	3.5	3.5	3.5
3150	28.5	28.5	28.5	3.5	3.5	3.5
4000	29.5	29.5	29.5	4.0	4.0	4.0
6300	33.0	33.0	33.0	9.0	9.0	9.0
8000	38.5	38.5	38.5	15.5	15.5	15.5

- It is important to point out that the MPANLs shown in Tables 1 and 2 are for monaural listening. When binaural listening occurs, 3 dB should be **subtracted** from the levels in Tables 1 and 2 to account for binaural summation.
- MPANLs shown in Tables 1 and 2 have a maximum uncertainty of 2 dB. ie a maximum threshold shift no greater than 2 dB may occur when pure-tone thresholds of 0 dB HL are obtained in an audiometric test room having ambient noise levels equal to those shown in Tables 1 or 2.
- If the measured ambient noise sound pressure levels do not exceed the levels shown in Tables 1 or 2 for the test condition and test frequency range to be employed, the test room is acceptable for testing at hearing levels >0 dB. If the measured ambient noise levels do not exceed the MPANLs shown in Tables 1 or 2 for ears-not-covered and the 125-8,000 Hz frequency range, the test room is acceptable for all test conditions and frequency ranges for testing at hearing levels >0 dB.
- Adjustment when hearing level employed is other than 0 dB: a simple proportionality is assumed between the minimum hearing level to be employed and the MPANL (i.e., equal trade-off in dB). For example, if testing is going to be conducted down to -10 dB HL, then 10 dB should be **subtracted** from the levels shown in Tables 1 and 2.

**Lankford JE, Hopkins CM. Ambient noise levels in nursing homes: implications for audiometric assessment. *American Journal of Audiology* 2000; 9:30-35.**

<http://aja.asha.org/cgi/content/abstract/9/1/30>

The study was designed to assess the ambient noise levels in various rooms of nursing homes to determine if valid hearing tests, both pure-tone air conduction and bone conduction, could be performed in these environments. Data from the nursing home facilities were compared to the maximum permissible ambient noise level (MPANL) criteria as specified in the newly revised ANSI S3.1-1999.

*Results:* For supra-aural earphones, none of the rooms met the standard at 250 or 500 Hz. Only 4 (12%) were in compliance at 1,000 Hz, with 25 (76%) at 2,000 Hz, 28 (85%) at 4,000 Hz, and 30 (91%) at 8,000 Hz. Comparing the room data with the standard using insert earphones, compliance levels were achieved as follows: 32 (97%) at 250 Hz, 30 (91%) at 500 and 1,000 Hz, and 33 (100%) at 2,000, 4,000, and 8,000 Hz.

At each of the frequencies for which bone conduction could be assessed (e.g., 250 through 4,000 Hz), only one room at one frequency (2,000 Hz) met the standard, and all other noise levels were in excess of those criterion levels.

*Implications:* The authors support the ASHA recommendation of using insert earphones when a soundproof booth is unavailable and ambient noise levels exceed ANSI standards in a nursing home facility. It should be recognized, that air- conduction thresholds could be elevated by ambient noise to 5 dB HL at 250, 500, and 1,000 Hz, even when insert earphones are used. Bone-conduction thresholds obtained in a nursing home environment can be dramatically elevated by excessive ambient noise levels to as high as 35 to 40 dB HL.

*Suggestions before hearing test is initiated*

- Evaluate the hearing sensitivity of an individual with known normal-hearing sensitivity in the environment to be used for hearing testing purposes in order to determine the potential elevation in air- and bone-conduction thresholds that might be expected in that environment. These results from the normal listener could be compared to the patient's data to determine if ambient noise may have elevated the resulting scores.
- Perform an otoscopic examination and immittance testing any time bone-conduction assessments have not been performed or were deemed to be elevated because of excessive ambient noise.

Frank T. ANSI update: maximum permissible ambient noise levels for audiometric test rooms. *American Journal of Audiology* 2000;9(1):3-8.

<http://aja.asha.org/cgi/content/abstract/9/1/3>

**TABLE 2.** Octave band ears covered maximum permissible ambient noise levels for three test frequency ranges as specified in ANSI S3.1-1999 when ears covered testing is done using a supra-aural or insert earphone

Octave Band Intervals	Supra-aural Earphone			Insert Earphone		
	125 to 8000 Hz	250 to 8000 Hz	500 to 8000 Hz	125 to 8000 Hz	250 to 8000 Hz	500 to 8000 Hz
125	35.0	39.0	49.0	59.0	67.0	78.0
250	25.0	25.0	35.0	53.0	53.0	64.0
500	21.0	21.0	21.0	50.0	50.0	50.0
1000	26.0	26.0	26.0	47.0	47.0	47.0
2000	34.0	34.0	34.0	49.0	49.0	49.0
4000	37.0	37.0	37.0	50.0	50.0	50.0
8000	37.0	37.0	37.0	56.0	56.0	56.0
<i>Note:</i> Values are in dB re: 20 $\mu$ Pa to nearest 0.5 dB and have been reprinted by permission of the Acoustical Society of America, New York, New York, U.S.A.						
5000				0.0	0.0	0.0
8000	14.0	14.0	14.0	9.0	9.0	9.0

*Note:* Values are in dB re: 20  $\mu$ Pa to the nearest 0.5 dB and have been reprinted by permission of the Acoustical Society of America, New York, New York, U.S.A.



## Section 7.2. Calibration

**Keywords: audiometry procedures calibration**

National Health and Nutrition Examination Survey. *Audiometry Procedures Manual*. National Center for Health Statistics, 2003

[http://www.cdc.gov/Nchs/data/nhanes/nhanes\\_03\\_04/AU.pdf](http://www.cdc.gov/Nchs/data/nhanes/nhanes_03_04/AU.pdf)

### *Calibration procedures*

- Use Bioacoustic Simulator to calibrate audiometer on a daily basis.
- The calibration of the bioacoustic simulator is checked at the beginning and end of each stand. It should be checked **before** it is used to check the calibration of the audiometer.
- Calibration checks should be conducted as the audiometric equipment is set up at the start of each stand, periodically throughout the stand, and again at the end of each stand to ensure that the accuracy has not shifted.
- Two measures require calibration on the Earscan units: air pressure and physical volume. These measures must be calibrated **every day**, including beginning and end of stand as well as each day throughout the stand.
- The sound level meter, octave filter set, and microphone should receive a comprehensive calibration annually (or sooner if problems are encountered). The calibration should be accomplished by the manufacturer (Quest Technologies) or by another laboratory whose calibrations are traceable to the National Institute of Standards and Technology (NIST).

**Keywords: audiometry techniques guidelines**

American Speech-Language-Hearing Association. *Guidelines for Manual Pure-Tone Threshold Audiometry*. ASHA, 2005

<http://www.asha.org/docs/html/GL2005-00014.html>

### *Audiometer and calibration (2005)*

- **Exhaustive electroacoustic calibrations should be performed annually** using instrumentation traceable to the National Institute of Standards and Technology.
- Functional inspection, performance checks, and bio-acoustic measurements should be conducted daily to verify the equipment performance before use.

**Keywords: audiometry ambient noise levels****Franks (2001) – Hearing measurement**

[http://www.who.int/occupational\\_health/publications/noise8.pdf](http://www.who.int/occupational_health/publications/noise8.pdf)

***Exhaustive calibration***

An exhaustive calibration requires the use of a sound level meter, octave band filters, an acoustic coupler and other instrumentation.

- Exhaustive audiometer calibrations should be performed by trained personnel who are familiar with the operations of audiometers, who have the necessary equipment, and who may adjust the audiometer to bring it back into calibration where necessary.
- If a bioacoustic simulator is used for daily threshold checks, it is important to perform a simulator test with the newly calibrated audiometer to obtain new reference levels.
- **NIOSH recommends and OSHA requires that audiometers receive an exhaustive calibration every two years** in accordance with relevant sections of ANSI S3.6-1996. These include: measuring output levels and output frequencies with comparison to tolerances of the standard, evaluating distortion of the test signals, checking for channel crosstalk and any other unwanted sounds in the earphone, and measuring duty cycle and rise/fall time of the signal when gated on and off.

**Keywords: audiometry procedures guidelines****British Society of Audiology. *Recommended procedure – Pure tone air and bone conduction threshold audiometry with and without masking and determination of uncomfortable loudness levels*. British Society of Audiology, 2004**

<http://www.thebsa.org.uk/docs/RecPro/PTA.pdf>

To enable the accurate testing of normal air and bone conduction hearing threshold levels down to 0 dB HL, ambient sound pressure levels should not exceed any of the levels shown in Tables 1 and 2 respectively (from BS EN ISO 8253-1). To measure minimum hearing threshold down to levels other than 0 dB HL, calculate the maximum permissible ambient sound pressure levels by adding the minimum hearing threshold level required to the values in Tables 1 and 2.

In general, the ambient noise should not exceed 35 dB (A). If it is higher than this, it is recommended that audiometry should not proceed.

**Table 1: Maximum permissible ambient sound pressure levels for measuring air conduction audiometry (supra-aural earphones) to a minimum hearing level of 0 dB HL between frequencies 250 and 8,000 Hz\***

Mid-frequency of one-third octave band (Hz)	dB re 20 µPa	Mid-frequency of one-third octave band (Hz)	dB re 20 µPa	Mid-frequency of one-third octave band (Hz)	dB re 20 µPa
31.5	66	250	19	2000	30
40	62	315	18	2500	32
50	57	400	18	3150	34
63	52	500	18	4000	36
80	48	630	18	5000	35
100	43	800	20	6300	34
125	39	1000	23	8000	33
160	30	1250	25		
200	20	1600	27		

\* Adapted from BS EN ISO 8253-1 (ISO, 1989)

### ***Calibration***

It is essential that audiometers are regularly calibrated in accordance with BS EN 60645-1 (IEC 60645-1) and the relevant BS EN ISO 389 (ISO 389) series standards. The following three-stage calibration programme is recommended.

### **Stage A: Routine checking and subjective tests**

In order to check the audiometer is functioning across the range, checks should be performed by an operator with preferably good hearing or alternatively known hearing thresholds. They should be carried out in the normal test room, with the equipment set up as installed.

Tests 1 to 7 should be carried out daily.

1. Clean and examine the audiometer and all accessories. Check earphone cushions, plugs, main leads and accessory leads for signs of wear or damage. Any badly worn or damaged parts should be replaced, and the audiometer should then undergo a stage B check.
2. Switch on equipment and leave for the recommended warm-up time. (If no warm-up period is quoted by the manufacturer, allow 5 minutes for circuits to stabilise.) Carry out any setting-up adjustments as specified by the manufacturer. On battery-powered equipment, check battery state using the specified method. Check that



- earphone and bone vibrator serial numbers tally with the instrument serial number.
3. Check that the audiometer output is approximately correct on both air and bone conduction by sweeping through at a hearing level of "just audible" tones (e.g. 10 or 15 dB HL). This test should be performed at all appropriate frequencies and for both earphones and the bone vibrator.
  4. Perform a high-level listening check on air and bone conduction at all frequencies used, on all appropriate functions and on both earphones (e.g. 60 dB for air conduction, 40 dB for bone conduction). Listen for proper functioning, absence of distortion, freedom from clicks when presenting the tone etc.
  5. Check all earphones (supra-aural and insert phones) and the bone vibrator for absence of distortion and intermittency; check plugs and leads for intermittency.
  6. Check that all the switches are secure and that lights and indicators work correctly.
  7. Check that the subject response button works correctly.

Tests 8 to 11 should be carried out weekly.

8. Listen at low levels for any sign of noise or hum, for unwanted sounds or for any change in tone quality as masking is introduced. Check that attenuators do attenuate the signals over their full range and that attenuators which are intended to be operated while a tone is being delivered are free from electrical or mechanical noise. Check that interrupter keys operate silently and that no noise radiated from the instrument is audible at the subject's position.
9. Check subject communication speech circuits.
10. Check tension of headset headband and bone vibrator headband. Ensure that swivel joints are free to return without being excessively slack. Check headbands and swivel joints for signs of wear strain or metal fatigue.
11. Perform an audiogram on a known subject, and check for significant deviation from previous audiograms (e.g. 10 dB or greater).

### **Stage B: Periodic objective tests**

Stage B checks are objective tests which ideally should be performed every 3 months, although this period can be extended provided the Stage A checks are regularly and carefully applied and it can be shown that the equipment is stable and reliable. The maximum interval between checks should not exceed 12 months. They should preferably be carried out in the normal test room, with the equipment set up as installed, particularly if inter-connecting leads are used through a booth wall.

Measure and compare with the appropriate standards:

1. Frequencies of test signals
2. Sound pressure levels in an acoustic coupler or artificial ear from earphones
3. Vibratory force levels on a mechanical coupler from bone vibrators
4. Levels of masking noise
5. Attenuator steps over a significant part of the range
6. Harmonic distortion

### **Stage C: Basic calibration tests**

Stage C checks need not be employed on a routine basis if stage A and B checks are regularly performed. They will only be required when a serious error or fault occurs, or when, after a long period of time, it is suspected that the equipment may no longer be performing fully to specifications. It may be advisable to submit equipment for a Stage C

check after, for example, five years' use if it has not received such a test in that time in the course of repair.

Stage C checks should be such that after the audiometric equipment has been submitted for a basic calibration, it shall meet the relevant requirements given in BS EN 60645-1 (IEC 60645-1). A suggested minimum requirement for a Stage C check would include all items covered at Stage B plus:

1. Rise and fall times of test tones
2. Interrupter effectiveness
3. Cross-talk between transducers and channels
4. Masking noise spectra
5. Distortion of speech and other external input systems.

<b>Keywords: audiometric testing environment</b>
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### **Navy and Marine Corps Public Health Center: The Audiometer & Test Environment**

<http://www-nmcpohc.med.navy.mil/downloads/occmcd/toolbox/AUDIOMETERANDTHETESTENVIRONMENT.ppt>

#### *Test Environment*

- Audiometric Booth Certification
  - Booths are not sound-proof, they are sound-treated. Noise levels inside the booth must meet ambient noise level criteria
  - Excessive background noise during patient testing may interfere with test results and elevate patient thresholds in the 250-500 Hz range
- Booth certification is required annually in accordance with ANSI S3.1. Noise levels inside the booth must be below established maximum levels
- Certification is typically performed by an Industrial Hygienist, Audiologist or trained technician
- Certification documentation must be placed in plain view of patients, typically on the outside of the booth door or wall

#### *Potential Causes of Excessive Noise in the Booth*

- Deterioration of door seals
- Leaks around jack panels
- Ventilation noise
- Excess internal noise

#### *Solutions for Excessive Noise in the Booth*

- Replace door seals
- Repair/replace jack panel
- Repair/replace ventilation fan
- Control exterior noise or change test schedule
- Relocate booth

#### *Audiometer Electroacoustic Calibration*

Don't confuse this with the daily biologic calibration

- Audiometric test equipment must be electroacoustically calibrated annually
- Meet the specific requirements stated in current version ANSI S3.6

- The audiometer will be tagged with a calibration Sticker which will state the date of next calibration
- Audiometers and headphones are calibrated together as a unit. Swapping headphones changes calibration! Always send headphones with units being repaired.
- Immediately following the annual calibration, establish a new DD2217 (biologic calibration) for each listener

#### *Functional Listening Check*

- A hands-on thorough equipment check
- Performed daily by the Hearing Conservation Technician
- Purpose is to detect any hardware problems and ensure equipment is working properly before seeing the first patient of the day

#### *Visual Check of Equipment*

- Earphone headband tension
- Earphone cushions
- Diaphragms
- Cords and connections

#### *Listening Check*

- Listen through headphones for
  - Frequency changes
  - Intensity changes
  - Tone quality
  - Crosstalk
  - Static

#### *Biological Calibration Check*

- Verifies that calibration is current by comparing hearing of a subject with baseline test of known hearing levels.
- Ensures the audiometer doesn't develop a problem between annual electroacoustic calibrations.
- Performed immediately after annual calibration and daily on every audiometer prior to use.
- Electro-acoustic ear preferred for stability, however may use a normal hearing human listener.
- The DD 2217 Form establishes a legal record verifying the audiometer's function, and must be maintained for 5 years.
- Human Listeners must have normal hearing (all thresholds less than 25 dB)
- Artificial ears can be used for this daily calibration, however, a secondary listener (or back-up artificial ear) is still necessary.
- Artificial ear thresholds range between 60 and 80 dB.
- Immediately following annual calibration, record the baseline thresholds for a primary and alternate listener for each audiometer. If only human listeners used, need at least 2 alternates.
- Daily calibration check must not differ from baseline calibration check by more than +/- 5 dB at 500-4,000 Hz & +/- 10 dB at 6000 Hz.
- If audiometer fails daily calibration, check all connections and condition of earphones, repeat bio-cal.
- Use second listener if problem persists.
- If audiometer fails calibration with 2nd listener, send out for repair and use backup audiometer (if available).

*Causes for Failed Daily Calibration Check*

In order of likelihood of occurrence...

- Improper earphone placement
- Poor connections at jack panel or to audiometer
- Worn out/flattened earphones
- Weak or dead batteries
- Audiometer electroacoustic calibration has expired
- Malfunctioning artificial ear
- Malfunctioning audiometer

*Audiometer Care & End of Day Procedures*

- Clean Earphone cushions daily with disinfectant (non-alcohol) wipes. Keep moisture away from diaphragms.
- Hang earphones on hook to maintain proper headband tension.
- Replace earphone cushions, cords and hand switches as needed.
- \* These components do not affect the audiometer calibration
- Back up audiometric data on an external drive.
- Properly shut down the system, so as not to cause data corruption.

*Infection Control***Critical Audiometric Equipment**

- Must be cleaned and sterilized after each use
- Includes objects that touch blood, mucous, ear drainage, cerumen or other bodily fluids
  - Probe tips for tympanometry testing
  - Non-disposable otoscope speculae
  - Ear gauges

**Non-Critical Audiometric Equipment**

- Must be cleaned and disinfected using disposable germicidal pre-moistened cloths, or hospital grade disinfectant
  - Headphones/earcups
  - Headbands
  - Hand Switch/Response buttons
  - Environmental surfaces in patient care area

**Section 7.3. Training and qualifications of person undertaking audiometry**

**Keywords: audiometric testing tester qualification, audiometry tester training, audiometric testing competency**

**Community Nurse Audiometrists Association**

*The Graduate Certificate in Audiometry Nursing course (postgraduate course)*

<http://www.cnaa.org.au/course.html>

**\*1269.4 Paragraph 7.2 – tester qualification, Appendix E also has competency**

[http://www.saiglobal.com/PDFTemp/Previews/OSH/as/as1000/1200/1269.4-2005\(+A1\).pdf](http://www.saiglobal.com/PDFTemp/Previews/OSH/as/as1000/1200/1269.4-2005(+A1).pdf)

**AS/NZS 1269.4:2005 Occupational noise management  
Part 4 Auditory assessment**

APPENDIX E  
COMPETENCY REQUIREMENTS FOR AUDIOMETRISTS  
(Normative)

Audiometric test procedures shall be carried out by a person or group who, through a combination of training and experience, have acquired the knowledge and skills to perform the procedures, interpret the results and present them in a manner that will enable the people in the workplace to make appropriate decisions.

In particular, a person or group carrying out assessments shall be able to demonstrate a thorough understanding of—

- (a) the objectives of the audiometric test in noise management;
- (b) the basic physics of sound;
- (c) the correct usage and limitations of audiometers and audiometric booths;
- (d) the basic anatomy and physiology of the auditory pathway;
- (e) the basic mechanisms of hearing;
- (f) an audiogram and its relationship to the detection and understanding of human speech;
- (g) noise induced hearing loss, its pattern, progress, cause and prevention;
- (h) correct headphone placement and test subject instruction;
- (i) correct audiometric test technique;
- (j) how to record the results of an audiometric test;
- (k) basic audiometric test result interpretation and how to explain the results to the test subject;
- (l) when to advise that a test subject requires referral for audiological, medical or rehabilitative purposes;
- (m) the correct selection, usage and limitations of personal hearing protectors;
- (n) this Standard, AS/NZS 1269.3 and NAL 80;
- (o) requirements of relevant legislation concerning audiometry in occupational noise management, particularly those relating to confidentiality of audiograms; and
- (p) awareness of ototoxic agents.

***Worksafe Victoria: Guide for assessing and fixing noise problems at work***

[http://www.worksafe.vic.gov.au/wps/wcm/resources/file/ebc8ff435b5f74a/noise\\_problems\\_at\\_work.pdf](http://www.worksafe.vic.gov.au/wps/wcm/resources/file/ebc8ff435b5f74a/noise_problems_at_work.pdf)

Employers who are required to provide “screening” audiometric testing should ensure that it is performed by a competent person who has the appropriate training or qualifications and has relevant experience. Persons who perform audiometric testing should also have a sound knowledge of the Occupational Health and Safety (Noise) Regulations 2004. Persons who may meet these criteria include:

- those who were approved to conduct audiometric testing under the old Occupational Health and Safety (Noise) Regulations 1992 and who have maintained their knowledge and skills;

- ear, nose and throat specialists;
- audiologists; and
- persons who have successfully completed an appropriate industrial screening audiometry course.

**Occupational Safety and Health Service. *Approved Code of Practice for the Management of Noise in the Workplace*. Wellington: Department of Labour, 2002**

<http://www.osh.govt.nz/order/catalogue/pdf/noise2a-ac.pdf>

***The “Competent” person (Appendix B): equivalent to 1269.4***

A person or group carrying out assessments should be able to demonstrate a thorough understanding of:

- objectives of audiometric tests in noise management;
- basic physics of sound;
- correct usage and limitations of audiometers and audiometric booths;
- basic anatomy and physiology of the auditory pathway;
- basic mechanisms of hearing;
- an audiogram and its relationship to the detection and understanding of human speech;
- noise-induced hearing loss, its pattern, progress, cause and prevention;
- correct headphone placement and test subject instruction;
- correct audiometric test technique;
- how to record the results of an audiometric test;
- basic audiometric test result interpretation and how to explain the results to the test subject;
- when to advise that a test subject required referral for audiological, medical or rehabilitative purposes;
- correct selection, usage and limitations of personal hearing protectors;
- AS/NZS 1269.3; and
- the requirements of the HSE Act and regulations relating to noise and audiometry in occupational noise management, particularly those relating to confidentiality of audiograms, and the reporting requirements of noise-induced hearing loss as serious harm.

**ISO 8253-1:1989 Acoustics – Audiometric test methods – Part 1: Basic pure tone air and bone conduction threshold audiometry**

[http://www.iso.org/iso/catalogue\\_detail.htm?csnumber=15356](http://www.iso.org/iso/catalogue_detail.htm?csnumber=15356)

**4.4 Qualified tester**

A qualified tester is understood to be someone who has followed an appropriate course of instruction in the theory and practice of audiometric testing. This qualification may be specified by national authorities or other suitable organizations.

Throughout this part of ISO 8253, it is assumed that tests will only be carried out by, or be under the supervision of, a qualified tester.

**Keywords: otolaryngology training audiometry**

Sataloff RT Certificate Program for Otolaryngology Personnel (CPOP): a good solution for many practice challenges *Ear, Nose and Throat Journal*/2006; 85(8): 468-470.

[http://www.thefreelibrary.com/Certificate+Program+for+Otolaryngology+Personnel+\(CPOP\):+a+good...-a0151200202](http://www.thefreelibrary.com/Certificate+Program+for+Otolaryngology+Personnel+(CPOP):+a+good...-a0151200202)

Otolaryngologists face many challenges while trying to fulfil our mission of providing outstanding healthcare. For example, there are not enough audiologists in the workforce to provide for all the auditory testing and rehabilitation needs of otolaryngology patients, let alone for the patients of pediatricians, internists, neurologists, and others involved in the assessment of hearing and balance. Even if there were an unlimited number of audiologists, economic pressures have forced physicians to consider the cost-effectiveness of each allied health professional whom we employ. Similar concerns exist for evaluation of patients with balance disorders, and other maladies.

To address these problems, during the past several years the American Academy of Otolaryngology Head and Neck Surgery has developed its Certificate Program for Otolaryngology Personnel (CPOP). The program was launched approximately 2 years ago, but many otolaryngologists remain unaware of its existence and its potential.

The only portion of the CPOP program available currently is the OTO Tech program. Its curriculum evolved from the audiometric technician program developed approximately a decade ago by the American Neurotologic Society (ANS). The three-part CPOP courses are given several times annually and have already proven highly successful. Students are all sponsored by otolaryngologists and have included nurses, physician assistants, medical assistants, secretaries, and even a few physicians.

The first part of the program involves self-study. Students are provided with educational materials, including a book, and they must pass an examination in order to proceed to the next level. Part 2 is a 21/2-day, hands-on training workshop with lectures provided by otolaryngologists and audiologists. Students learn to perform otoscopic examinations, tuning fork tests, pure tone and speech audiometry with and without masking, and tympanometry. They are also given basic informational lectures on more advanced audiologic testing, hearing aids, balance problems, and other relevant subjects. Scope-of-practice training is stressed.

The third part of the program is a supervisory period of approximately 6 months, during which specific numbers of procedures must be performed and reviewed for accuracy. At the conclusion of the 6-month period, logbooks are submitted to the AAOHNS, and a certificate is awarded for satisfactory completion of the program.

Information about the OTO Tech program can be obtained through the Academy at [www.entnet.org/education/CPOP.cfm](http://www.entnet.org/education/CPOP.cfm).

OTO technicians are not audiologists and are not intended to replace audiologists. Rather, they are designed to fill an important role in collaboration with otolaryngologists and audiologists, helping to provide excellent, cost-effective hearing healthcare and improve patients' access to expert hearing evaluation.

Prior to the development of the OTO Tech program and its antecedent audiometric technician program under the auspices of the ANS, there were few options for training staff to perform audiometry. Either people committed 6 years to a master's degree in audiology and licensure, or they performed testing with no formal training or certificate. Audiometry is often performed in the offices of family practitioners and pediatricians by office personnel who have received no training at all beyond reading the audiometer manual (and sometimes not even that); and the practice in the offices of some otolaryngologists without audiologists has not always been much better. Now that there is a reasonable training alternative that does not require an excessive time commitment, such informal and inconsistent training has become obsolete for nonaudiologist personnel who are called upon to test hearing.

The OTO Tech program is only the first of planned, psychometrically sound, meticulously designed training programs for otolaryngology personnel. The Academy should be commended on the success of its initial effort and encouraged to proceed with plans to launch certificate program training for front-office personnel, balance technicians, and voice technicians, and to fill other needed roles. Private and academic otolaryngologists would do well to consider incorporating CPOP personnel into their practices as adjuncts to certified audiologists, speech-language pathologists, and other traditional allied health personnel.

Initial experience with OTO technicians suggests that office personnel trained through CPOP programs can become even more valuable and dedicated assets to the physician's office than they were before training. Not only does the practice benefit, but the technicians also benefit from their increased knowledge and their ability to recognize clinical situations that exceed the limits of their expertise and scope of practice, and require referral to an audiologist.

It is reasonable to anticipate that this experience will be duplicated in areas other than hearing assessment. As we strive to provide superior patient care, optimize the time and use of our certified audiologists and speech-language pathologists, and remain economically viable, expanded use of trained technicians may prove to be a very effective strategy for otolaryngologic practice in the 21st century.

<b>Searched: Websites of otolaryngology professional organisations in New Zealand, Australia and USA</b>
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### **Australian Society for Otolaryngology Head and Neck Surgery**

**OHNS Training Syllabus:** [http://www.asohns.org.au/about/surgical\\_training/copy\\_of\\_ohns-training-syllabus/?searchterm=audiometry#section-4](http://www.asohns.org.au/about/surgical_training/copy_of_ohns-training-syllabus/?searchterm=audiometry#section-4)

#### **Audiology**

- Pure tone audiometry AC/BC
- Masking
- Psychoacoustics: physiology of sound
- Speech audiometry
- Impedance audiometry



- Paediatric testing: at risk register, otoacoustic emissions
- ABR; ECoG, Auditory evoked potential – measurements and applications
- Functional hearing loss: sensorineural testing in adults
- NIHL: epidemiology, diagnosis and management
- Rehabilitation, hearing aids, speech reading
- Tinnitus: aetiology, management and medicolegal issues

### **American Academy of Otolaryngology-Head and Neck Surgery**

Certificate Program for Otolaryngology Personnel

<http://www.entnet.org/ConferencesAndEvents/cpop.cfm>

CPOP (Certificate Program for Otolaryngology Personnel) Program Objectives:

Understand basic:

- Personal roles and professional relationships
- Patient confidentiality
- Need for physician diagnosis
- Anatomy and physiology of the ear and vestibular system
- Types of hearing loss patterns and variations
- Physics of sound and hearing
- Causes of hearing loss and audiometric patterns
- Personal limitations as a technician

Perform:

- Documentation of patient case history and exam
  - Review patient history
  - Summary of patient visit
- Basic examination of the ear
- Patient instructions/education regarding basic hearing testing
- Tuning fork tests
- Pure tone air and bone conduction audiometry with and without masking
- Speech audiometry with and without masking
- Tympanometry

Identify:

- Existing problems that preclude accurate testing and the need for referral to an otolaryngologist

Develop an awareness of:

- Other hearing tests
  - Otoacoustic emission testing
  - Evoked potential response
  - Electrocochleography (ECoG)
  - Central Auditory Testing
  - Pseudo-hypoacusis testing
- Hearing aids and devices
- Types, causes, and purpose of vestibular disorders and tests
- ENG

## Section 7.4. Audiometric test procedures

Erlandsson B, et al. Comparison of the hearing threshold measured by manual pure-tone and by self-recording (Békésy) audiometry. *International Journal of Audiology* 1979;18(5):414-429

<http://informahealthcare.com/doi/abs/10.3109/00206097909070067?journalCode=ija>

The hearing thresholds of 115 subjects aged 25-63 years and working on a shipyard were determined both by Békésy sweep audiometry and by conventional manual octave pure-tone audiometry at fixed audiometric frequencies. The attenuation rate was 2.5 dB s<sup>-1</sup> with pulsed-tone presentation and the sweep time from 0.25 to 10 kHz was 400 s for the Békésy audiometer. Manual pure-tone audiometry was performed in 5-dB steps. The Békésy method gave the lowest values for the hearing thresholds. It has been possible to find a useful linear relation between pure-tone and Békésy hearing thresholds. With the help of a retest experiment, it has been established, that the standard deviations of hearing thresholds obtained under similar conditions in a pure-tone investigation are about twice as large as those obtained in a Békésy investigation.

## Section 7.5. Reliability of air and bone conduction audiometry

**Keywords:** reliability audiometry, reliability audiometric testing, tester reliability audiometry

Howell RW, Hartley BPR. Variability in audiometric recording. *British Journal of Industrial Medicine* 1972;29:432-435  
<http://oem.bmj.com/content/29/4/432.abstract>

It was thought that some estimate of the extent of observer error might be obtained by repeating recent pre-employment audiograms at two works, at the same time exchanging operators. Eighty-seven dual recordings were obtained from one works and 56 from the other. One operator obtained means which were higher than those of the other operator at both workplaces.

Result: For nearly half the employees, **the difference between the results obtained by the two operators amounted to 5 dB or more, with differences up to and including 21 dB.** Of the two operators' lists of men in the lowest decile of hearing threshold levels, only half the names were common to both operators; there was clearly wide variation between the operators.

### *Implications:*

- It may be that single observations are not reliable enough and that the mean of two or three readings, taken within a short interval of time, should be used (Burns, 1968).
- Given the variations apparently possible between identically trained operators (and probably larger variations between those trained by different methods), consideration should also be given to the **basic training requirements for operators**, the need for re-testing them at intervals and the need for refresher courses.

**Keywords:** audiometric testing reliability

Schmuziger N, Probst R, Smurzynski J. Test-retest reliability of pure-tone thresholds from 0.5 to 16 kHz using Sennheiser HDA 200 and Etymotic Research ER-2 earphones. *Ear and Hearing* 2004;25(2):127-132  
<http://cat.inist.fr/?aModele=afficheN&cpsidt=15693757>

Aim: (1) To evaluate the intrasession test-retest reliability of pure-tone thresholds measured in the 0.5-16 kHz frequency range for a group of otologically healthy subjects using Sennheiser HDA 200 circumaural and Etymotic Research ER-2 insert earphones and (2) to compare the data with existing criteria of significant threshold shifts related to ototoxicity and noise-induced hearing loss.

Results: There were no significant differences in repeatability for the two transducer types for all frequency ranges. The intrasession variability increased slightly, but significantly, as frequency increased with the greatest amount of variability in the 14 to 16 kHz range. Analyzing each individual frequency, variability was increased particularly at 16 kHz.

Implication: Measurements in the extended high-frequency range from 8 to 14 kHz, but not up to 16 kHz, may be recommended for monitoring purposes.

**Macrae J. Improvement of clinical monitoring audiometry. *Australian Journal of Audiology* 1988;10(1):12-15**

<http://www.nal.gov.au/Select%20Bibliography%201999.htm#M>

### **How to reduce test-retest variability of audiometry**

- Improved calibration standards; a considerable difference in hearing threshold levels can occur as a result of difference in calibration.
- Smaller intensity steps; adoption of a smaller step size (smaller than 5 dB)
- Repeated testing of thresholds; repeated testing of thresholds in a single session with removal and replacement of headphones in between tests. Averaging across three tests better than averaging results of two tests, but little gained beyond three.
- Averaging of HTLs at adjacent frequencies.

**Macrae JH. Improved detection of hearing threshold impairment caused by occupational noise exposure. *Australian Journal of Audiology* 1994;16(1):25-35**

<http://www.nal.gov.au/Select%20Bibliography%201999.htm#M>

Two experiments; one investigated whether the effects averaging of repeated testing or averaging of HTLs across frequencies can be additive and independent and the second carried out to determine the limits of the test-retest variability of thresholds averaged in this manner.

### **Experiment 1**

- Found that the variance of HTLs averaged across runs at each frequency diminishes as the number of runs increases (three tests best).
- The greater the number of frequencies included in the average, the smaller the variance associated with the average. Frequency range: In early stages of threshold impairment, probably more effective to average across 3, 4 and 6 kHz than across a wider range.
- Variability of average thresholds across frequencies and runs; for averages of HTLs across frequency, the variance diminishes as the number of runs included in the average increases (three runs best).

### **Experiment 2**

Repeatedly tested a large group of subjects in order to determine the test-retest reliability of average thresholds, where the thresholds are averaged across 3, 4 and 6 kHz and across two tests and where an audiometric step size of 5 dB is used

- In steps of 5dB, a deterioration of 10 dB at 3 or 4 kHz or of 15 dB at 6 kHz must take place before it can be concluded that a real change has occurred

- In case of average thresholds, the overall standard deviation is 1.75 dB. Setting the limit of test-retest variability at two standard deviations, a real change in average threshold can be assumed if deterioration greater than 3.5 dB takes place.

**Hartley BPR, et al. Subject variability in short-term audiometric recording. *British Journal of Industrial Medicine* 1973;30:271-275**  
<http://oem.bmj.com/content/30/3/271.abstract>

The reliability of a single audiogram at one examination has not been established under industrial conditions. It has previously been suggested that when audiograms are taken they should be performed at least three times, preferably not at one sitting, and that the mean level at each frequency should be taken as the definitive value of hearing level.

This study seeks to compare the reliability of three audiograms taken at a single session, but with a break between tests, with three audiograms taken at roughly weekly intervals. One hundred and thirty-two apprentices (average age 16 years) without occupational noise exposure were examined with a Peters audiometer, using one operator only at each of the two works involved. At a third works 45 men (average age 36 years), mostly with occupational noise exposure, had three audiograms taken within an hour using a self-recording audiometer. Not only did the mean of three audiograms from a single session show no practical difference when compared with the mean of three readings taken on separate occasions roughly a week apart, but the second audiogram of the first three was found to be generally representative of the mean of these three. In only 4 of 132 subjects did the second audiogram vary by more than 3 dB from the mean of the first three readings. It is suggested that single audiogram examination should be replaced by two audiograms routinely carried out at a single session, and that in the absence of any large difference (say 5 dB) between the two readings the second should be adopted.

In this series, variability between operators (at 3 and 4 kHz) exceeded mean subject variability. There appeared to be no reduction in subject variability when a self-recording machine was used.

## Section 7.6. Additional audiometric procedures for diagnosis of NIHL

**Keywords:** otoscopy tympanometry comparison

Gimsing S, Bergholtz LM. Otoscopy compared with tympanometry. *Journal of Laryngology and Otology* 1983;97(7):587-592  
<http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=1118988>

A study comparing otoscopy with tympanometry was carried out in 1702 ears in seven- and ten-year-old children.

*Results:* Pneumatic otoscopy produced an 88 per cent agreement with tympanometry in the two age groups studied. The agreement was somewhat better in ears classed as normal than in ears classed as abnormal, and the accuracy of otoscopy was better in the older children than in the younger ones. Simple otoscopy gave results that were about five per cent poorer—besides, 15 per cent of the ears could not be evaluated conclusively.

Williams RG, Haughton PM. Tympanometric diagnosis of middle ear effusions. *Journal of Laryngology and Otology* 1977;91:959-962  
<http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=1131596>

This investigation is to determine the reliability of tympanometry when the otoscopic diagnosis is uncertain in the less than ideal circumstances of an out-patient clinic.

*Present study:* The medical records of 120 children admitted consecutively for aspiration of the middle ear have been reviewed. Pre-operative tympanometric data were available in each case although tympanometry was not used in making the initial diagnosis.

*Results:* When otoscopy was ambiguous, tympanometry was also inconclusive (incapable of providing a diagnosis) in 18 ears (11 per cent). In 92 ears, it predicted the absence of fluid and this was confirmed surgically in 81 instances, an accuracy of 88 per cent. **Fluid was predicted tympanometrically in 54 ears and found in 46 of them—an accuracy of 85 per cent.** In roughly half of those cases where the clinician was confident of his diagnosis (50 ears) the subsequent aspiration revealed a dry middle ear. In these seemingly straightforward cases tympanometry incorrectly indicated a dry middle ear in 14 instances (28 per cent) and in 2 cases it was ambiguous.

*Implications:* Obviously not all otoscopically doubtful cases are ambiguous by tympanometry; in our survey only 11 per cent were ambiguous. In many clinically dubious cases tympanometry can resolve the doubt by making a diagnosis which is sufficiently reliable to allow a decision on whether or not treatment is needed. When the otoscopic findings are seemingly decisive but the clinical and tympanometric findings conflict, tympanometry is the more likely to be correct.

**Haughton PM, Pardoe K. A comparison of otoscopy and tympanometry in the diagnosis of middle ear effusion. *Clinical Physics and Physiological Measurement* 1982;3(3):213-220**

<http://www.ncbi.nlm.nih.gov/pubmed/7140159>

Tympanometry shows only the likelihood that an effusion is present; it is not an absolute indicator of this condition. It is therefore not surprising that some ears represented in the upper right hand part of figure 2 have a 'dry' otoscopic diagnosis and vice versa. What is surprising, however, is that three observers (B, C and D) gave diagnoses which were distributed at random. Thus it appears that the otoscopic diagnosis of middle ear effusion is, at least for some clinicians, a rather difficult task.

**Tympanometry should be regarded as an almost indispensable adjunct to otoscopy in cases where middle ear effusion is suspected.**

As a diagnostic tool, tympanometry is, of course, most reliable when middle ear pressure and admittance (or gradient) are normal or when these quantities have extreme values whereas the diagnostic significance of intermediate values is sometimes equivocal. Fortunately it appears that an ambiguous tympanometric result is not associated with uncertainty in the otoscopic diagnosis.

**Holt JJ. Cholesteatoma and otosclerosis: two slowly progressive causes of hearing loss treatable through corrective surgery. *Clinical Medicine and Research* 2003;1(2):151-154**

<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1069039/>

"On examination, the ear canal and eardrum are normal. Otosclerosis cannot be seen on an office examination. The audiogram indicates a conductive type of hearing loss. A special type of testing, stapedia reflexes, indicates limited or no movement of the bones of hearing."

**Habig A. The clinical value of immittance testing in the identification of middle ear pathology in South African mineworkers. Thesis, University of Pretoria, 2005**

<http://upetd.up.ac.za/thesis/available/etd-10182005-085508/unrestricted/00dissertation.pdf>

Immittance testing improved sensitivity to ear disease.

## Section 7.8. Quality Assurance

<b>Keywords: quality assurance audiometry</b>
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Franks JR, Stephenson MR, Merry CJ (Eds.). *Preventing Occupational Hearing Loss – A Practical Guide: audiometric evaluation*. NIOSH Publication No. 96-110. Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1996  
<http://www.cdc.gov/niosh/docs/96-110/audio.html>

NOTE: that these guidelines relate to monitoring audiometry.

### Management responsibilities

Practices should adhere to the following;

1. The audiograms must be administered using properly calibrated audiometers in a sound-treated room with acceptable background sound levels during testing. Circumaural earphone enclosures (earphones inside earmuffs), which are designed to reduce external noise, should not be substituted for a sound treated room, and generally should not be used because of inherent problems with calibration and earphone placement.
  2. The same type of audiometer (and preferably the same instrument) should be used from year to year. This may help prevent measurement variations caused by subtle differences among machine models/types or by the type of responses required from the person being tested.
  3. The training of audiometric technicians should meet as a minimum the current requirements of the Council for Accreditation in Occupational Hearing Conservation. Use of microprocessor-controlled or computer-based audiometric equipment should **NOT** exempt a technician from receiving training.
  4. All audiometric technicians should use the same testing methods for all of the company's employees.
  5. All testing should be done under the supervision of an audiologist or a physician knowledgeable about hearing loss prevention
- One of the best ways to assure the quality of the audiograms collected is to make prior audiograms for each employee available to the tester at the time of the test. If the tester's comparison of audiograms reveals a threshold shift (equal to 15 dB or more at any frequency), the tester can refit the earphones, reinstruct the employee, and conduct a retest.
  - Management should also make sure that the individual who reviews the audiograms is a qualified professional with specific training and experience in the area of occupational hearing conservation.



**Program implementer responsibilities**

- The results of the hearing testing are most valuable to the employee if they are provided immediately following the test. The audiogram should be compared to the baseline or reference audiogram while the employee is watching.
- *Annual audiometric examinations (but not baselines) should be scheduled well into the work shift* so that comparisons with baseline audiograms will reveal any early indications of hearing loss or temporary threshold shifts due to hearing protector inadequacies
- Daily functional and listening checks of audiometer function are critical if audiogram are to be accurate, and the program implementer must ensure that these checks are properly documented. To measure thresholds accurately, the test room must be quiet enough to meet appropriate American National Standards Institute requirements (ANSI S3.1-1991 or its successor), which is especially important for employees with normal hearing. Complete audiometer calibrations should be scheduled annually, but the audiometer should not actually be adjusted unless it fails to meet standard tolerances.
- The program implementer must make sure that every baseline, annual, retest, and follow-up audiogram is reviewed.
- OSHA requires follow-up referrals under certain conditions (and section (g)(8)(ii) in the OSHA noise standard). The program implementer must be familiar with these provisions, and must see that they are carried out. Sometimes medical referrals are necessary to determine the cause of a hearing loss, and medical treatment can be an important next step
- Although OSHA regulations specify required follow-up actions when a standard threshold shift is identified, follow-up for smaller shifts in hearing is recommended for optimal protection.

<b>Keywords: quality assurance audiometry</b>
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***Council for Accreditation in Occupational Hearing Conservation – Update***<http://www.caohc.org/index.php>

Hearing conservation regulations stipulate that audiometers must be calibrated annually or whenever there is a deviation of 10 dB or more on the daily functional equipment check. In addition, ambient noise levels in the test environment must be compliant within allowable levels *at the time of testing*, but there are no absolute timelines specified for documenting these sound level measurements. **In general practice, ambient noise measurements are typically performed once a year when the audiometer is calibrated, providing the audiometer is used in a stationary location.** In the case of mobile van service providers, ambient noise levels are typically re-measured at each physical location where testing is conducted. It is critical that these measurements be done within a timeframe that is representative of the acoustic environment during actual hearing testing.

Franks JR, Stephenson MR, Merry CJ (Eds.). *Preventing Occupational Hearing Loss – A Practical Guide: audiometric evaluation*. NIOSH Publication No. 96-110. Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1996

<http://www.cdc.gov/niosh/docs/96-110/audio.html>

Whether the audiometric testing is performed internally or externally, the company will not receive the benefit of quality audiometric evaluations unless the following practices are adhered to:

1. The audiograms must be administered using properly calibrated audiometers in a sound-treated room with acceptable background sound levels during testing. Circumaural earphone enclosures (earphones inside earmuffs), which are designed to reduce external noise, should not be substituted for a sound treated room, and generally should not be used because of inherent problems with calibration and earphone placement.
2. The same type of audiometer (and preferably the same instrument) should be used from year to year. This may help prevent measurement variations caused by subtle differences among machine models/types or by the type of responses required from the person being tested.
3. The training of audiometric technicians should meet as a minimum the current requirements of the Council for Accreditation in Occupational Hearing Conservation. Use of microprocessor-controlled or computer-based audiometric equipment should **NOT** exempt a technician from receiving training.
4. All audiometric technicians should use the same testing methods for all of the company's employees.
5. All testing should be done under the supervision of an audiologist or a physician knowledgeable about hearing loss prevention.

Management should provide the audiometric technician with sufficient time to perform the tests thoroughly and to give noise-exposed employees proper attention. Because the audiometric session provides an ideal opportunity to motivate employees' concern for hearing loss prevention, technicians should have time to inform employees about their hearing status immediately after completing the audiogram and to check their hearing protection devices. When the technician is too hurried to do more than a rapid screening audiogram because of other duties, the employee correctly perceives that the exercise is performed only in response to regulatory requirements, without a sincere interest in protecting anyone's hearing. In such a situation employees often lose their motivation to participate in the hearing loss prevention program.

One of the best ways to assure the quality of the audiograms collected is to make prior audiograms for each employee available to the tester at the time of the test. If the tester's comparison of audiograms reveals a threshold shift (equal to 15 dB or more at any frequency), the tester can refit the earphones, reinstruct the employee, and conduct a retest. If the shift persists on the retest, the change can be considered as reliable. If not,

the retest can be taken as the reliable test and it will be included in the record system and the first test will be discarded. It is estimated that as many as 70% of all audiograms showing shift will be resolved if the earphones are refitted, the employee is reinstructed, and a retest is administered at the time of the initial test. Management can facilitate quality assurance by providing the audiometric technician with time to conduct the retest and with authority to hold the employee back for a retest.

***Tremetrics RA650 Microprocessor Group Audiometer Operations Manual***

<http://www.tremetrics.com/eprise/main/Tremetrics/Products/ProductData/650/650.Op.pdf>

To guarantee accuracy, each audiometer must be re-calibrated at least once each year and receive an exhaustive calibration every two years. Daily biological tests through the use of an Electroacoustic Ear (for daily comparisons to acoustic ear baseline obtained at time of calibration) and the operator listening to each frequency and verifying the attenuator operation, ensures accuracy and purity of the audiometer tones.