Automated Hearing Tests

Robert H. Margolis

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Audiology Incorporated

Beyond the Audiology Clinic:
Innovations and Possibilities of Connected Health
18-20 September 2013

Advantages of Automation

- **Optimize use of audiologists' time**
- **Standardization**
- **Quantitative quality assessment**
- **Decrease errors**
- **Decrease cost**
- **Increase Access**
- **Telemedicine**

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Making effective communication, a human right, accessible and achievable for all.

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Untreated Hearing Loss in Adults—A Growing National Epidemic

Introduction

The statistics are alarming. According to the National Institute on Deafness and Other Communication Disorders (NIDCD), 36 million Americans have a hearing loss—this includes 17% of our adult population. The incidence of hearing loss increases with age. Approximately one third of Americans between ages 65 and 74 and nearly half of those over age 75 have hearing loss (NIDCD, 2010). Hearing loss is the third most prevalent chronic health condition facing older adults (Collins, 1997). Unfortunately, only 20% of those individuals who might benefit from treatment actually seek help. Most tend to delay treatment until they cannot communicate even in the best of listening situations. On average, hearing aid users wait over 10 years after their initial diagnosis to be fit with their first set of hearing aids (Davis, Smith, Ferguson, Stephens, & Gianopoulos, 2007).

Our population is aging. According to the Administration on Aging (2011, para. 1), "the older population will burgeon between the years 2010 and 2030 when the 'baby boom' generation reaches age 65." In 2009, people over 65 represented 12.9% of the population; by 2030, they will represent 19.3%. The population of individuals over 65 is expected to double between 2008 and 2030 to a projected 72.1 million (Administration on Aging, 2011, para. 2).

29 million Americans have untreated hearing loss

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Hearing Evaluation: Obstacles to Access

- Personnel
- Equipment Cost
- Calibration
- Patient Resistance
- Travel to Care Center
- Treatment Costs

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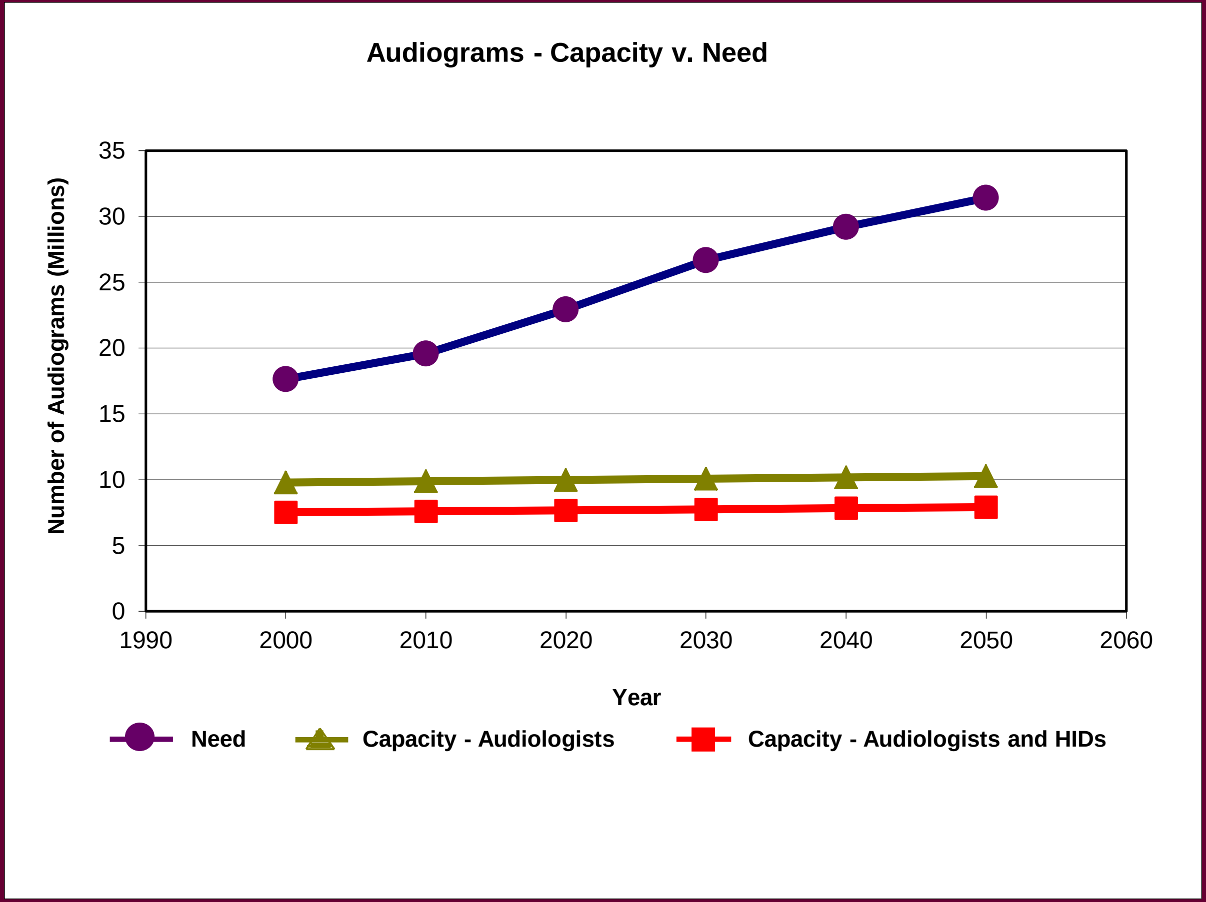

Margolis, R.H., Morgan, D.E.. Automated Pure-Tone Audiometry: An Analysis of Capacity, Need, and Benefit. *Amer J Audiology*, 17, 109-113, 2008.

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Automating Pure Tone Audiometry

Disadvantage of Automation

Loss of audiologist expertise

AMTAS®

(U.S. Patents 6496585, 7704216, 8075494)

Features

- **Single-interval forced choice**
- **Self-paced**
- **Contralateral masking always presented**
- **Adult and child versions**
- **Complete air and bone conduction audiogram without examiner intervention**
- **Remote Monitor**
- **Quantitative quality assessment**

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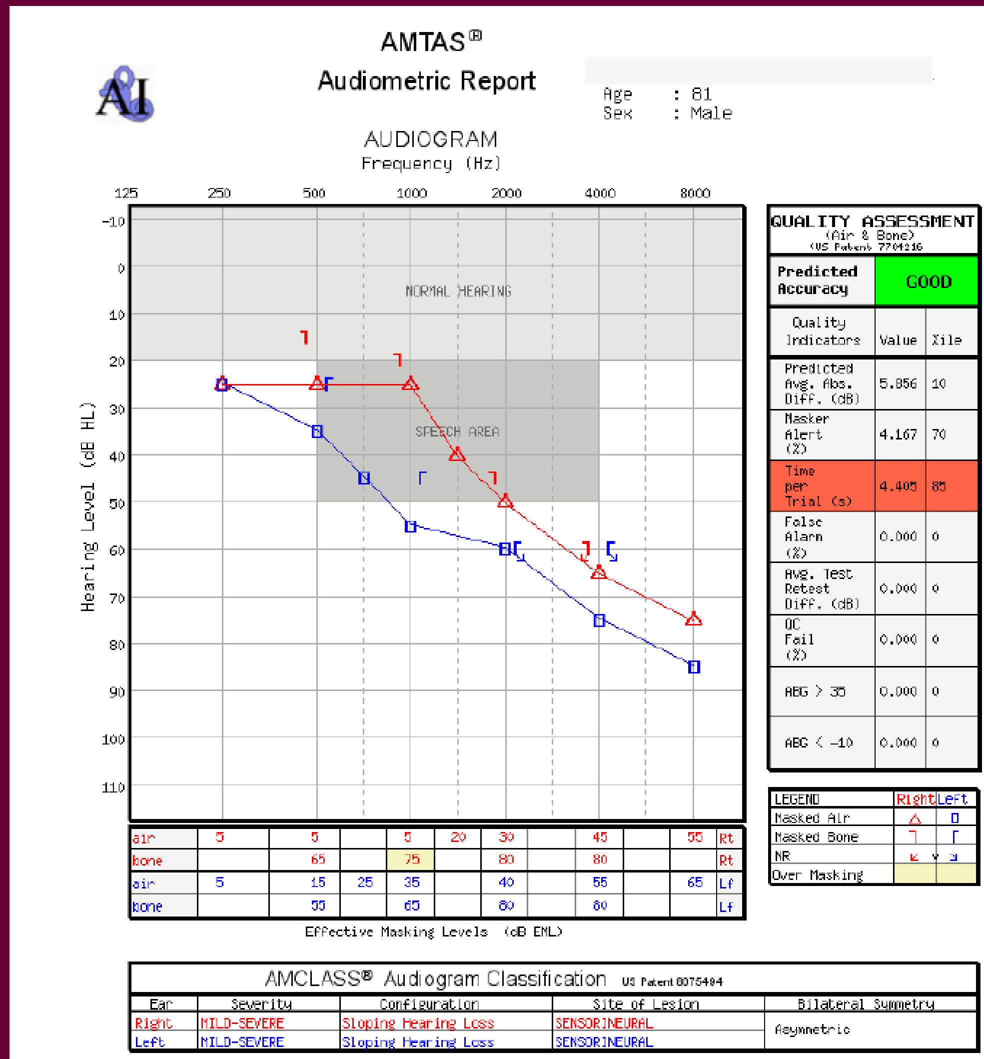

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QUALITY ASSESSMENT

Principles

- Removing the audiologist from the test process eliminates the expertise required to identify problems.
- The information used by audiologists to identify problems can be tracked, quantified, and used by computers.
- Subject characteristics and behaviors (Quality Indicators) exist that are correlated with test accuracy.
- Quality Indicators can be used to quantitatively predict test accuracy.

Qualind ®

(U.S. Patent 7,704,216)

A Method for Predicting the Accuracy of a Test Result

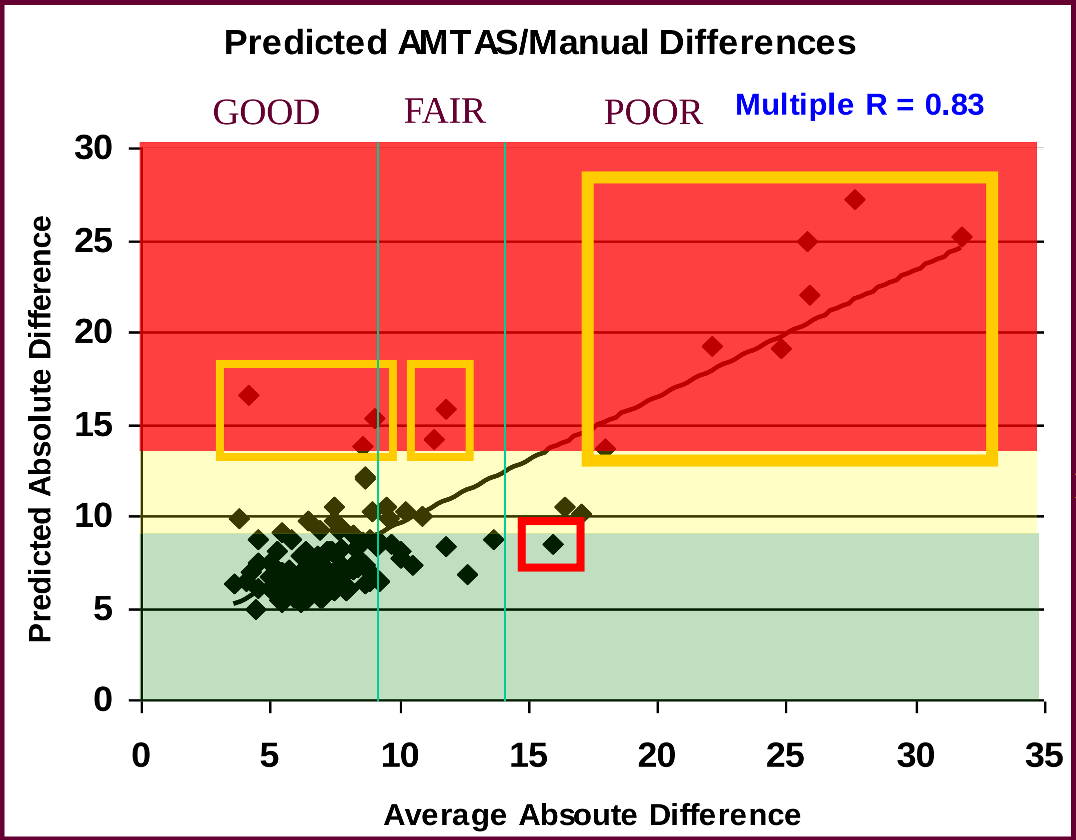
Qualind

Quality Indicators

- **Masker Alert Rate**
- **Time per Trial**
- **False Alarm Rate**
- **Test-retest Difference**
- **Quality Check Fail Rate**
- **Air-Bone Gap > 35 dB**
- **Air-Bone Gap < -10 dB**

Quality Assessment

N = 123 Adult Ss with sensorineural hearing loss



Automating Pure Tone Audiometry

Technical Problems

Transducers routinely used for audiometry are poorly designed for automated testing.

Audiometric Earphones

Design Objectives

Calibration
Ambient Noise Attenuation
Interaural Attenuation
Comfort
Occlusion Effect
Cost

Audiometric Earphones

Options

Supra-aural		Inserts	
Telephonics TDH		ER3A	
Interacoustics DD45		ER5	

Audiometric Earphones

Options

Circumaural

Sennheiser HDA 200

Sennheiser HD 280Pro

Bone Conduction

Bone Conduction Vibrators

Radioear B71

Radioear B81

Bone Conduction Vibrator Location

Mastoid

Forehead

Air-Bone Gaps

The 4 kHz Air-Bone Gap

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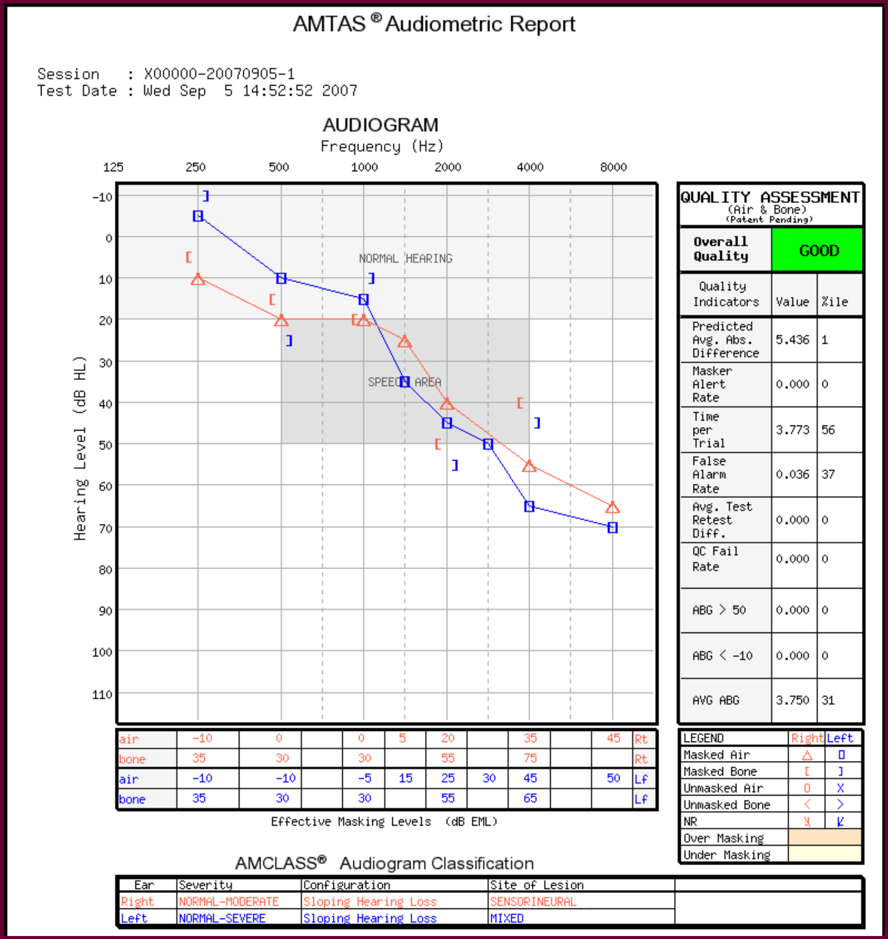
Air-Bone Gaps



4 kHz Air-Bone Gaps

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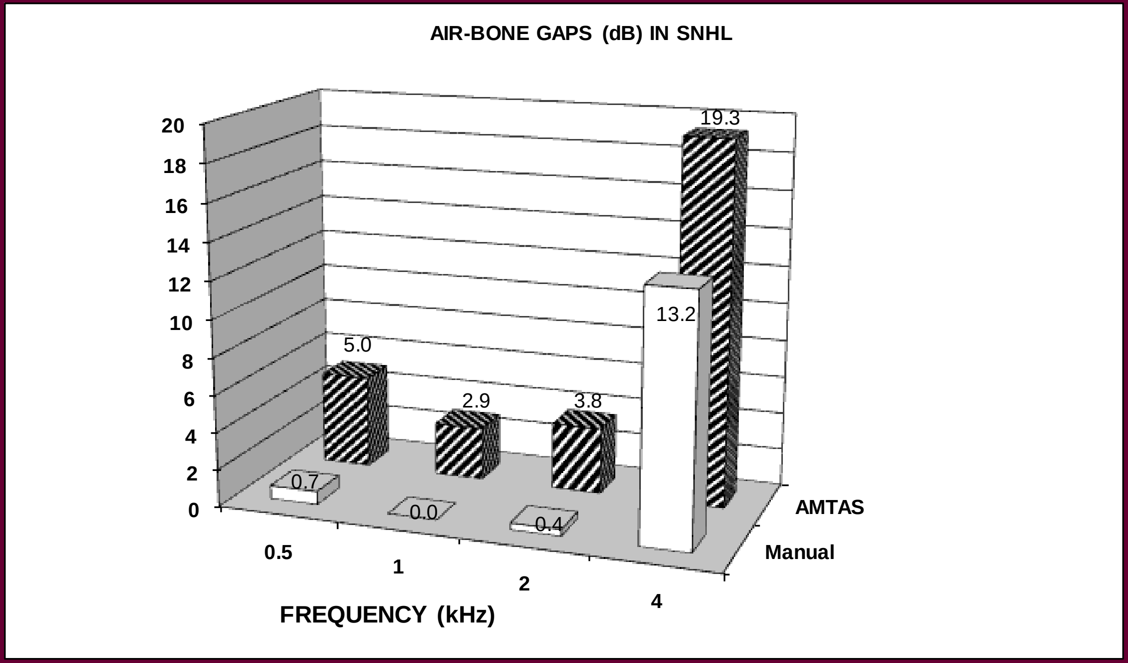
Air-Bone Gaps

Air-Bone Gaps in Sensorineural Hearing Loss



Margolis, R.H., Glasberg, B.R., Creeke, S., Moore, B.C.J. AMTAS® - Automated Method for Testing Auditory Sensitivity: Validation Studies. *Int J Audiology*, 49, 185-194, 2010.

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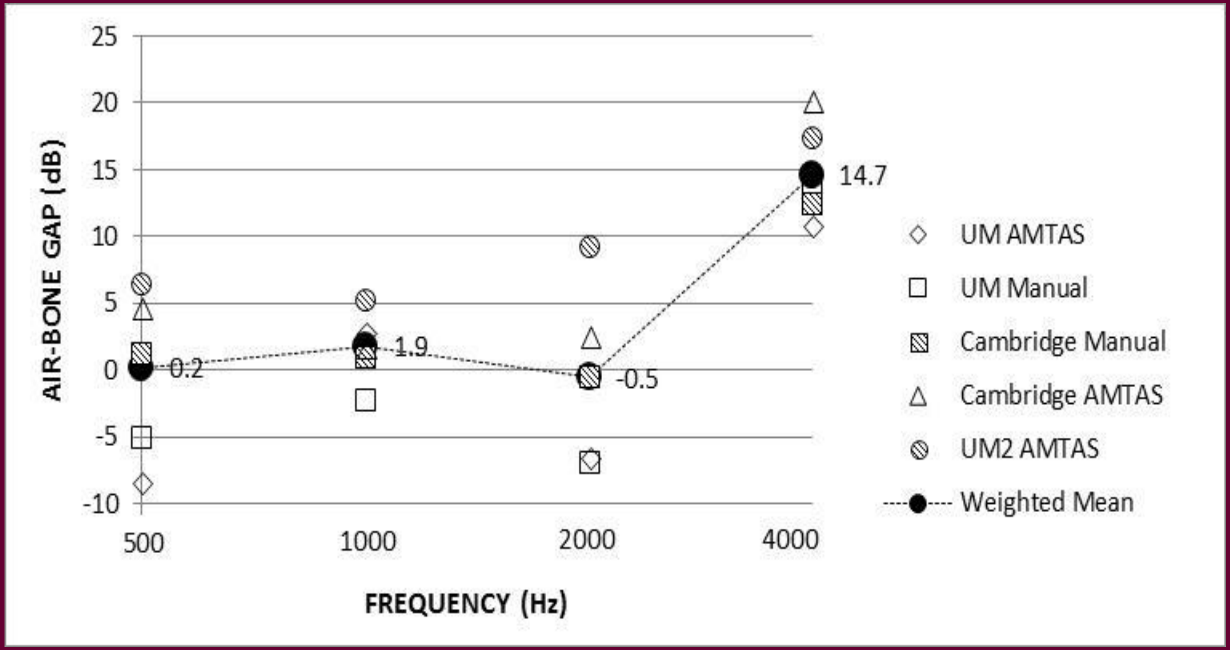
Air-Bone Gaps



Margolis R.H., Moore B.C.J. 2011. AMTAS – Automated method for testing auditory sensitivity: III. Sensorineural hearing loss and air-bone gaps. *Int. J. Audiol.* In press.

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International Journal of Audiology 2013; 52: 526–532

informa
healthcare

Original Article

False air-bone gaps at 4 kHz in listeners with normal hearing and sensorineural hearing loss

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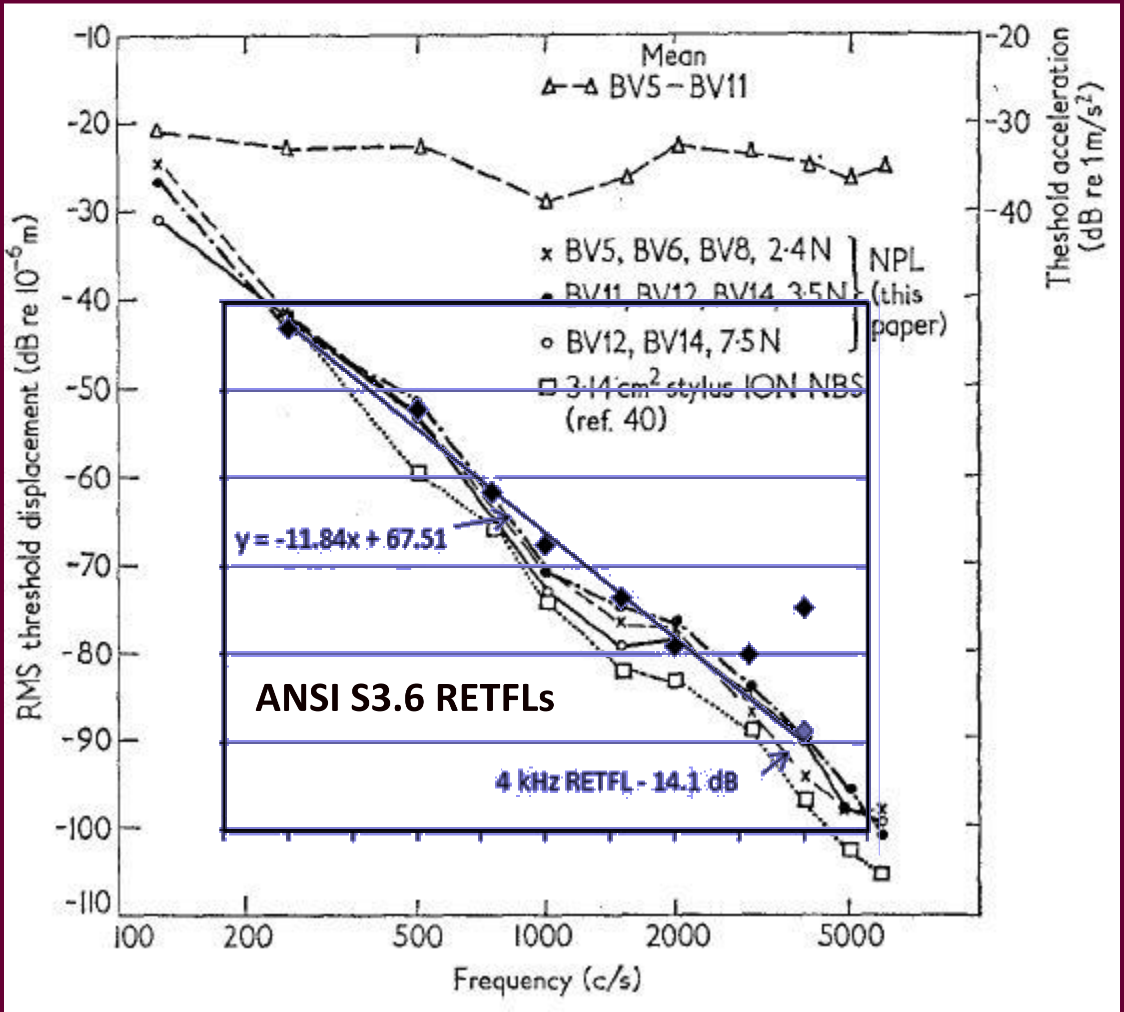

Whittle 1965

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Air-Bone Gaps

- How to eliminate the 4 kHz air-bone gap:
- Calibrate 4 kHz bone conduction to a Reference Equivalent Force Level 14.1 dB *lower* than standard
- Mastoid - 21.4 dB re: 1µN
- Forehead - 29.4 dB re: 1µN

Variability of Air-Bone Gaps

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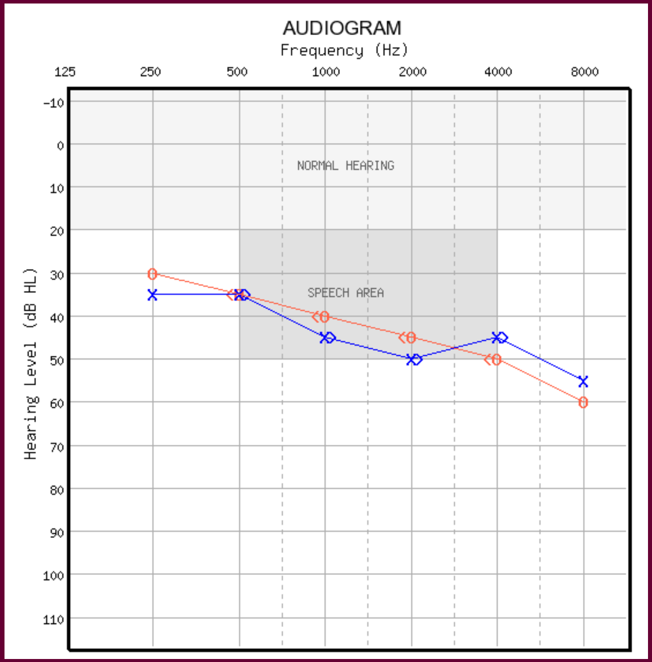
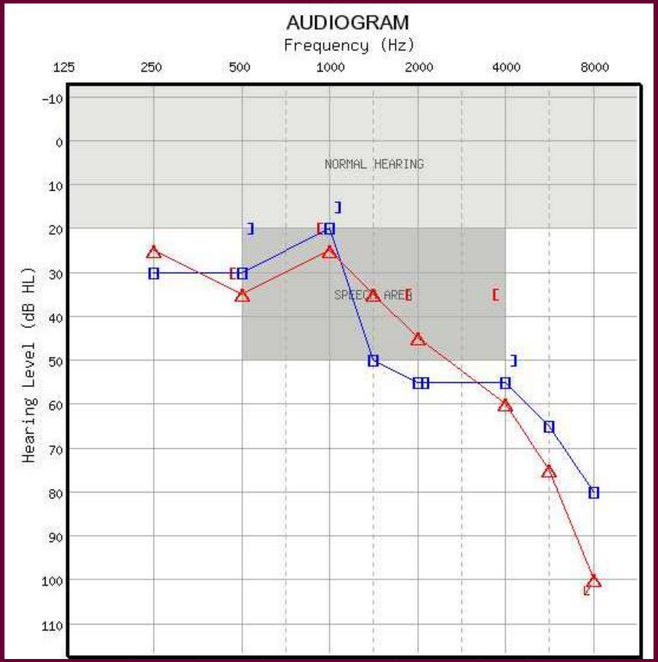
Air-Bone Gaps





Air-Bone Gaps

INTERTEST VARIABILITY AND THE AIR-BONE GAP

Gerald A. Studebaker
University of Oklahoma Medical Center
Oklahoma City, Oklahoma

Studebaker (1967). Intertest variability and the air-bone gap. *J. Speech Hear Dis 32*, 82-86.

The air-bone gap is a normally-distributed variable

The distribution of air-bone gaps is the distribution of differences between air-conduction and bone-conduction thresholds

The standard deviation of the air-bone gap is 5 dB

Air-bone gap is zero 38% of the time

The probability that ABG = 0 for entire audiogram (5 frequencies) = 1/16,000

Air-Bone Gaps

Audiology's Dirty Little Secret

Bone Conduction Testing is a Biased Experiment

In manual pure-tone audiometry
Air Conduction and Bone Conduction are NOT Independent

THE MODEL

ASSUMPTIONS

- Air conduction thresholds and bone conduction thresholds are normally-distributed variables.
- ABG is a normally-distributed variable with a variance that is the sum of the variances of air-conduction and bone-conduction thresholds (Studebaker 1967).
- The standard deviation of air conduction thresholds for adult listeners is 3.34 dB (Busselton Study).
- The standard deviation of bone conduction thresholds can be derived from the best fit normal distribution of air-bone gaps.

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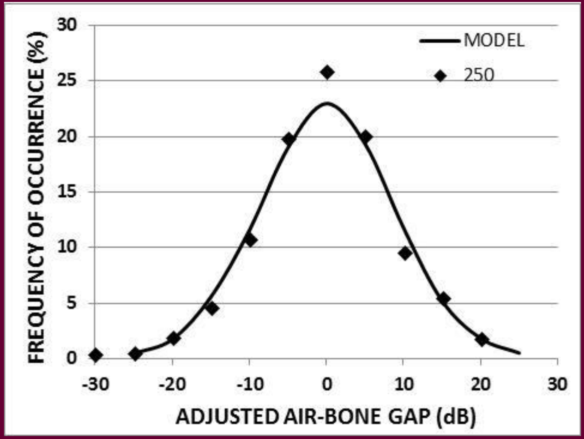

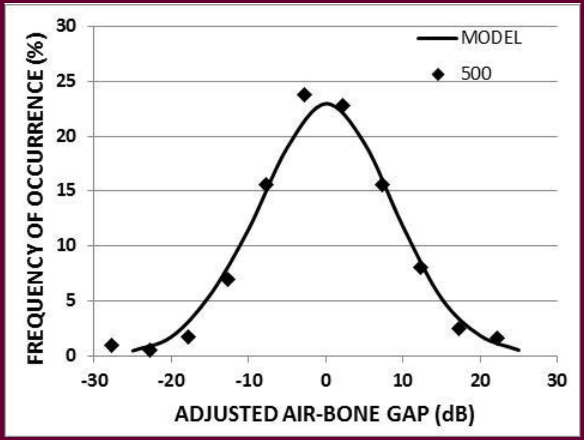

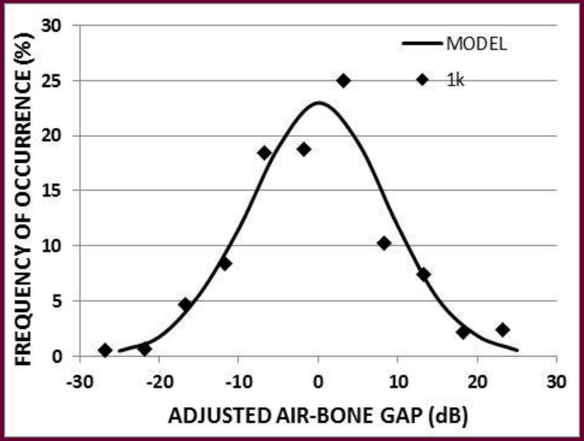

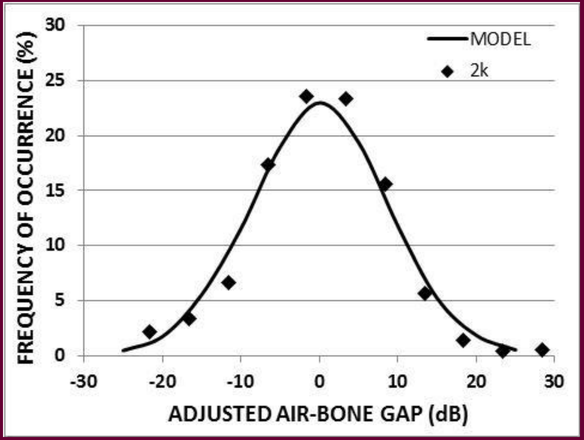

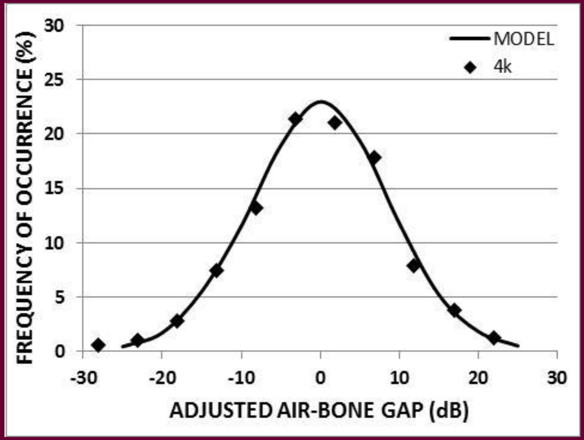

Distributions of Air-Bone Gaps
Busselton Healthy Ageing Study

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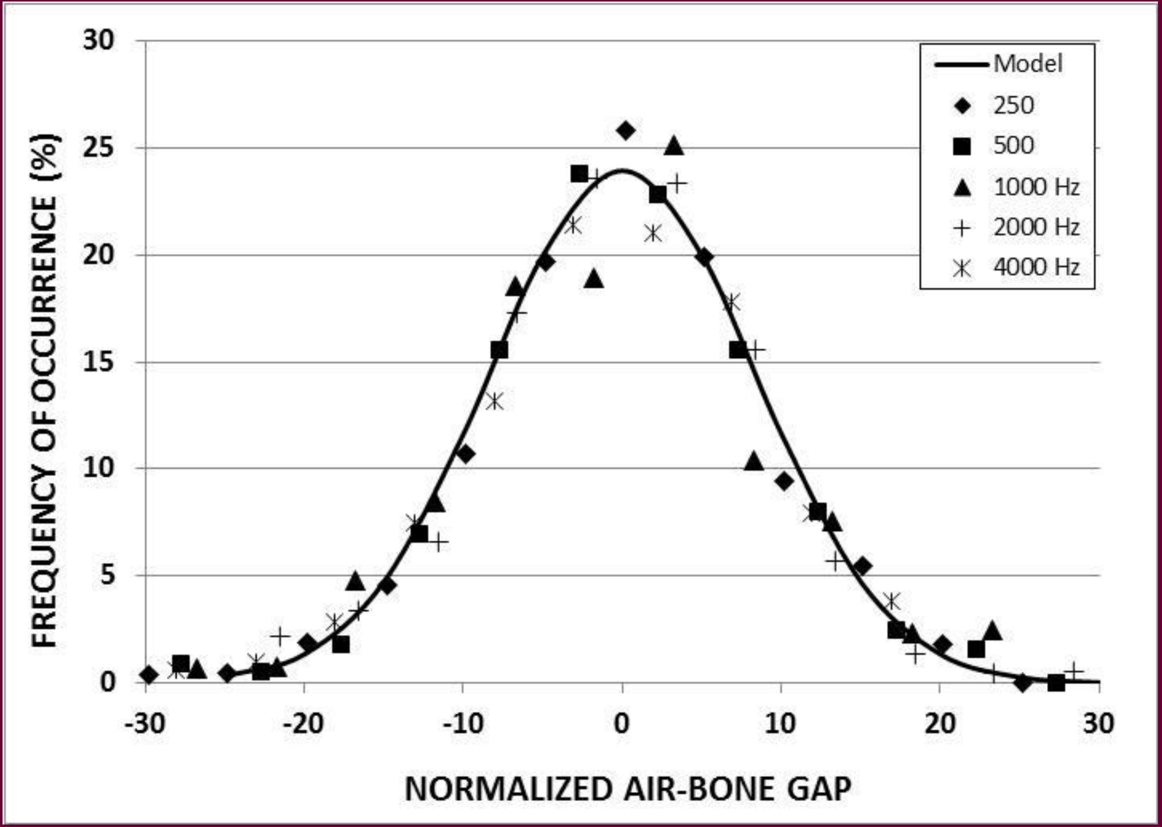
The Model



Composite Distribution of Air-Bone Gaps
Busselton Healthy Ageing Study

s_{ac} = 3.34 dB

s_{bc} = 7.53 dB

s_{ABG} = 8.24 dB

Probability that 10 ABGs = 0:

1/1.6 million

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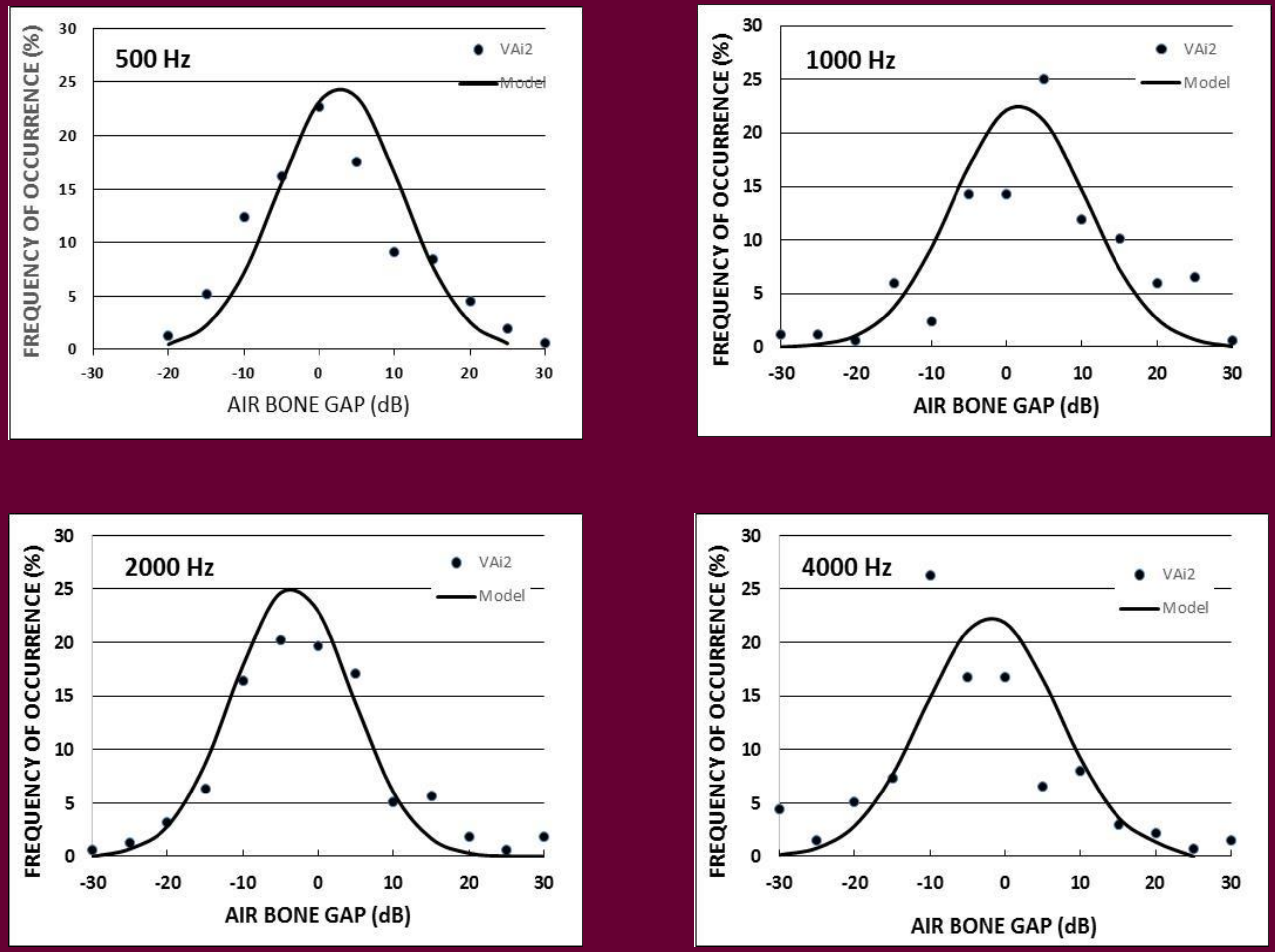

Distributions of Air-Bone Gaps
VAi2 Study

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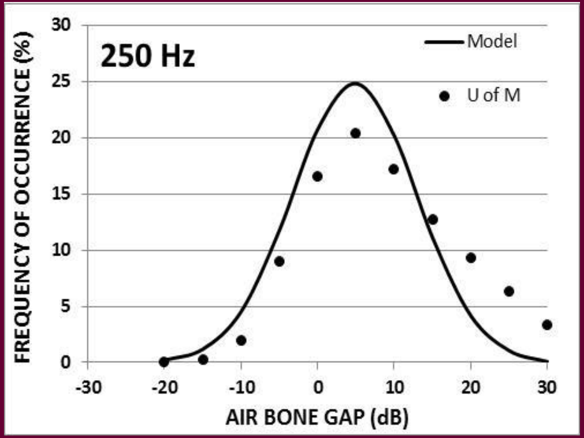

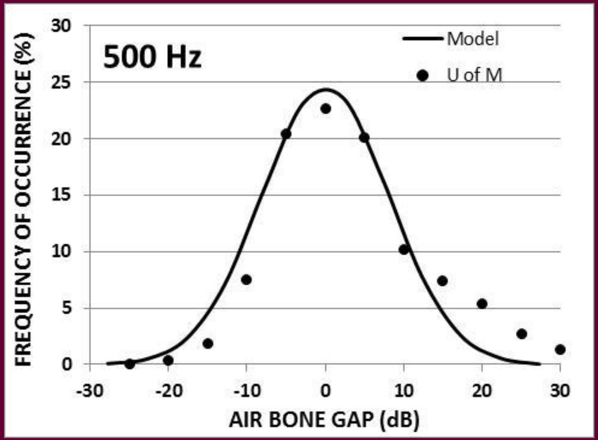

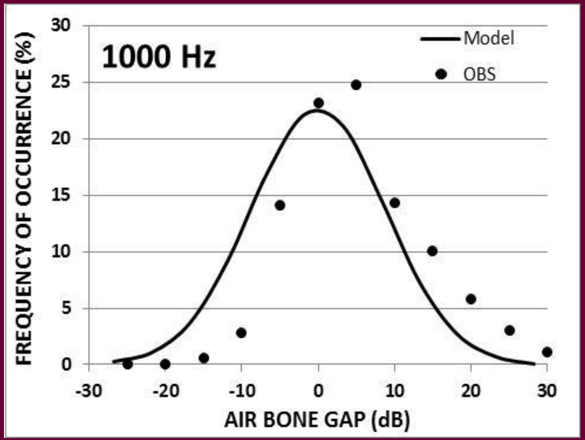

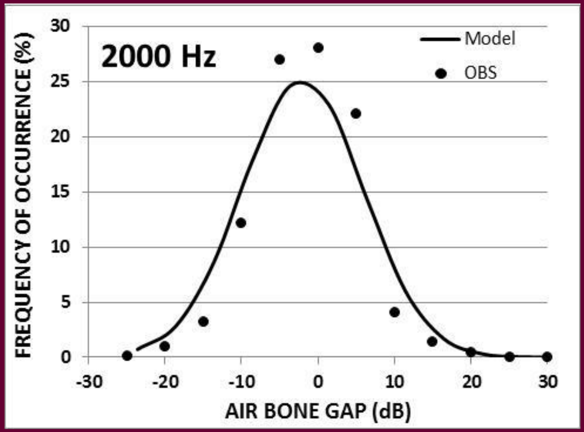

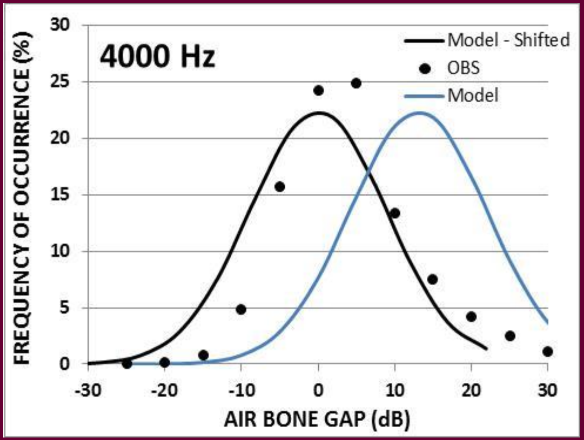

Distributions of Air-Bone Gaps
University of MN Study

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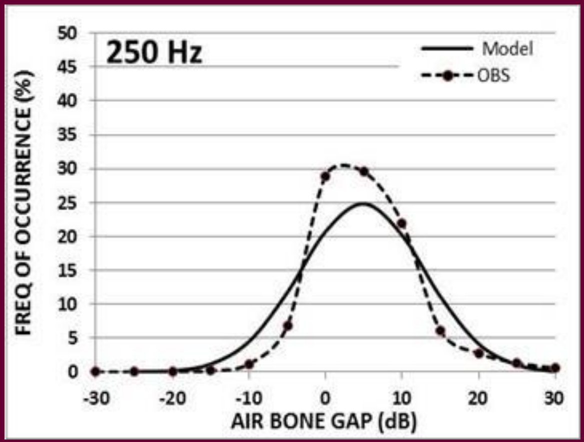

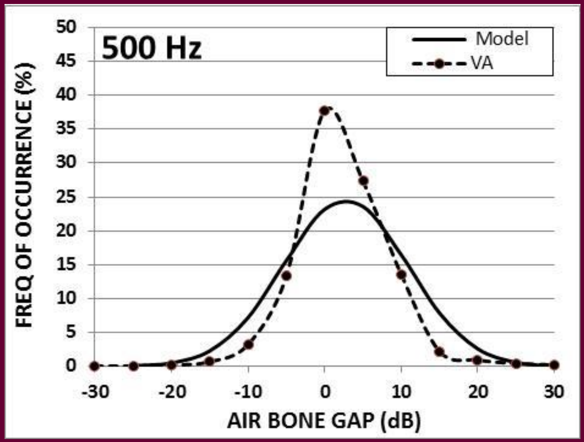

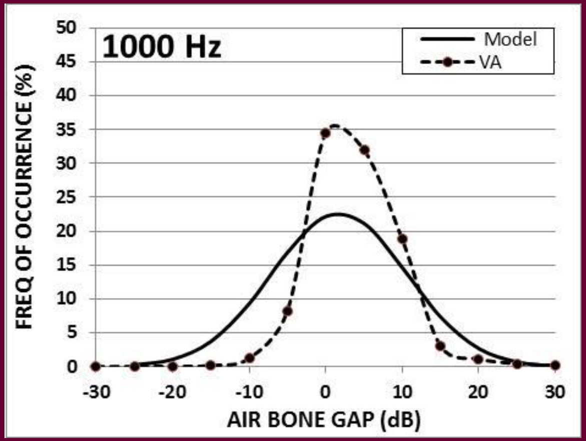

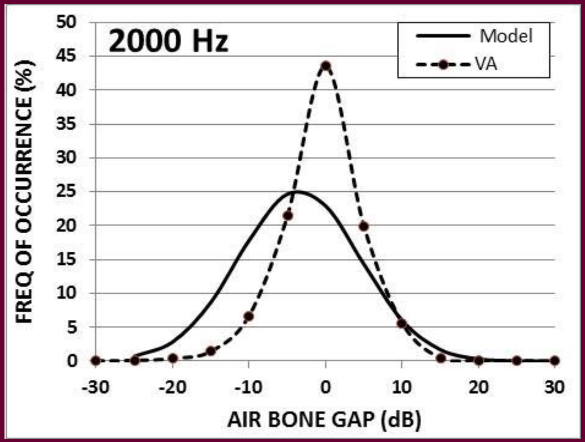

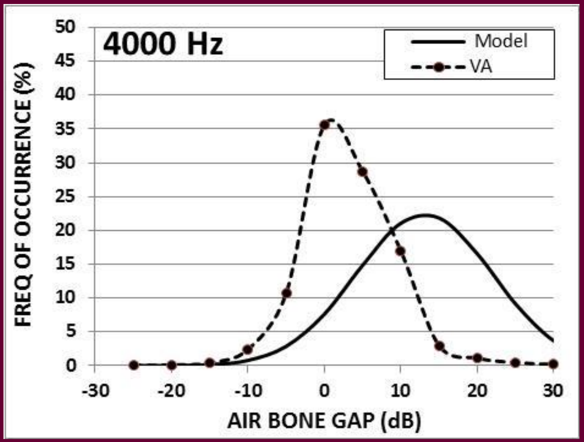

Distributions of Air-Bone Gaps
VA (DALC) Database

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How do you evaluate normality of a distribution?

Skewness is a measure of asymmetry

$$S = \frac{\Sigma (Yi - \overline{Y})^3}{(n-1)\, s^3}$$

Kurtosis is a measure of whether the data are peaked (leptokurtic) or flat (platykurtic) relative to a normal distribution

$$K = \frac{\Sigma (Yi - \overline{Y})^4}{(n-1)\, s^4}$$

NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, 2013.

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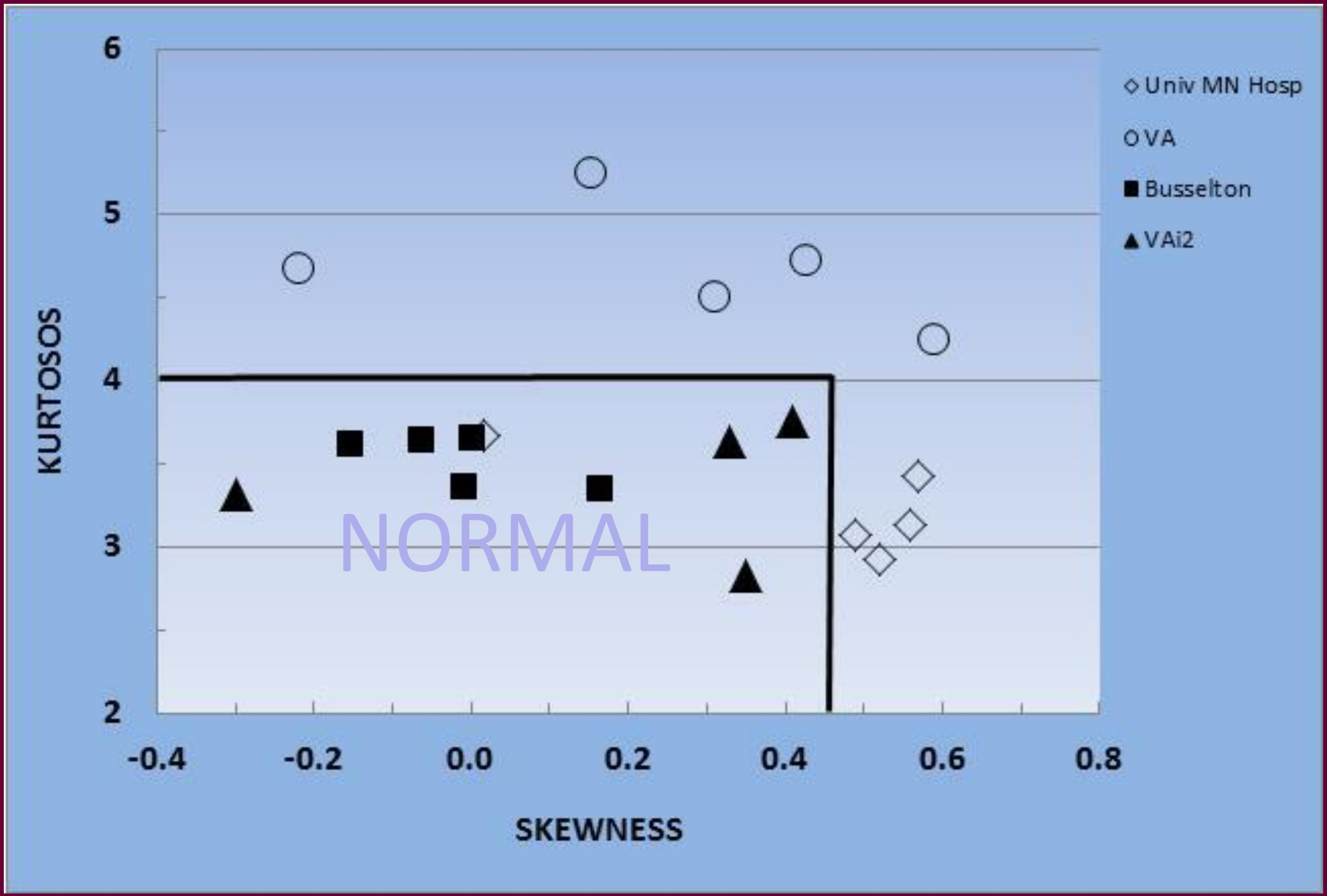

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AMCLASS® Automated Classification of Audiograms

The Problem

Number of unique audiograms – Air and Bone Conduction

376 Billion

AMCLASS – Automated Classification of Audiograms

Configuration	Severity	Site of Lesion	Symmetry
Normal Hearing		Conductive Sensorineural Mixed Sensorineural or Mixed	Symmetrical Hearing Loss Asymmetrical Hearing Loss
Flat Hearing Loss	Mild Moderate Severe Profound		
Sloping Hearing Loss	Normal-Mild Normal-Moderate Normal-Severe Mild-Moderate Mild-Severe Moderate-Severe Severe-Profound Profound		
Rising Hearing Loss	Mild-Normal Moderate-Normal Moderate-Mild Severe-Normal Severe-Mild Severe-Moderate Profound-Severe Profound		
Trough-shaped Hearing Loss	Mild Moderate Severe		
Peaked Hearing Loss	Mild Moderate Severe		
Other	Mild Moderate Severe		

- **23 Rules for Configuration**
- **45 Rules for Severity**
- **56 Rules for Site of Lesion**
- **37 Rules for Asymmetry**

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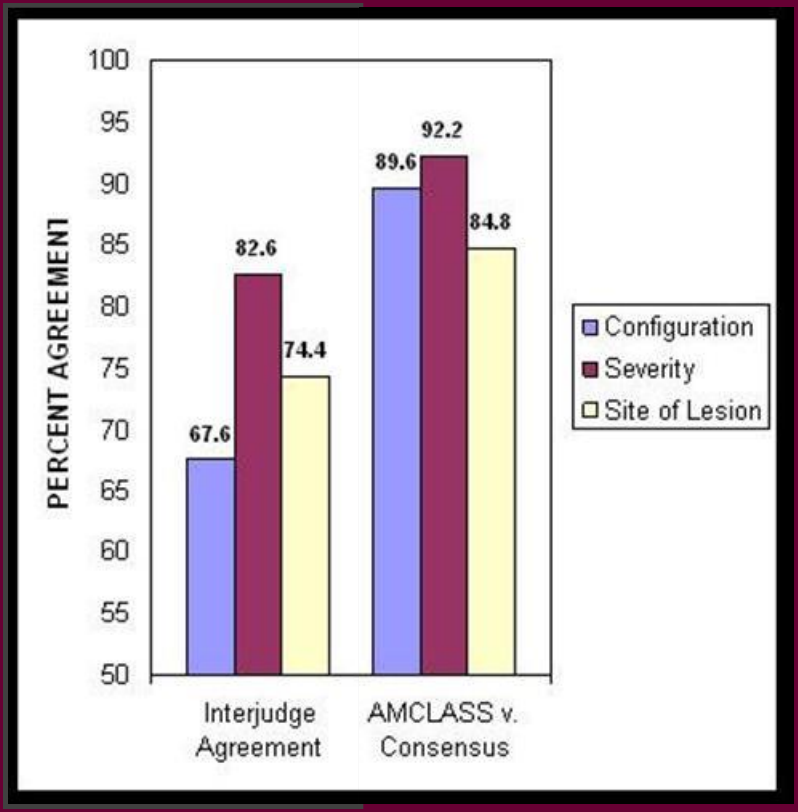

AMCLASS

Interjudge Agreement

AMCLASS v. Consensus Agreement

Margolis, R.H., Saly, G.S. Toward a standard description of hearing loss. *Int. J. Audiology* 46:746-758, 2007.

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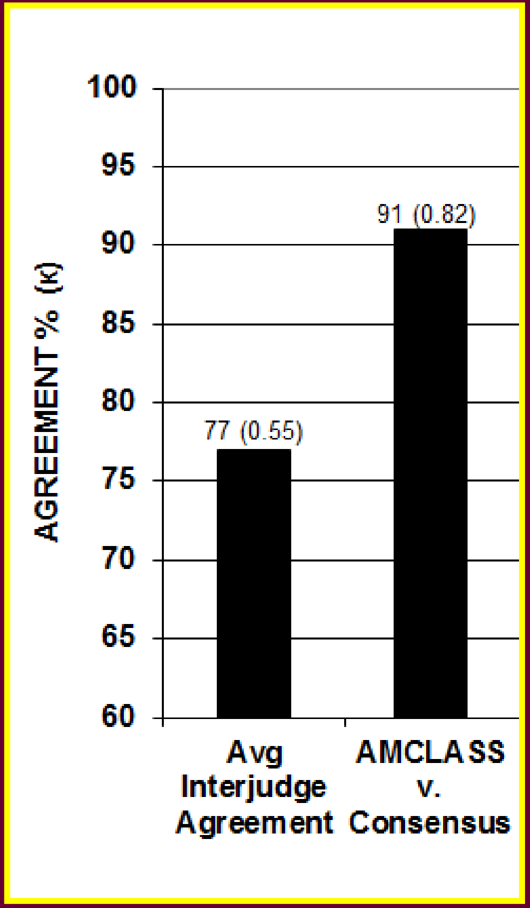

AMCLASS - Symmetry

Interjudge Agreement

AMCLASS v. Consensus Agreement

Margolis, R.H., Saly, G.L. Asymmetrical Hearing Loss: Definition, Validation, Prevalence. *Otology and Neurotology*, 29, 422-431, 2008.

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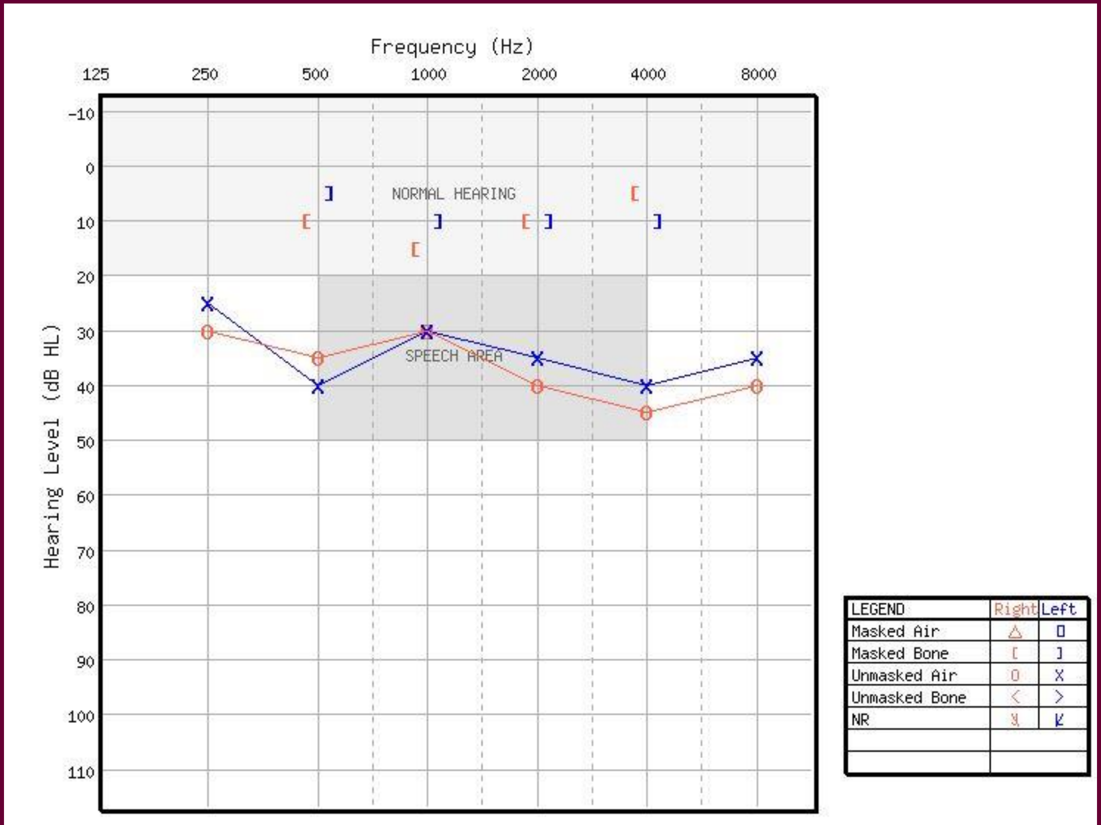

Ear	Severity	Configuration	Site of Lesion	
Right	MILD	Flat Hearing Loss	CONDUCTIVE	SYMMETRICAL
Left	MILD	Flat Hearing Loss	CONDUCTIVE	

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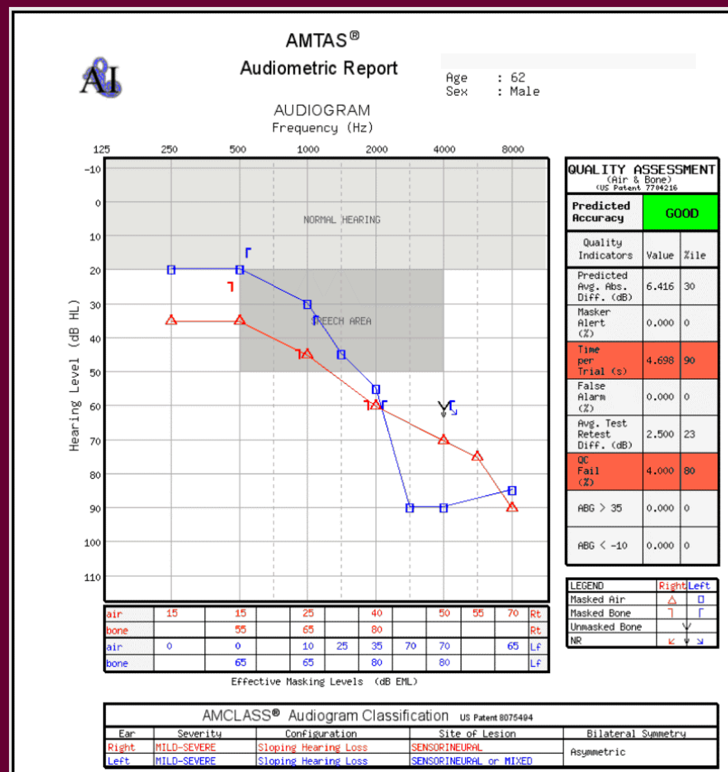

AMCLASS® Audiogram Classification US Patent 8075494				
Ear	Severity	Configuration	Site of Lesion	Bilateral Symmetry
Right	MILD-SEVERE	Sloping Hearing Loss	SENSORINEURAL	Asymmetric
Left	MILD-SEVERE	Sloping Hearing Loss	SENSORINEURAL or MIXED	

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Bone Conduction Calibration

Bone Conduction Calibration

Bruel & Kjaer Type 4930 Artificial Mastoid

Bone Conduction Calibration

"Basic to the design of an artificial mastoid is the **fact** that the bone vibrator **must** be placed on a material or device that will simulate, accurately and reliably, the mechanical impedance of the skin, flesh, and bone of the human mastoid" (p. 248).

Sanders JW, Olsen WO 1964. An evaluation of a new artificial mastoid as an instrument for the calibration of audiometer bone-conduction systems. J Speech Hear. Dis. **29**, 247-263.

The artificial mastoid "**must** present to the bone vibrator under test the same mechanical impedance as average human mastoid over the required frequency range …

Whittle LS (1970). Problems of calibration in bone conduction. British J Audiol 4, 35-41.

Bone Conduction Calibration

The calibration device must produce a reproducible measure of the vibrator output that can be related to the normal threshold of audibility when the device is placed on the head.

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AMBONE

Patent Pending

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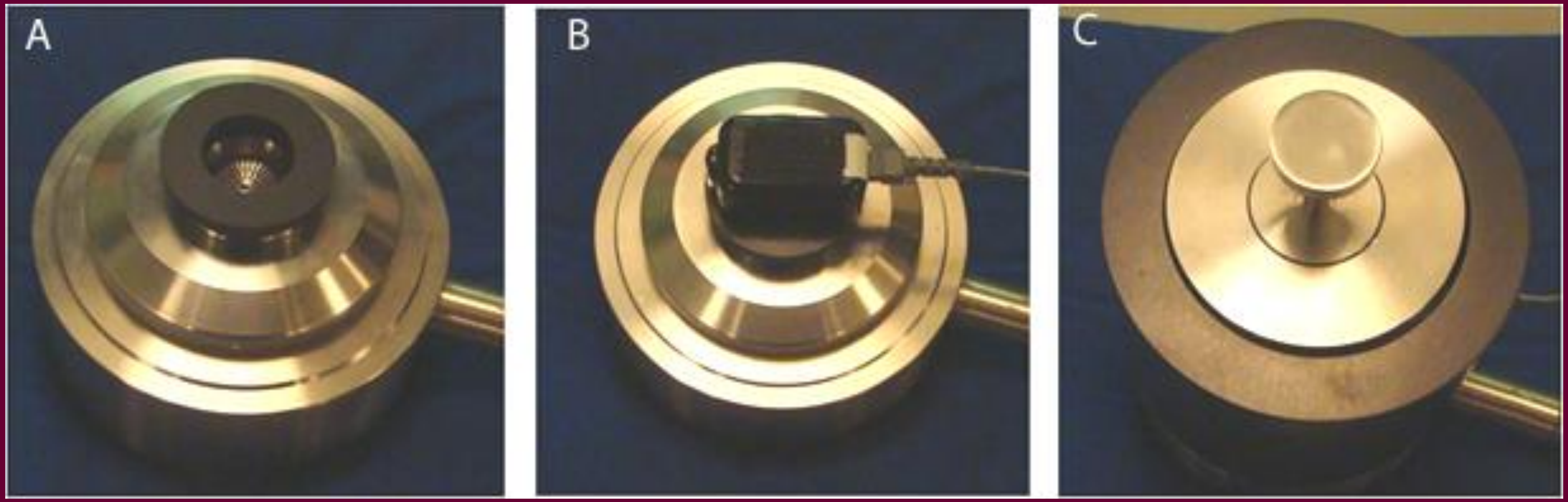
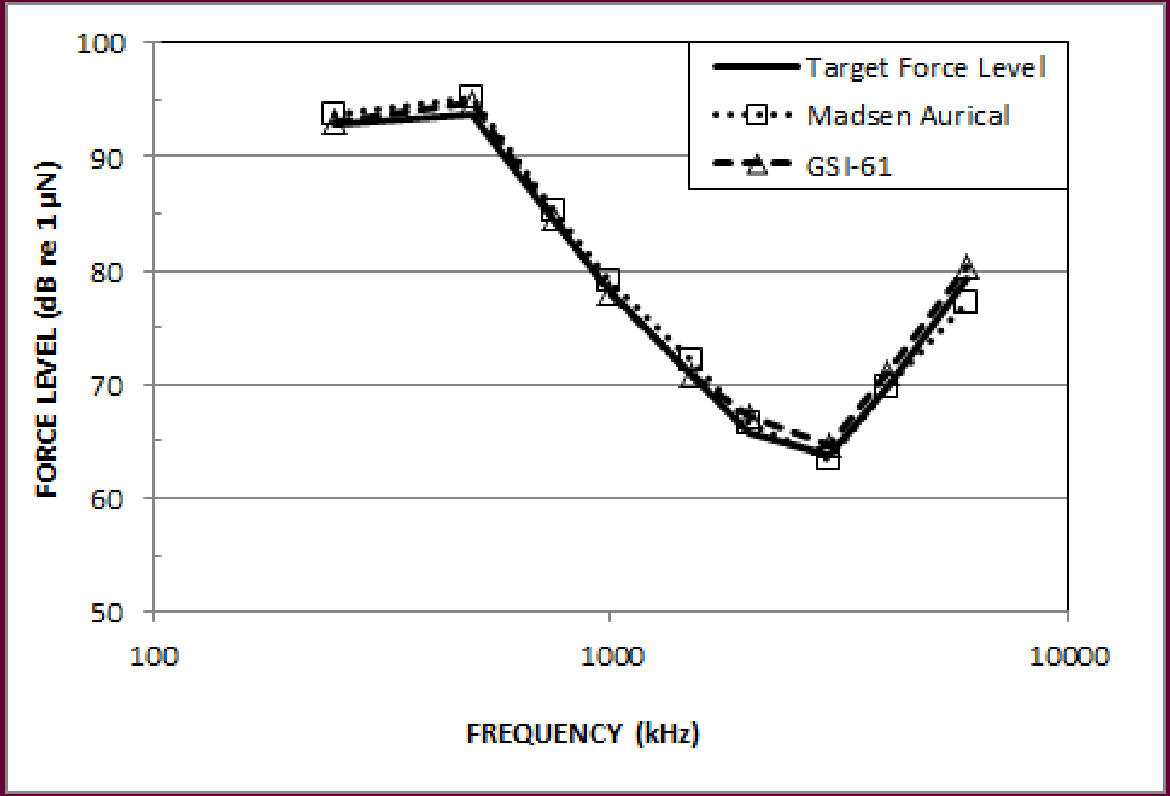
AMBONE



Margolis, R.H., Stiepan, S.M. Acoustic Method for Calibration of Audiometric Bone Vibrators. *J. Acoust. Soc. Amer.* 131, 1221-1225, 2012.

AMBONE



Margolis, R.H., Stiepan, S.M. Acoustic Method for Calibration of Audiometric Bone Vibrators. *J. Acoust. Soc. Amer.* 131, 1221-1225, 2012.

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AMWARE

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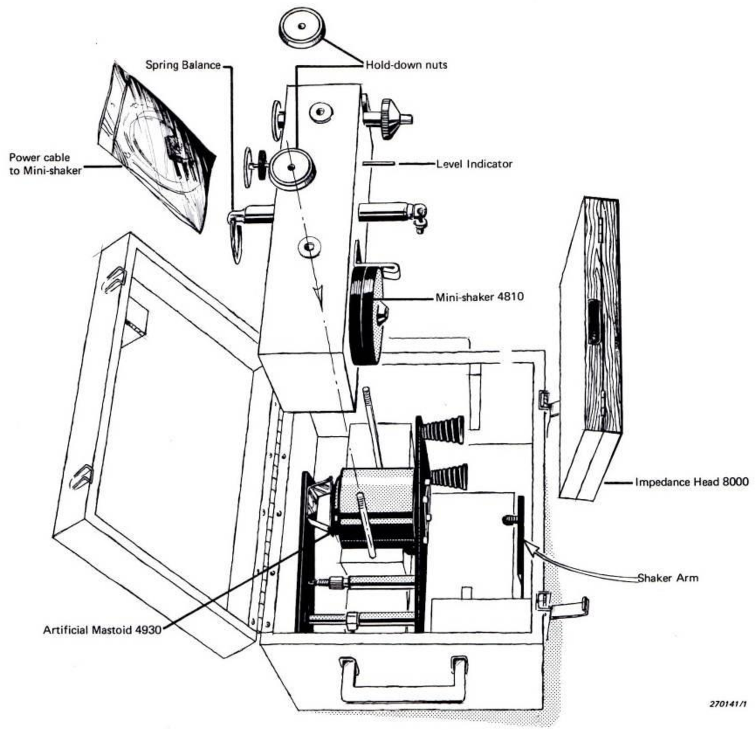

Fig. 4.2. Sketch showing how the Calibration Set fits into its carrying case

Bruel & Kjaer Type 4930 Instruction Manual

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INTELLIGENT HEARING SYSTEMS

HOME HEARING TEST™

Beyond the Audiology Clinic:
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Collaborators

Audiology Incorporated

Robert H. Margolis
George S. Saly

Etymotic Research, Inc.

Mead Killion
Gail Gudmundsen
David Friesema

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Goal

Develop an affordable, accurate, automated hearing test
that can be self-administered at home

The test should have the following features:

- Calibration should meet standards for audiometers
- Instructions should be simple and clear
- Results should be accurate
- Quantitative measure of accuracy
- Results should be communicated in clear understandable language

Home Hearing Test®

Beyond the Audiology Clinic:
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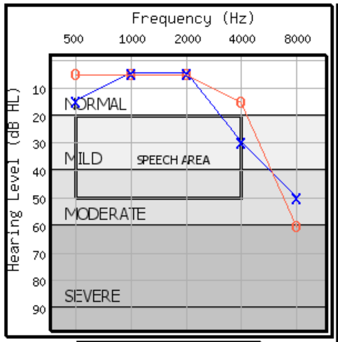
ETYMŌTIC "true to the ear"

AMTAS ®
Home Hearing Test

ID : rhm
Test Time: 16:22:30
Test Date: 2012-01-07

AUDIOGRAM



LEGEND	Right	Left
Threshold	O	X

Accuracy	FAIR

The audiogram is a graph that shows what sounds you are able to hear and what sounds you can't hear. Each mark on the audiogram (O for the right ear, X for the left ear) is the softest sound you can hear - your threshold - for a particular frequency or pitch. Normal - hearing people hear sounds that are 20 decibels (dB) or less at all the frequencies.

Hearing loss can be described by the degree of loss - how loud sounds have to be for you to hear them - and the pattern of the thresholds shown on the audiogram. The degree of loss can be mild, moderate, severe, or profound.

The speech area on the audiogram represents the sounds that make up everyday conversational speech. The location of your thresholds - above, in, or below the speech area - tells us how much of normal speech you can hear and how much you can't hear.

Hearing loss is a symptom of a problem somewhere in the ear. It can be in the outer ear, the middle ear, or the inner ear. Some of these conditions can be treated with medication or surgery. Many people with hearing loss are helped by hearing aids. It is important to find out the cause of the hearing loss so that the appropriate treatment can be provided.

The Home Hearing Test Report is a more detailed description of your hearing than the one presented in the video.

Your audiogram shows that the hearing in your RIGHT ear is A NORMAL TO MILD, SLOPING HEARING LOSS.

A sloping hearing loss is one where the thresholds for the low frequencies (the left side of the audiogram) are better (higher) than the thresholds for high frequencies (on the right side of the audiogram). Your thresholds for low frequencies are above the speech area so you are able to hear the low pitches in speech (like vowel sounds). Your thresholds at high frequencies may dip into the speech area causing difficulty hearing some of the high pitches in speech (like s, p, t, th). You may have difficulty understanding speech when there is background noise, a soft speaker, or a reverberant room. A hearing aid for this ear may be very helpful for you.

Your audiogram shows that the hearing in your LEFT ear is A NORMAL TO MODERATE, SLOPING HEARING LOSS.

A sloping hearing loss is one where the thresholds for the low frequencies (the left side of the audiogram) are better (higher) than the thresholds for high frequencies (on the right side of the audiogram). Your hearing for low frequencies is above the speech area so you are able to hear the low pitches in speech (like vowel sounds). Your hearing at high frequencies drop below the speech area so you have difficulty hearing some of the high pitches in speech (like s, p, t, th). This probably causes difficulty understanding speech when there is background noise, a soft speaker, or a reverberant room. A hearing aid for this ear may be very helpful for you.

You should have a hearing evaluation by a licensed audiologist.

The Home Hearing Test is intended to determine if you need a complete hearing evaluation in a clinical environment
The results may be different from those you would get at a Hearing Clinic.

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Your Hearing Report