Automated Hearing Tests

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Beyond the Audiology Clinic:
Innovations and Possibilities of Connected Health
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Advantages of Automation

- Optimize use of audiologists’ time
- Standardization
- Quantitative quality assessment
- Decrease errors
- Decrease cost
- Increase Access
- Telemedicine
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).
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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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Automating Pure Tone Audiometry
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Disadvantage of Automation

Loss of audiologist expertise
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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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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.
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Qualind ®
(U.S. Patent 7,704,216)

A Method for Predicting the Accuracy of a Test Result
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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
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Quality Assessment

N = 123 Adult Ss with sensorineural hearing loss

Predicted AMTAS/Manual Differences

Average Absolute Difference

Multiple R = 0.83
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Automating Pure Tone Audiometry

Technical Problems
Transducers routinely used for audiometry are poorly designed for automated testing.
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Audiometric Earphones

Design Objectives

Calibration
Ambient Noise Attenuation
Interaural Attenuation
Comfort
Occlusion Effect
Cost
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Audiometric Earphones

Options

Supra-aural

Telephonics TDH

Inserts

Interacoustics DD45

ER3A

ER5

ER5

ER3A
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Audiometric Earphones

Options

Circumaural

Sennheiser HDA 200

Sennheiser HD 280Pro
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Bone Conduction
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Bone Conduction Vibrators

Radioear B71

Radioear B81
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Bone Conduction Vibrator Location

Mastoid

Forehead
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Air-Bone Gaps
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The 4 kHz Air-Bone Gap
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Air-Bone Gaps

4 kHz Air-Bone Gaps
Air-Bone Gaps

Air-Bone Gaps in Sensorineural Hearing Loss

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Air-Bone Gaps

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Original Article

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

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Whittle 1965

ANSI S3.6 RETFLs

y = -11.84x + 67.51

4 kHz RETFL - 14.1 dB
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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
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Variability of Air-Bone Gaps
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Air-Bone Gaps
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Air-Bone Gaps

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

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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
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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

\[ s_{ac} = 3.34 \text{ dB} \]

\[ s_{bc} = 7.53 \text{ dB} \]

\[ s_{ABG} = 8.24 \text{ dB} \]

Probability that 10 ABGs = 0:

\[ 1/1.6 \text{ million} \]

Composite Distribution of Air-Bone Gaps
Busselton Healthy Ageing Study
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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
How do you evaluate normality of a distribution?

Skewness is a measure of asymmetry

\[ S = \frac{\sum (Y_i - \bar{Y})^3}{(n-1) s^3} \]

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

\[ K = \frac{\sum (Y_i - \bar{Y})^4}{(n-1) s^4} \]

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AMCLASS® Automated Classification of Audiograms

The Problem

Number of unique audiograms – Air and Bone Conduction

376 Billion
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## AMCLASS – Automated Classification of Audiograms

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Severity</th>
<th>Site of Lesion</th>
<th>Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Hearing</td>
<td>Mild</td>
<td>Conductive</td>
<td>Symmetrical Hearing Loss</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>Sensorineural</td>
<td>Asymmetrical Hearing Loss</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>Mixed</td>
<td></td>
</tr>
<tr>
<td>Flat Hearing Loss</td>
<td>Normal-Mild</td>
<td>Symmetrical Hearing Loss</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal-Moderate</td>
<td>Asymmetrical Hearing Loss</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal-Severe</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mild-Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mild-Severe</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate-Severe</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Severe-Profound</td>
<td></td>
<td></td>
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<tr>
<td>Sloping Hearing Loss</td>
<td>Mild-Normal</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Moderate-Normal</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Moderate-Mild</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Severe-Normal</td>
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<tr>
<td></td>
<td>Severe-Mild</td>
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<tr>
<td></td>
<td>Severe-Profound</td>
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<tr>
<td>Rising Hearing Loss</td>
<td>Mild-Profound</td>
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<tr>
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<td>Moderate-Profound</td>
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<tr>
<td></td>
<td>Severe-Profound</td>
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<tr>
<td></td>
<td>Normal-Profound</td>
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<tr>
<td></td>
<td>Normal-Normal</td>
<td></td>
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<tr>
<td></td>
<td>Normal-Moderate</td>
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<td></td>
<td>Normal-Severe</td>
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<tr>
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<td>Mild-Moderate</td>
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<td>Mild-Severe</td>
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<td>Moderate-Severe</td>
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<tr>
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<td>Severe-Profound</td>
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<td></td>
<td>Normal-Profound</td>
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<td>Trough-shaped Hearing Loss</td>
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<td>Moderate</td>
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<tr>
<td></td>
<td>Severe</td>
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<tr>
<td>Peaked Hearing Loss</td>
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<td></td>
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<tr>
<td></td>
<td>Severe</td>
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<td></td>
</tr>
<tr>
<td>Other</td>
<td>Mild</td>
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<td></td>
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<tr>
<td></td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 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

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AMCLASS - Symmetry
Interjudge Agreement
AMCLASS v. Consensus Agreement


University of Minnesota
Driven to Discover
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![Graph showing hearing levels and frequency]

<table>
<thead>
<tr>
<th>Ear</th>
<th>Severity</th>
<th>Configuration</th>
<th>Site of Lesion</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>MILD</td>
<td>Flat Hearing Loss</td>
<td>CONDUCTIVE</td>
<td></td>
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<tr>
<td>Left</td>
<td>MILD</td>
<td>Flat Hearing Loss</td>
<td>CONDUCTIVE</td>
<td>SYMMETRICAL</td>
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</tbody>
</table>
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Bone Conduction Calibration
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Bone Conduction Calibration

Brueel & 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).


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

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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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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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AMBONE
Bone Calibration Coupler

Manufactured for Intelligent Hearing Systems
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HOME HEARING TEST™
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Collaborators

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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
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Home Hearing Test®
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YOUR HEARING REPORT

The audiogram is a graph that shows what sounds you are able to hear and what sounds you cannot 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.