Making the Most of Middle Ear Measurements: 
_Part 2. Acoustic Stapedial Reflexes_

- A Long Tradition with Acoustic Reflexes
- Middle Ear Muscles and Acoustic Reflex Anatomy
- Acoustic Reflex Measurements
- Clinical Applications and Populations
Acoustic Reflex Measurements: 

*Historical Perspective (1)*

- Luscher (1929) In Germany observed acoustic reflex
- Jepsen (1951) Confirmed stapedius muscle acoustic reflex
- Klockhoff (1961) Clinical study of acoustic reflexes
- James Jerger (1970) applied electro-acoustic impedance device clinically in U.S.A.
- Anderson, Barr & Wedenberg (1970) Early detection of 8th nerve tumors with acoustic reflex
Acoustic Reflex Measurements: 
Historical Perspective (2)

- Keith (1975) Acoustic reflex in neonates
- Jerger & Hayes (1976) Crosscheck principle in pediatric audiology
- Weatherby & Bennett (1980) Acoustic reflex in neonates
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Acoustic Reflex Amplitude in Auditory Dysfunction

Dissertation: James W. Hall III, 1979

ACOUSTIC REFLEX AMPLITUDE IN
AUDITORY DYSFUNCTION

A Dissertation Submitted to the Faculty of
The Graduate School
Baylor College of Medicine

In Partial Fulfillment of the
Requirements for the Degree of

Doctor of Philosophy

by

JAMES W. HALL III

Houston, Texas
August 3, 1979
Published Articles Based on PhD Dissertation

Stapedius muscle

- Small striated muscle (smallest in the body)
- Located in a canal posterior to tympanic cavity
- Attached at one end to the canal and the other to the neck of the stapes
- Innervated by a branch of the 7th (facial) cranial nerve
- Consensual reflex (unilateral stimulus bilateral response)
- Stimulated in various ways including
  - Acoustic reflex by sounds of about 85 dB HL
  - Gentle tactile stimulation of outer ear
  - Electrical stimulation of ear canal wall
  - Voluntary contraction (can you wiggle your ears?)
Tensor tympani muscle

- Striated muscle
- Located in a small canal above the auditory canal
- Attached at one end to the walls of the canal and the other to the manubrium of the malleus
- Innervated by mandibular branch of the 5th (trigeminal) cranial nerve
- Contracts as part of general startle response
- Response is usually transient and not repeatable
Middle Ear Muscles
Acoustic Stapedial Reflex Pathways According to Erick Borg

Acoustic Reflex Measurements

Theories on the Function of Middle Ear Muscles (1)

- von Bekesy (1960)
  - Restricted ossicular movement, prevent sub-harmonics
  - Prevention of the separation of inter-ossicular joints during transmission of energy from high intensity sound

- Wever & Bray (1956)
  - Acoustic reflex contributes to maintaining relatively constant level of sound as stimulus intensity varies
  - “Automatic gain control” for high intensity low frequency sounds thus minimizing distortion

- Prevention of damage from high intensity sound but ...
  - Protection limited to sound frequencies < 1000 Hz
  - Latency of reflex (up to 60 ms) would limit protection
  - Muscle fatigue would limit protection with sustained sound
Acoustic Reflex Measurements

Theories on the Function of Middle Ear Muscles (1)

- Improved perception of important external sounds
  - At high intensities low frequency sounds can mask higher frequency sounds (e.g., speech sounds)
  - Middle ear muscle contraction might enhance perception of complex signals such as speech in noise

- Reduction of masking effect of self-produced sound
  - Muscles contract during swallowing and vocalization
  - Contraction may reduce masking self-produced sounds, as in chewing

- Stabilization of middle ear response
  - Resting muscle tone may “smooth out” the middle ear response to sound
  - Minimize natural dips and peaks due to resonances
Polling Question

Which muscle is involved in the acoustic reflex that we record clinically (HINT: The smallest muscle in the body)?

- a. Tensor tympani
- b. Sternocleidomastoid
- c. Levator auris
- d. Stapedius
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Making the Most of Middle Ear Measurements: *Acoustic Reflex Measurements*

- Acoustic threshold (ART) or minimum response level
- Acoustic reflex amplitude
- Acoustic reflex decay
- Acoustic reflex latency
- Estimation of hearing threshold with acoustic reflex
- Differentiating among auditory disorders with acoustic reflexes
- Electrically evoked acoustic reflex measurement in cochlear implants (*not covered today*)
Acoustic Reflex Measurements

**Acoustic Reflex Threshold**
Acoustic Reflex Measurements

**Normative Data for Acoustic Reflex Threshold**

*(Hunter & Shahnaz, 2014)*

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**Table 6-4.** The 10th and 90th Percentile Cutoff Values for Contralateral Acoustic Reflex Thresholds at 500, 1000, and 2000 Hz

<table>
<thead>
<tr>
<th>Hearing Thresholds (HL)</th>
<th>Acoustic Reflex Thresholds (10th-90th Percentiles; dB HL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500 Hz</td>
</tr>
<tr>
<td>0</td>
<td>75–95</td>
</tr>
<tr>
<td>5</td>
<td>75–95</td>
</tr>
<tr>
<td>10</td>
<td>75–95</td>
</tr>
<tr>
<td>15</td>
<td>75–95</td>
</tr>
<tr>
<td>20</td>
<td>75–95</td>
</tr>
<tr>
<td>25</td>
<td>75–95</td>
</tr>
<tr>
<td>30</td>
<td>75–95</td>
</tr>
<tr>
<td>35</td>
<td>75–95</td>
</tr>
<tr>
<td>40</td>
<td>75–95</td>
</tr>
<tr>
<td>45</td>
<td>80–95</td>
</tr>
<tr>
<td>50</td>
<td>80–100</td>
</tr>
<tr>
<td>55</td>
<td>80–105</td>
</tr>
<tr>
<td>60</td>
<td>85–105</td>
</tr>
<tr>
<td>65</td>
<td>90–110</td>
</tr>
<tr>
<td>70</td>
<td>95–115</td>
</tr>
<tr>
<td>75</td>
<td>95–120</td>
</tr>
<tr>
<td>80</td>
<td>100–120</td>
</tr>
<tr>
<td>85</td>
<td>100 to &gt;125</td>
</tr>
<tr>
<td>≥90</td>
<td><em>≥125</em></td>
</tr>
</tbody>
</table>

*Note that the use of 10th percentile cutoff below 60 dB hearing threshold is not recommended for identifying functional hearing losses (Gelfand, 1994).*

*Colored regions indicate caution that presentation at upper limit results in stimulus levels outside safe presentation levels (105 dB HL) and should be avoided.*

*At >90 dB HL and above, the 10th percentile is 10 dB above the hearing threshold.*

*Source: From Gelfand et al. (1990).*
Making Acoustic Reflex Measurements
Plotting Acoustic Reflex Threshold Results
Making the Most of Middle Ear Measurements

Acoustic Reflex Measurements

- Acoustic threshold (ART) or minimum response level
- Acoustic reflex amplitude
- Acoustic reflex decay
- Acoustic reflex latency
- Estimation of hearing threshold with acoustic reflex
- Differentiating among auditory disorders with acoustic reflexes
Clinical Application of Acoustic Reflexes: Amplitude in Young Normal Subjects

(Dissertation: James W. Hall III, 1979)

Figure 1.3. Ipsilateral and contralateral reflex amplitude for three signals (1000 Hz, 4000 Hz, noise band [500 - 1500 Hz]) in 28 young, normal hearing subjects (14 male, 14 female). Data are plotted in cm$^3$. Signal intensity is in dB RE: Acoustic Reflex Threshold (ART). Data are averaged for both ears. Brackets (1) indicate standard error of the mean.
Making the Most of Middle Ear Measurements

*Acoustic Reflex Measurements*

- Acoustic threshold (ART) or minimum response level
- Acoustic reflex amplitude
- **Acoustic reflex decay**
- Acoustic reflex latency … cannot be measured with current clinical instrumentation
- Estimation of hearing threshold with acoustic reflex
- Differentiating among auditory disorders with acoustic reflexes
Patterns of Acoustic Reflex Deflections: Normal and Abnormal
(From Hall JW III. *Introduction to Audiology Today*. Boston: Pearson, 2014)
Making the Most of Middle Ear Measurements

**Acoustic Reflex Measurements**

- Acoustic threshold (ART) or minimum response level
- Acoustic reflex amplitude
- Acoustic reflex decay
- Acoustic reflex latency … can now be measured with the latest clinical instrumentation
- Estimation of hearing threshold with acoustic reflex
- Differentiating among auditory disorders with acoustic reflexes
Acoustic Reflex Measurements:  
*Acoustic Reflex Latency (ARL) … Not a New Concept*

Acoustic Reflex Measurements: 
Acoustic Reflex Latency (ARL) … Not a New Concept

- Standard default (Measurement-Method) versus custom algorithms and settings for ARL
- Choose number of samples to average in Configuration
- Can measure different latency points
- Zoom feature for display and marking points
Acoustic Reflex Measurements:
ARL Measurement with TympStar Pro
(ARLT = Acoustic Reflex Latency Test)
Acoustic Reflex Measurements:

**ARL Measurement with TympStar Pro**

(*ARLT = Acoustic Reflex Latency Test*)
Acoustic Reflex Measurements:
**ARL Measurement with TympStar Pro**
(ARLT = Acoustic Reflex Latency Test)
Acoustic Reflex Measurements: ARL Measurement with TympStar Pro (ARLT = Acoustic Reflex Latency Test)
Making the Most of Middle Ear Measurements

**Acoustic Reflex Measurements**

- Acoustic threshold (ART) or minimum response level
- Acoustic reflex amplitude
- Acoustic reflex decay
- Acoustic reflex latency ... can now be measured with the latest clinical instrumentation
- **Estimation of hearing threshold with acoustic reflex**
- Differentiating among auditory disorders with acoustic reflexes
## SPAR Criteria

<table>
<thead>
<tr>
<th>Noise-Tone Difference</th>
<th>BBN ART in dB SPL</th>
<th>Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;20 dB</td>
<td>Anywhere</td>
<td>Normal</td>
</tr>
<tr>
<td>15 to 19</td>
<td>&lt; 80</td>
<td>Normal</td>
</tr>
<tr>
<td>15 to 19</td>
<td>&gt; 80</td>
<td>Normal-Moderate</td>
</tr>
<tr>
<td>10 to 14</td>
<td>Anywhere</td>
<td>Mild-Moderate</td>
</tr>
<tr>
<td>&lt; 10</td>
<td>&lt; 90</td>
<td>Mild-Moderate</td>
</tr>
<tr>
<td>&lt; 10</td>
<td>&gt; 90</td>
<td>Severe</td>
</tr>
<tr>
<td>AR not observed</td>
<td></td>
<td>Profound</td>
</tr>
</tbody>
</table>
Estimation of Hearing Thresholds with Acoustic Reflexes: A Sampling of Publications

- Hall JW III and Koval C. Accuracy of hearing prediction by the acoustic reflex. The Laryngoscope 92: 140-149, 1982
Simplified SPAR (Sensitivity Prediction by the Acoustic Reflex)
### Acoustic Reflex Presence as a Function of Age

(From Kankkunen & Liden (1988). Ipsilateral acoustic reflex thresholds in neonates and in normal-hearing and hearing impaired preschool children. Scand Audiol, 13, 139-144)

<table>
<thead>
<tr>
<th>Age of Child</th>
<th>Percentage of Children with Reflexes Present (600 Hz Probe Tone)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 month</td>
<td>100%</td>
</tr>
<tr>
<td>2 months</td>
<td>92%</td>
</tr>
<tr>
<td>3 months</td>
<td>90%</td>
</tr>
<tr>
<td>4 months</td>
<td>87%</td>
</tr>
<tr>
<td>5-11 months</td>
<td>85%</td>
</tr>
<tr>
<td>1 year</td>
<td>72%</td>
</tr>
<tr>
<td>2 years</td>
<td>67%</td>
</tr>
<tr>
<td>3 years</td>
<td>47%</td>
</tr>
<tr>
<td>4 years</td>
<td>47%</td>
</tr>
</tbody>
</table>

- 66 full term infants
- Acoustic reflexes recorded with 1000 Hz probe tone
- Tone and BBN stimuli
- All neonates had acoustic reflexes
# Acoustic Reflexes in Neonates


<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Median ART (dB HL)</th>
<th>90% Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Hz</td>
<td>80</td>
<td>70 - 95</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>70</td>
<td>60 - 85</td>
</tr>
<tr>
<td>4000 Hz</td>
<td>65</td>
<td>50 - 80</td>
</tr>
<tr>
<td>BBN</td>
<td>55</td>
<td>50 – 75</td>
</tr>
</tbody>
</table>

* N = 68 ears
Polling Question

For normal hearing subjects a broadband noise (BBN) stimulus elicits an acoustic reflex at approximately what intensity level?

a. 0 to 20 dB  
b. 60 to 75 dB  
c. 85 to 95 dB  
d. 100 to 110 dB
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Confirming normal versus abnormal middle ear function

Differentiation among

- Sensory hearing loss
- Conductive hearing loss
- Neural hearing loss
- Central auditory (brainstem) dysfunction

Objective prediction of hearing loss in young children

Diagnosis of auditory neuropathy spectrum disorder (ANSD)
Plotting the Results of Acoustic Reflex Measurements

Acoustic reflex patterns ("faces")
- Conductive/efferent pattern
- Sensory pattern
- Neural pattern
- Brainstem pattern

Abnormal Acoustic Reflex

Crossed (contralateral)
Sound in ear
- Right
- Left

Uncrossed (ipsilateral)
Probe and sound in ear
- Right
- Left
Plotting the Results of Acoustic Reflex Measurements

Vertical pattern
- Mild conductive hearing loss pattern or efferent (7th CN) pattern (normal tymp and no air bone gap) on right ear

Abnormal Acoustic Reflex

Contralateral (Crossed)
Sound Right
Probe Left

Ipsilateral (Uncrossed)
Sound Right
Probe Right

Contralateral (Crossed)
Sound Left
Probe Right

Ipsilateral (Uncrossed)
Sound Left
Probe Left
Plotting the Results of Acoustic Reflex Measurements

**Inverted “L” pattern**
- Moderate or severe conductive hearing loss on right ear

- **Abnormal Acoustic Reflex**
  - Contralateral (Crossed)
    - Sound Right
    - Probe Left
  - Ipsilaterial (Uncrossed)
    - Sound Right
    - Probe Right
  - Contralateral (Crossed)
    - Sound Left
    - Probe Right
  - Ipsilaterial (Uncrossed)
    - Sound Left
    - Probe Left
Plotting the Results of Acoustic Reflex Measurements

Diagonal pattern
- Severe sensory hearing loss or 8th nerve auditory dysfunction on right ear

Abnormal Acoustic Reflex

Right

Contralateral (Crossed)
Sound Right
Probe Left

Ipsilaterial (Uncrossed)
Sound Right
Probe Right

Contralateral (Crossed)
Sound Left
Probe Right

Left

Ipsilateral (Uncrossed)
Sound Left
Probe Left
Plotting the Results of Acoustic Reflex Measurements
(From Hall JW III. *Introduction to Audiology Today*. Boston: Pearson, 2014)
Plotting the Results of Acoustic Reflex Measurements

Horizontal pattern
- Brainstem auditory dysfunction

Abnormal Acoustic Reflex

Contralateral (Crossed)
- Sound Right
- Probe Left

Ipsilaterial (Uncrossed)
- Sound Right
- Probe Right

Contralateral (Crossed)
- Sound Left
- Probe Right

Ipsilaterial (Uncrossed)
- Sound Left
- Probe Left
A New Acoustic Reflex Pattern

Susan Jerger, MS; James Jerger, PhD; James Hall, MA

- A new crossed-vs-uncrossed acoustic reflex pattern has been observed in four patients with retrocochlear disorder. The new reflex pattern is characterized by a unique "uni-box" configuration. Reflexes are abnormal with sound to the affected ear on crossed stimulation only. In one additional patient, a variation of the uni-box pattern was found on supra-threshold reflex amplitude measures. We observed a large ear difference between reflex amplitude functions in the crossed condition, but not in the uncrossed condition. This observation suggests that reflex amplitude measures may be a valuable addition to threshold measures in some patients.

(Arch Otolaryngol 105:24-28, 1979)

diagnostically nonspecific inverted L-shaped pattern.

This article concerns the one exceptional reflex pattern. This unusual finding occurred in a 53-year-old woman with a large acoustic schwannoma on the right side. At surgery, the tumor was noted to displace and distort adjacent brain stem structures. Figure 1 shows this patient's audiogram and acoustic reflex results. The audiogram shows a mild sensorineural loss in the right (eighth nerve) ear and normal sensitivity in the left ear. Pure-tone average (PTA) scores for 500, 1,000, and 2,000 Hz are 32 dB for the right ear and 1 dB for the left sound to the affected ear on crossed stimulation only.

We first suspected that the reflex abnormality in this patient was due to middle ear disorder. However, bone conduction thresholds on both ears were superimposed on air conduction thresholds. Further, tympanometry showed normal, bilaterally symmetrical, tympanograms on both ears.

In short, we appeared to be observing a unique new reflex pattern. However, we were reluctant to regard this pattern as a distinct retrocochlear sign. Several possible explanations for this unexpected finding could not be adequately ruled out retrospectively. In undetected middle ear disorder,
Acoustic Reflex Measurements

Clinical Applications and Value

- Confirming normal versus abnormal middle ear function
- Differentiation among types of auditory dysfunction
  - Sensory hearing loss
  - Conductive hearing loss
  - Neural hearing loss
  - Central auditory (brainstem) dysfunction
- Objective prediction of hearing loss in young children
- Diagnosis of auditory neuropathy spectrum disorder (ANSD)

- 5% of children with hearing loss diagnosed with ANSD
- Acoustic reflexes played role in the diagnosis
Assorted Applications of Admittance Measurement: Assessment of False and Exaggerated Hearing Loss

- Other terms
  - “Non-organic hearing loss
  - Pseudohypacusis
  - Functional hearing loss

- Risk factors for false or exaggerated hearing loss
  - Children
    - Adolescent girls
    - Trauma (physical, sexual, psychological)
  - Adults
    - Potential compensation
    - Legal action
    - Trauma (physical, sexual, psychological)
Assessment of False or Exaggerated Hearing Loss

Why Prompt Diagnosis is Important

- Elimination of unnecessary health care costs. e.g.,
  - Radiological studies
  - Laboratory studies
  - Compensation for non-existent impairment
  - Referral to specialists

- Prevention of inappropriate treatment, e.g.,
  - Medical
  - Surgical
  - Audiological

- Prompt intervention for underlying cause or factors
  - Counseling
  - Psychological or psychiatric management
Making the Most of Middle Ear Measurements: 
*Billing (CPT) Codes*

- **Deleted code**
  - 92569: Acoustic reflex testing, decay (deleted 2010)

- 92567: Tympanometry (impedance testing)

- 92568: Acoustic reflex testing, threshold

- 92550: Tympanometry and reflex threshold measurements
  - Do not report in conjunction with 92567 or 92568

- 92570: Acoustic immittance testing, includes
  - Tympanometry (impedance testing)
  - Acoustic reflex threshold testing
  - Acoustic reflex decay testing
  - Do not report in conjunction with 92567 or 92568
The acoustic reflex provides NO information for which of the following sites of auditory dysfunction:

a. Middle ear  
b. Cochlea  
c. Lower brainstem  
d. Thalamus
Thank You!

Questions?