LM228: New Developments in Science and Application of Otoacoustic Emissions

Sumitrajit Dhar, PhD
Northwestern University
s-dhar@northwestern.edu

James W. Hall III, PhD
Nova Southeastern University
Salus University
University of Pretoria South Africa
jwhall3phd@gmail.com
New Developments in Science and Application of Otoacoustic Emissions

- Introduction *(5 minutes)*
- OAE Mechanisms
  - Scientific Developments *(10 minutes)*
    - TEOAEs vs DPOAEs
    - Specifics of DPOAE generation
  - Potential Clinical Application *(10 minutes)*
- OAE Fine Structure
  - Scientific Developments *(10 minutes)*
    - Potential Clinical Application *(10 minutes)*
- Where Do We Go From Here? *(5 minutes)*
- Questions From Audience *(10 minutes)*
Description of emails received (JWH3) from audiologists within the past month:

- Case 1: “I saw an interesting patient yesterday. The baby slept throughout the entire eval. Otoscopic exam revealed clear ear canals. 1000 Hz tymps showed good TM compliance but positive pressure bilaterally. DPOAE testing showed present and robust emissions for the frequencies 1500-8000 Hz. Her threshold ABR was performed…”.
Description of emails received (JWH3) from audiologists within the past month:

Case 2: “… Anyway I think I have recorded a CM – see attached traces (each ear also has a no sound trial which is the flat line trace). OAEs were absent on the right, present left but if this is a CM why have I also recorded one in the contralateral channel when there was no stimulus in that ear (left ear).”
Description of emails received (JWH3) from audiologists within the past month

- Case 3: “I have a very unusual case and would like your input. ... This was 2 years ago and all resolved. OAEs were present at time of loss and at recovery. Now, he experienced as of December 2013 a rapid progressive loss to the left ear. No recovery. Moderate in Feb and almost complete loss as of yesterday.”
Selected limitations of current clinical OAE measurement approaches:

- Audiologists typically record either transient or distortion product OAEs, but not both.
- DPOAE protocols include stimuli at relatively few frequencies (≤ 3 or 4 frequencies/octave) rather than measurement of “fine structure” of OAEs.
- Audiologists almost always simply report “presence “or “absence” of OAEs for a fixed stimulus intensity level rather than more detailed analysis of OAE amplitude relative to normal values at multiple intensities.
New Developments in Science and Application of Otoacoustic Emissions: Introduction (5)

- New models for OAE mechanisms of OAEs and more sophisticated techniques for recording OAEs are not yet applied clinically.
- Specifically, the diagnostic value of OAEs may be increased with measurement of:
  - different OAE types in appropriate cases.
  - more detailed characteristics of OAEs.
- Basic OAE research leads to more diagnostically powerful clinical applications and clinical data from new applications shapes future research directions.
New Developments in Science and Application of Otoacoustic Emissions

- Introduction (5 minutes)
- OAE Mechanisms
  - Scientific Developments (10 minutes)
    - TEOAEs vs DPOAEs
    - Specifics of DPOAE generation
  - Potential Clinical Application (10 minutes)
- OAE Fine Structure
  - Scientific Developments (10 minutes)
  - Potential Clinical Application (10 minutes)
- Where Do We Go From Here? (5 minutes)
- Questions From Audience (10 minutes)
Classification of OAEs

- Without stimulation
  - Spontaneous otoacoustic emissions

- With stimulation
  - Clicks or tone bursts – Transient (T)OAEs
  - Two tones – Distortion Product (DP)OAEs
  - Single tones – Stimulus frequency (SF)OAEs
Mechanism-Based Classification

- DPOAE
- SFOAE
DPOAE Phase [distortion/wave fixed]
DPOAE Phase [distortion/wave fixed]
DPOAE Phase [distortion/wave fixed]
DPOAE Phase [distortion/wave fixed]
DPOAE Phase [distortion/wave fixed]

Approximate scaling symmetry of the cochlea (at least in the basal half) results in invariant DPOAE phase as a function of frequency.
SFOAE Phase [reflection/place fixed]

stapes

base

apex
SFOAE Phase [reflection/place fixed]
SFOAE Phase [reflection/place fixed]
Steep SFOAE phase gradient suggests a “place fixed” mechanism of SFOAE “re-emission.”
Incoming signal is “reflected” randomly by outer hair cells; some reflections are coherent and contribute to the outward-traveling energy.
Coherent Reflection Filtering

Zweig, Shera (1995 on)

Incoming signal is “reflected” randomly by outer hair cells; some reflections are coherent and contribute to the outward-traveling energy.
Coherent Reflection Filtering

Incoming signal is “reflected” randomly by outer hair cells; some reflections are coherent and contribute to the outward-traveling energy.

Coherent reflectors near the peak region of the traveling wave have enough magnitude to contribute significantly to ear-canal OAE.
[Mechanism Based] Classification of OAEs

- **Reflection**
  - Spontaneous otoacoustic emissions

- **Distortion**

- **Mixed**
  - Clicks or tone bursts – Transient (T)OAEs
  - Two tones – Distortion Product (DP)OAEs
  - Single tones – Stimulus frequency (SF)OAEs
Prestin KO
Prestin KO

Liberman et al., 2004

DP in Ear Canal (dB SPL)

$A \quad f_2=22.6 \text{ kHz}$

Loss of Gain
Stereocilin-deficient mice reveal the origin of cochlear waveform distortions

Elisabeth Verpy, Dominique Weil, Michel Leibovici, Richard J. Goodyear, Ghislaine Hamard, Carine Houdon, Gaelle M. Lefèvre, Jean-Pierre Hardelin, Guy P. Richardson, Paul Avan & Christine Petit
Stereocilin-deficient mice reveal the origin of cochlear waveform distortions

Elisabeth Verpy, Dominique Weil, Michel Leibovici, Richard J. Goodyear, Ghislaine Hamard, Carine Houdon, Gaelle M. Lefèvre, Jean-Pierre Hardelin, Guy P. Richardson, Paul Avan, and Christine Petit

---

(a) Strc^{+/+} (b) Strc^{-/-}

(c) (d)
Stereocilin-deficient mice reveal the origin of cochlear waveform distortions

Elisabeth Verpy, Dominique Weil, Michel Leibovic, Richard J. Goodyear, Ghislaine Hamard, Carine Houdon, Gaelle M. Lefèvre, Jean-Pierre Hardelin, Guy P. Richardson, Paul Avan, and Christine Petit.
Stereociliary nonlinearity is the source of DPOAEs. The boost from electromotility causes distortion at lower input levels.
Selected Clinical Applications of OAEs in Pediatric Populations

- Pediatric Applications
  - Newborn hearing screening
  - Diagnosis of auditory dysfunction in young children
    - Differentiation of outer versus inner hair cell dysfunction
    - Auditory neuropathy spectrum disorder (ANSD)
  - Monitoring ototoxicity
  - Pre-school/school screenings
  - Identification of false and exaggerated hearing loss

**Subjects**
- 50 randomly selected premature infants (23 female, 27 male)
- Risk factors included one or more of the following:
  - Admission to NICU
  - Mechanical ventilation
  - Ototoxicity

**Procedure**
- TEOAEs recorded at 80 dB SPL stimulus level (AudxPlus)
- DPOAEs (no recording parameters provided)
New Developments in Science and Application of OAEs: TEOAEs vs. DPOAEs in Infants at Risk for Hearing Loss

- Pass/fail criteria = 6 dB OAE-NF difference
- Findings
  - TEOAE
    - 71% of ears passed
  - DPOAE
    - 97% of ears passed
- Lingering question about DPOAE stimulus intensity levels
Selected Clinical Applications of OAEs in Pediatric Populations

- **Pediatric Applications**
  - Newborn hearing screening
  - **Diagnosis of auditory dysfunction in young children**
    - Differentiation of outer versus inner hair cell dysfunction
    - Auditory neuropathy spectrum disorder (ANSD)
  - Monitoring ototoxicity
  - Pre-school/school screenings
  - Identification of false and exaggerated hearing loss
11-month old infant who failed hearing screening at birth

Diagnostic auditory findings (except OAEs)

- Normal tympanograms bilaterally
- ABR
  - Right Ear: Normal thresholds for clicks and tone bursts
  - Left Ear: Click & HF TB thresholds at 70 - 80 dB nHL

OAE findings

- TEOAE
  - Normal with linear averaging (influence of stimulus artifact?)
  - Absent with standard nonlinear averaging
- DPOAE
  - Absent with L1 = 65 dB SPL; L2 = 55 dB SPL
  - Normal for low frequencies with L1 = L2 = 75 dB SPL
New Developments in Science and Application of OAEs:
*TEOAEs vs. DPOAEs in Auditory Diagnosis of Children*
(Courtesy of Carolyn Abdala, Christopher Shera & Radha Kalluri)

Linear TEOAE

DPOAE (L1 = 65 dB; L2 = 55 dB)
Non-linear TEOAE

<table>
<thead>
<tr>
<th>TEOAE Waveforms</th>
<th>DP-gram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DPOAE (L1 = L2 = 75 dB SPL)
Clinical Applications of OAEs in Pediatric and Adult Populations

- Adult Applications
  - Diagnosis of cochlear versus retrocochlear dysfunction
  - Diagnosis of false and exaggerated hearing loss
  - Monitoring ototoxicity
  - Hearing screening
    - industrial settings
    - Military personnel
  - Early detection of cochlear dysfunction in at risk populations, e.g.,
    - Noise/music exposure
    - Diabetes
  - Diagnosis and management of tinnitus and hyperacusis
OAEs in Early Detection of Outer Hair Cell Dysfunction

Normal OHC (OAEs)  Abnormal OHC (OAEs)
Del Ninno et al (2014). Distortion-product otoacoustic emissions and selection sensorineural loss in IDDM. *Diabetes Care*, 21, 1317-1321 [Catholic University, Rome]

**Subjects**
- 47 IDDM patients with normal hearing and average duration of diabetes of 13 years (+/- 6 years)
- 44 healthy age- and gender matched control subjects with normal hearing (HTLs of ≤ 20 dB at octave frequencies from 250 through 8000 Hz)

**Procedure**
- TEOAEs recorded at 80 dB SPL (Otodynamics)
- DPOAEs recorded at L1 = L2 = 70 dB (Otodynamics)
Findings for Del Ninno et al (2014). Distortion-product otoacoustic emissions and selection sensorineural loss in IDDM. *Diabetes Care*, 21, 1317-1321 [Catholic University, Rome]

- **TEOAEs**
  - Reduced amplitude in IDDM patients who had peripheral neuropathy (reduced nerve conduction velocity)
  - No difference in IDDM patients without peripheral neuropathy (of peroneal and sural nerves)

- **DPOAEs**
  - Reduced amplitude in high frequency region in IDDM patients with *and* without peripheral neuropathy
New Developments in Science and Application of OAEs: TEOAEs vs. DPOAEs in Insulin-Dependent Diabetes Mellitus (Mokrian et al, 2014)

Otoacoustic Emission Amplitude (dB SPL)

<table>
<thead>
<tr>
<th></th>
<th>Left Ear</th>
<th>Right Ear</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TEOAE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Subjects</td>
<td>12.7</td>
<td>12.5</td>
</tr>
<tr>
<td>Tinnitus Subjects</td>
<td>12.7</td>
<td>13.8</td>
</tr>
<tr>
<td><strong>DPOAE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Subjects</td>
<td>9.2 *</td>
<td>10.0 **</td>
</tr>
<tr>
<td>Tinnitus Subjects</td>
<td>6.7</td>
<td>7.5</td>
</tr>
</tbody>
</table>

* P value 0.006  ** P value 0.008
New Developments in Science and Application of Otoacoustic Emissions

- Introduction (5 minutes)
- OAE Mechanisms
  - Scientific Developments (10 minutes)
    - TEOAEs vs DPOAEs
    - Specifics of DPOAE generation
  - Potential Clinical Application (10 minutes)
- OAE Fine Structure
  - Scientific Developments (10 minutes)
  - Potential Clinical Application (10 minutes)
- Where Do We Go From Here? (5 minutes)
- Questions From Audience (10 minutes)
Mixed DPOAEs
Mixed DPOAEs
Mixed DPOAEs

RT (Left)

$f_1$  $f_2$

Level [dB SPL]

Frequency [Hz]

Outer ear  Middle ear  Cochlea
• Contribution from two cochlear regions.

• Different mechanisms operational at two regions.

• Contribution from two cochlear regions.

• Different mechanisms operational at two regions.

Talmadge, Long, Tubis & Dhar (1999): JASA
Talmadge, Long, Tubis & Dhar (1999); JASA
Talmadge, Long, Tubis & Dhar (1999); JASA
Talmadge, Long, Tubis & Dhar (1999); JASA
Video not available in MP4 Version

Talmadge, Long, Tubis & Dhar (1999); JASA
Video not available in MP4 Version

Talmadge, Long, Tubis & Dhar (1999): JASA
New Developments in Science and Application of Otoacoustic Emissions

- Introduction (5 minutes)
- OAE Mechanisms
  - Scientific Developments (10 minutes)
    - TEOAEs vs DPOAEs
    - Specifics of DPOAE generation
  - Potential Clinical Application (10 minutes)
- OAE Fine Structure
  - Scientific Developments (10 minutes)
  - Potential Clinical Application (10 minutes)
- Where Do We Go From Here? (5 minutes)
- Questions From Audience (10 minutes)

**Subjects**
- 8 patients with mild to moderate cochlear hearing loss of varying configurations and etiologies

**DPOAEs**
- 48 primary pairs/octave
- Stimulus intensity: L1 = L2 = 60 dB SPL
New Developments in Science and Application of OAEs: 
**OAE Fine Structure in Cochlear Dysfunction**

(Mauerman et al, 1999)
New Developments in Science and Application of OAEs: 
*OAE Fine Structure in Cochlear Dysfunction* 
(Mauerman et al, 1999)

**Audiogram**

subject DI right

![Audiogram](image)

- 2f1-f2
- f2
New Developments in Science and Application of OAEs:  
*OAE Fine Structure in Cochlear Dysfunction*  
(Mauerman et al, 1999)  

![Graph showing OAE fine structure in cochlear dysfunction](image)
Conclusions

- DPOAEs are produced by two sources including the characteristic place of the primaries ($f_2$) and source of $f_{DP}$.
- DPOAE fine structure is mainly influenced by the local state of the cochlea at the characteristic place of $f_{DP}$.
- Fine structure is more sensitive indicator of cochlear damage than DPOAE level alone.

DPOAE generation

- Site close to $f_2$ is caused by nonlinear interaction.
- Re-emission from site of $f_{DP}$ is coherent reflection.

Fine structure improves the clinical value of DPOAE for early identification of hearing loss and to monitor recovery of cochlear function.
DPOAE Fine Structure in Type 1 Diabetes

(Courtesy of Christopher Spankovich, AuD, PhD, MPH)
DPOAE Fine Structure in Type 1 Diabetes
(Courtesy of Christopher Spankovich, AuD, PhD, MPH)

Reflection Component

Distortion Component
Thank You … Questions?

Plural Publishing
(www.pluralpublishing.com)
150 pages, Softcover, 5 x 7.5"
ISBN10: 1-50756-342-0
$45.00
Thank You …
Questions?

Plural Publishing
(www.pluralpublishing.com)
150 pages, Softcover, 5 x 7.5"
ISBN10: 1-50756-342-0
$45.00