Recasting Coherent Reflection

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GRC 2014
- Cochlear (i.e., mammalian) micromechanics still not well understood

- Increasing focus on structural detail (e.g., tectorial membrane, organ of Corti geometry)
OAEs tied to forward auditory transduction

- Audiometric ‘dips’ correlate to presence of SOAEs

- SOAE ‘suppression’ tuning curves match those of ANFs

- SFOAE ‘phase-gradient delays’ also accurately estimate ANF sharpness of tuning

Taschenberger et al (1997)

Long & Tubis (1988)

Joris et al (2011)
But what do OAEs tell us about cochlear mechanics?
OAE Taxonomy

- BM traveling waves

Wave-centric framework, including notion of ‘coherent reflection’

Mechanism-Based Taxonomy for OAEs

Otoacoustic Emissions

- OAEs that arise by Linear Reflection
  - Reflection Emissions
    - Due to coherent reflection from 'random' impedance perturbations
    - Examples: Echo emissions (SFOAEs and TEOAEs) at low levels
  - Spontaneous Emissions
    - Due to standing waves caused by 'run-away' multiple internal coherent reflection (from 'random' perturbations and stapes) stabilized by cochlear nonlinearities

- OAEs that arise by Nonlinear Distortion
  - Distortion Emissions
    - Due to nonlinearities acting as 'sources' of cochlear traveling waves
    - Examples: DPOAEs when coherent reflection from the DP place is negligible
  - Evoked Emissions
    - Typically, a mixture of emissions produced by both mechanisms

Shera & Guinan (1999)
Present goal

Argue that:

➢ Useful framework, but...

➢ ... wave-centric focus hides a more general/ powerful biophysical principle at work

Illustrate via a comparative viewpoint
Tyto alba
Hunting in absolute darkness
Comparative Approach: Morphological differences

LIZARDS
- Papilla short to medium
- Two types of hair cell
  - Low-frequency hair cell
  - Afferent nerve fibers
  - Efferent nerve fibers

High-frequency hair cell

ARCHOSAURS
- Papilla medium to long
- Two types of hair cell
  - Short hair cell
  - Tall hair cell

10 μm

Low-frequency papilla
- Large variation in TM structure
- Tectorial membrane

100 μm

High-frequency papilla

Manley (2000)
Comparative approach: Morphological differences

**Human**
- BM length: ~30-35 mm
- # of hair cells: ~20000
- overlying tectorial membrane (TM)

**Barn owl (Tyto alba)**
- BM length: ~10 mm
- # of hair cells: ~16000
- Thick TM coupled to papilla
- BM waves = ???

**Lizard (Anolis)**
- BM length: ~0.45 mm
- # of hair cells: ~150
- free-standing bundles (i.e., no TM)
- no BM traveling wave
How does morphology affect performance?

→ Non-mammalian ears can exhibit similar thresholds/tuning as mammals*

* In general, high frequency hearing (>10 kHz) is unique to mammals
- Lightly anesthetized
- Middle ear vented
Results: Spontaneous OAEs (SOAEs)
Dynamics of spontaneous otoacoustic emissions

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Background

Acoustic phenomena have been observed in the auditory system for many years. Early studies focused on the acoustic properties of the inner ear, but more recent research has expanded to include the outer and middle ears as well. Otoacoustic emissions (OAEs) are non-linear phenomena that occur when the middle ear is subjected to sound vibrations. The presence of OAEs is a sensitive indicator of cochlear health, and they are often used in clinical diagnostics to assess the integrity of the cochlear apparatus.

Results

1. OAEs are generated by the cochlea in response to sound stimulation. The cochlea contains the inner hair cells, which are sensitive to sound and generate electrical signals that are transmitted to the brain. The electrical signals are then amplified and processed by the brain to create the perception of sound.

2. OAEs can be categorized into two types: transient otoacoustic emissions (TOAEs) and distortion product otoacoustic emissions (DPOAEs). TOAEs are generated by the inner ear and are a reflection of the cochlear system's response to sound stimulation. DPOAEs, on the other hand, are generated by the outer and middle ears and are a reflection of the non-linear interactions between the two.

3. OAEs are sensitive to changes in cochlear health. For example, OAEs can be used to detect hearing loss, which is a common condition that affects millions of people worldwide. OAEs can also be used to monitor the progression of hearing loss and to assess the effectiveness of treatment.

Discussion

1. To study OAEs, researchers use a variety of techniques, including tone-bursts, noise bursts, and clicks. Tone-bursts are a series of short sound pulses that are repeated at a fixed frequency. Noise bursts are random noise stimuli that are used to stimulate the cochlea. Clicks are high-intensity sound pulses that are used to stimulate the cochlea.

2. OAEs can be measured using a variety of instruments, including OAE meters and otoacoustic emission microscopes. OAE meters are portable devices that are used to measure OAEs in real-time. Otoacoustic emission microscopes are used to visualize the outer and middle ears and to assess their function.

3. OAEs are used in clinical diagnostics to assess the integrity of the cochlea. For example, OAEs can be used to detect hearing loss, to monitor the progression of hearing loss, and to assess the effectiveness of treatment. OAEs can also be used to monitor the effects of noise exposure and to assess the effectiveness of hearing protection devices.

Conclusion

OAEs are a valuable tool for the assessment of cochlear health. By measuring OAEs, researchers can detect hearing loss and monitor its progression. OAEs can also be used to assess the effectiveness of treatment and to monitor the effects of noise exposure. OAEs are an important tool for the development of new hearing aids and for the assessment of cochlear implants.
Results (owl): SOAE Interactions with (External) Swept Tones

Tone level = 20 dB SPL

Data from two representative animals

- Strong interactions with (flat-level) stimulus tone at ear canal
  (even for small SOAE peaks)
Results (owl): SOAE Interactions with (External) Swept Tones

- SOAEs appear as horizontal lines, (external stimulus) swept tone as diagonal
- Localized interactions (e.g., ‘suppression’) apparent
- Allows for determinations of SOAE frequencies during SFOAE measurements

Tone level = 20 dB SPL

Data from two representative animals

Animal 1

Animal 2
Results (owl): SFOAEs

Robust SFOAEs (e.g., residual can be stronger than evoking stimulus!)

SOAE and SFOAE peak locations not always correlated

Allows estimation of SFOAE phase accumulation between adjacent SOAEs

Animals:

- Animal 1
- Animal 2

Lp = 20 dB SPL
Ls= 35 dB SPL
fs= fp+ 40 Hz
Results (owl): SFOAE phase accumulation re SOAEs

Data compiled from 15 ears of 9 owls

- Integral number of cycles of phase accumulation between SOAE peaks
- Independent of frequency and phase (un)wrapping
All species show integral # of cycles of SFOAE phase accumulation between adjacent SOAE peaks......

.... despite gross morphological/biomechanical differences (e.g., no BM waves)
Connecting back to models (of SOAE generation)

➢ To first order, data consistent with seemingly disparate models

➢ Is this telling us something important?
De-waving coherent reflection

Recast the basic biophysical picture:

- **Coherent reflection** → ‘phase coherence of coupled oscillators’

**Basic gist:**

- Consider inner ear as collection of coupled nonlinear/active oscillators
- ‘Systems’ view: *The whole is more than the sum of the parts*
A more general biophysical principle emerges...

*phase coherence of coupled oscillators*

- More universal/parsimonious framework for describing/understanding inner ear mechanics
  (i.e., human/owl/lizard ears are both similar & different)

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**Entrainment of Neuronal Oscillations as a Mechanism of Attentional Selection**

Peter Lakatos, George Karmos, Ashesh D. Mehta, Istvan Ulbert, Charles E. Schroeder

4 APRIL 2008 VOL 320 SCIENCE

- Basic idea likely holds in other areas of hearing (and beyond)...

Bergevin & Shera (2010)
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Carl von Ossietzky University (Oldenburg, Germany)

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Funding
- Natural Sciences and Engineering Research Council of Canada (NSERC)
- Deutsche Forschungsgemeinschaft (CRC/TRR 31 “Active Hearing”)
Fini
Otoacoustic Emissions (OAEs)

- Presumably by-product of amplification mechanism

- OAEs used for newborn hearing screening *(only ‘healthy’ ears emit)*

- Much faster/easier than evoked electrical potentials