

ABSTRACT: Models of otoacoustic emission (OAE) generation mechanisms often attribute important features of OAEs to waves traveling along the cochlear partition. Since the lizard basilar papilla manifests no obvious analog of the mammalian traveling wave, detailed comparisons between lizard and mammalian OAEs offer an important opportunity to test and extend our knowledge of emission mechanisms. We report a comparison of the frequency and intensity dependence of human and leopard-gecko stimulus-frequency emissions (SFOAEs). In both species, SFOAE amplitude-vsfrequency functions (measured at fixed level) and amplitude-vs-level functions (measured at fixed frequency) manifest pronounced notches. The characteristics of these notches suggest that they result from interference between two out-of-phase components. Preliminary data indicate that a subset of these notches in frequency and level space can be strongly correlated. We interpret the data in light of existing models and the known anatomical and functional differences between the two species.

INTRODUCTION

• In mammals, otoacoustic emission generation is generally thought to involve BM traveling waves [Shera and Guinan, 1999] and HC somatic motility [Liberman et al. 2002].

• However, OAEs have been observed in non-mammals where both traveling waves [Peake and Ling, 1980, Manley et al. 1988 and Manley et al. 1999] and somatic motility [Koppl et al. 2004 and He et al. 2003] are believed to be absent.

• The leopard gecko (Eublepharus macularius) has a relatively simple inner ear anatomy [Wever, 1978] and shown the presence of spontaneous OAEs [Manley et al. 1996]. Additionally, these animals appear to have thresholds [Weaver, 1978] and frequency selectivity [Sams-Dodd and Capranica, 1994 and Manley *et al.* 1999] comparable to mammals.

• By examining OAE properties comparatively between geckos and humans, we aim here to extend our knowledge of generation mechanisms and the underlying cochlear physiology.

NONLINEAR EMISSION GROWTH

• Evoked otoacoustic emission (eOAE) growth with stimulus level has been observed to exhibit nonlinear behavior. In particular:

- growth is *non-monotonic* and exhibits *level notches* at moderate stimulus intensities



(phase)

- these level notches are accompanied by *phase jumps*, ranging from 0-0.5 cycles

QUESTION I - How do OAE growth properties compare between humans and geckos?

• A single mechanism model has been proposed [Lukashkin and Russell, 2003] to explain how this nonmonotonic growth in DPOAEs arises:



- nonlinearity in model stems from hair cell transduction curve and takes the form of a 2'nd order Boltzmann function with a variable operating range/point and positive feedback - Taylor expansion about the operating point for a given input characterizes the output response at the different frequencies (the nonlinearity causes distortion, thereby generating new frequencies)

- model predicts non-monotonic growth based upon competition among higher order terms, which are 180° out of phase with each other

—— Simple model produces both non-monotonic growth and phase jumps as seen in DPOAE data. A similar model has also been proposed for the origin of SFOAEs (Siegel and Cerka, 2005).

QUESTION II - Is this simple model consistent with actual observation of evoked OAE growth?

MEASURING OAE GROWTH

• Two different types of emissions were examined:

1. Stimulus Frequency Emissions (SFOAEs) - when ear is stimulated with a single tone (fp), these OAEs arise at that probe frequency

2. Distortion Product Emissions (**DPOAEs**) - stimulation with **two different tones** (f1 and f2) evokes these emissions arising at harmonic and intermodulation frequencies (3f₁, 2f₂ - f₁, etc.)

o We used the same measurement system/paradigms for both humans and geckos. An Etymotic ER-10C probe containing a microphone and two earphones was tightly coupled to the outer ear and calibrated using flat-spectrum noise. Measurement system intermodulation distortion was close to the acoustic noise floor (or about 100 dB below the primary levels), however the harmonic distortion was not well characterized.

• Geckos (N=9) were lightly anesthetized (Nembutal, 20-25 mg/kg i.p.) for experiments, but all recovered completely and were subsequently used for multiple sessions. Human subjects (N=3) sat comfortably in a noise reduction booth.

• SFOAEs were measured using a suppression paradigm in which the OAE was obtained by vector subtraction of the probe frequency components measured in response to the probe alone and in the presence of a nearby suppressor (f_s) [Shera and Guinan, 1999].

A comparative study of evoked otoacoustic emissions in humans and geckos

Chris Bergevin, Christopher Shera, and Dennis Freeman Harvard/MIT HST Speech and Hearing Bioscience & Technology Program







- components), verified by numeric computation
- or stair-casing

- generation.
- explaining OAE generation mechanisms.

He et al. (2003) J. Physio. 546 (2), 511-520 Meenderink and van Dijk (2005) JASA 118 (1), 279-286 Peake and Ling (1980) JASA 67 (5), 1736-1745 Koppl, Forge, and Manley (2004) J. of Comp. Neuro. (479), 149-155 Sams-Dodd and Capranica (1994) Hearing Research 76, 16-30 Liberman et al. (2002) Nature 419, 300-304 Shera and Guinan (1999) JASA 105 (2), 782-798 ukashkin and Russell (2002) IASA 111 (6) 2740-2748 Siegel and Cerka (2005) ARO Abst. #659 Manley, Yates, and Koppl (1988) Hearing Research 33 (2), 181-189 Wever, E.G. (1978), The Lizard Ear (Princeton U.P., Princeton NJ) Manley, Gallo, and Koppl (1996) JASA 99 (3), 1588-1603 Manley, Koppl, and Sneary (1999) Hearing Research 131 (1-2), 107-116







MIT Micromechanics Group

IMPLICATIONS

- Similarity between both species suggest BM waves and HC somatic motility are not necessary to account for a wide range of eOAE properties. Also important to examine differences (phase gradients, more distortion in gecko, ...)

II - The single mechanism model proposed for DPOAEs appears too simple to account for a wide range of eOAE growth phenomena: del Predictions [Lukashkin and Russell, 2003

- model does not predict non-monotonic growth of SFOAEs (growth at primary frequencies is strictly monotonic due to lack of 'out of phase'

- does not account for a wide range of DPOAE growth features: linear growth at low levels, phase jumps less than 1/2 cycle (which leads to notches only occurring at certain frequencies), rotating phase with level,



(opposed to the more 'point-source' approach taken by the model here) that considers a *spatial summation of distributed sources* (which could be coupled via the fluids, tectorial membrane, ...)

III - Correlation between level and frequency notches (in both species) strengthens the need for a more *distributed* approach. Additionally, the level dependence of the OAE phase gradients needs to be considered when interpreting these slopes in terms of an actual 'time delay'.

SUMMARY

- Similarities (and differences) in eOAE properties between mammals and non-mammals (the latter which lacks physiological mechanisms thought to play an integral role in mammalian OAEs) suggest strong parallels in OAE

- Although a single mechanism model produces DPOAE notches and phase jumps, it cannot account for many eOAE growth features. It may prove beneficial to pursue a *distributed* approach rather than a *point-source* one in

REFERENCES & ACKNOWLEDGMENTS

- We would like to acknowledge insightful discussions with John Guinan, John Rosowski, and AJ Aranyosi. This work was supported by R01 DC003687 (CAS), R01 DC0023821 (DMF), and T32 DC00038 (SHBT training grant) from the NIDCD, National Institute of Health. All experimental protocols were subject to the MIT DCM/CAC, MIT COUHES, and MEEI Human Studies Committee approval.





The Harvard-MIT Division of Health Sciences and Technology