# SFOAE PHASE-GRADIENT DELAYS AND AUDITORY-NERVE TUNING IN A NON-HUMAN PRIMATE

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This poster addresses questions prompted by the following observations:

. Humans have significantly longer stimulus-frequency otoacoustic emission (SFOAE) phase-gradient delays than any other species so far examined.

2. The hypothesized triangle of interrelationships shown in Figure 1 predicts correlations between SFOAE delays, BM delays, and the sharpness of cochlear tuning (Shera, Guinan & Oxenham 2002, 2007). However, recent papers (Siegel et al. 2005; Ruggero & Temchin 2005, 2007) have questioned these relationships.

### **Question 1 - Are human OAE delays truly exceptional?**

We address this question by measuring SFOAEs in rhesus monkeys (Macaca mulatta), a species of Old-World monkey phylogenetically more similar to humans than the laboratory animals typically used in OAE studies (e.g., cats, guinea pigs, chinchillas).

### **Question 2 - Do SFOAE delays predict the sharpness** of cochlear tuning?

This question is addressed by comparing SFOAE delays with auditory-nerve-fiber (ANF) derived estimates of cochlear tuning (Joris et al. 2006) in the rhesus monkey.

### BACKGROUND

**FILTER THEORY:** The left-hand edge of the triangle in Figure 1 represents relationships between tuning and group delay expected from filter theory (e.g., Bode 1945). In general, sharper tuning involves longer delays.

In filters of fixed order, the quality factor (Q) and center-frequency group delay (N, measured in periods) vary in constant proportion. For example, Figure 2 shows how Q and N covary in a simple, second-order filter. Despite large changes in  $Q_{\prime}$  the ratio Q/N remains constant.

Although cochlear filters are not simple second-order systems, a similar covariation between neural tuning and delay occurs across CF in the chinchilla (Shera, Guinan & Oxenham 2007; Recio-Spinoso et al. 2005).

**COHERENT REFLECTION:** The bottom edge of the triangle in Figure 1 represents relationships between near-CF mechanical delays of the basilar membrane and SFOAE phase-gradient delays predicted by the coherent-reflection model of reflection-source OAE generation (Zweig & Shera 1995; Talmadge et al. 1998). Although the predicted relationships are complicated, longer mechanical delays generally produce longer OAE delays.

## METHODS

**SFOAE Measurements** (Bergevin, Kalluri, Shera): Otoacoustic emissions were measured in healthy, adult Rhesus monkeys (*Macaca mulatta*). The monkeys were members of a colony used for (nonauditory) neurophysiological studies at the Massachusetts Institute of Technology. Their ages ranged from 4–22 years and their weights from 4–15 kg. Some animals had chronic neural implants in their skulls.

Monkeys were lightly anesthetized with Telazol (5 mg/kg) and received maintenance doses of 2.5 mg/kg Telazol or 5 mg/kg ketamine as needed.

SFOAEs were measured using the suppression method (Shera & Guinan 1999) implemented on the Mimosa Acoustics measurement system, which employs the Etymotic Research ER10c probe system. For the data reported here, probe and suppressor levels were 40 and 55 dB SPL, respectively. System distortion limited the measurements to probe frequencies below  $\sim$ 7 kHz.

ANF Recordings (Joris, McLaughlin, van der Heijden): Auditory-nerve recordings were obtained in acute experiments on 15 macaque monkeys (11 Cynomolgus and 4 Rhesus) under barbiturate anesthesia. The auditory nerve was exposed via a posterior fossa approach. In some experiments, a large portion of the midline and lateral cerebellum were removed. Upon visualization of the nerve, recording electrodes (3M NaCl pipettes, impedance ~40 M $\Omega$ ) were visually positioned peripheral to the schwann-glia border.

Search stimuli were tones, broadband noise, or frequency sweeps. Current pulses were also used. Spontaneous rates (SR) were measured over a 15 s silent period. Threshold tuning curves were obtained using a two-down one-up tracking paradigm.

**Analysis**: SFOAE group delays were calculated from unwrapped phases using centered differences and expressed in dimensionless form ( $N_{SFOAE} = CF \cdot Delay$ ). Data points less than 10 dB above the noise floor were excluded from the analysis. The sharpness of ANF tuning was quantified using Q<sub>ERB</sub>, defined as CF/ERB, where ERB, the equivalent rectangular bandwith, was computed from the ANF tuning curves using standard procedures. The data shown here are based on units with thresholds within 20 dB of the best-threshold curve. Trend lines were computed using locally linear regression (loess).



FIGURE 1: Hypothesized triangle of interrelationships between the sharpness of cochlear tuning, near-CF basilar-membrane mechanical delays, and SFOAE delays. (Adapted from Shera, Guinan & Oxenham 2007.)









**Answer 2** - Yes, SFOAE delays do predict ANF tuning. Rhesus monkeys have SFOAE delays and ANF tuning that are intermediate between humans and other laboratory animals (e.g., cats).

1. Rhesus monkey SFOAE delays are intermediate between those of humans

→ Human OAE delays are therefore less exceptional than they previously appeared. Human SFOAE delays may reside at one extreme of a near con-

2. The relative size of rhesus monkey SFOAE delays (e.g., longer than cats) predicts the relative sharpness of their ANF tuning curves (sharper than cats).

 $\rightarrow$  Our results support previous suggestions that (1) OAE measurements provide a noninvasive measure of cochlear tuning and (2) human cochlear tuning is sharper than that of common laboratory animals (Shera,

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