Modeling otoacoustic emission group delays in the lizard auditory periphery

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Work done in collaboration w/ Christopher Shera (HMS)

REFERENCE FRAME

WHAT'S WRONG WITH THOSE TALKS?

N. David Mermin

My friend Professor Mozart recently ran across some advice to young physicists on how to give talks (James C. Garland's article in PHYSICS TODAY, July 1991, page 42). He came to me seething with indignation. "What's the problem, W. A.?" I asked. "I thought Jim Garland spelled out concisely and effectively just about everything the novice ought to take into consideration."

"As you say," he snarled, "it was a precise recipe for how to produce a contemporary physics talk—an almost perfect codification of all the ingredients."

"Well what more could you ask?"

He gave me a look of withering scorn. "The contemporary physics talk is a disaster," he proclaimed. "The only pleasure it affords is the relief that washes over you as you realize, finally, that perhaps the end is in sight. To assemble a respectable audience you have to bribe people with cookies and muffins. You must offer gallons of coffee to those honorable enough not to take the food and run, to help them maintain consciousness during the next hour. The article in PHYSICS TODAY did a masterful job of passing on to future generations everything necessary to maintain this dreary art form."

"You're unfair," I reprimanded him. "There are too many things about lecturing that you, an experienced speaker, simply take for granted. If you think the article gave young physicists bad advice, have you anything better to offer?"

"They were not given bad advice. They were given excellent advice for making the best of an inherently hopeless situation. But pretending that the standard physics talk of today is an acceptable form of communication breeds hypocrisy in the old and experienced and nurtures self-doubt in the young and innocent, who not only have to undergo the wretched experience of attending physics talks but also torture themselves worrying why they're not enjoying the ordeal. I would have urged speakers to get to the root of the problem."

"And just what might that be?"

Without another word he thrust into my hands a battered handwritten manuscript covered with coffee stains and smeared with muffin crumbs, evidently labored over during many hours of intolerably dull seminars and colloquia. Then he walked off in a huff.

Though appalled by some of the opinions expressed in the document he handed me, I reproduce it below in its entirety as a counterbalance to the conventional wisdom.

Advice to Beginning Physics Speakers (and Intermediate or Advanced Ones)

William A. Mozart

Bill Mozart is Rachmaninoff Professor of Physical Science somewhere in the depths of central New York. He has been forced to embed these precepts in another's article, because PHYSICS TODAY discriminates against imaginary people.

If you have taught physics you know it is virtually impossible to write too easy an exam. Yet nobody acknowledges that the same is even more true of the physics talk. It is absolutely impossible to give too elementary a physics talk. Every talk I have ever attended in four decades of lecture-going has been too hard. There is therefore no point in advising you to make your talk clear and comprehensible. You should merely strive to place as far as possible from the beginning the grim moment when more than 90% of your audience is able to make sense of less than 10% of anything you say.

It is in the nature of physics talks that they should be boring and confusing. You, the speaker, struggled through ten years of college and graduate school to reach the point where you could do research in your chosen area, acquiring arcane skills available to only a narrow range of practitioners. To attempt in the space of an hour to provide your audience with even the minimal background necessary to savor your recent research achievements is a doomed undertaking.

Yet we do give talks. Why? Only when this is understood can there be hope of producing an acceptable lecture.

The best reason to lecture on your work is that it affords you the opportunity to rediscover why you did it. The most important question to ask yourself in preparing your talk is why on earth any physicist might be interested. This is dangerous: There is always the risk you will find no answer. But that is not necessarily a cause for alarm. Often when working on a problem for a long time, one does indeed forget what first led one into that line of endeavor, so if at first you can find no answer, think some more. What is there in the subject to capture the imagination of one lacking your highly specialized skills?

Give yourself a week. If you still can find no reason why anyone not directly involved in the work should find it anything but tediously obscure, then you should find something else to talk about. Indeed you might then seriously consider finding another area of research. Often merely preparing to give a talk can yield up such beneficial insights without your ever actually having to deliver the talk.

But suppose you do remember why you got into your current line of research. If you succeed in conveying that early freshness and excitement to somebody else, your talk will be an unqualified success, even if you never manage to describe a single one of the splendid things you uncovered when

David Mermin is a professor of physics at Cornell University. The first physics colloquium he ever gave was so dreadful he was not invited back for 22 years.

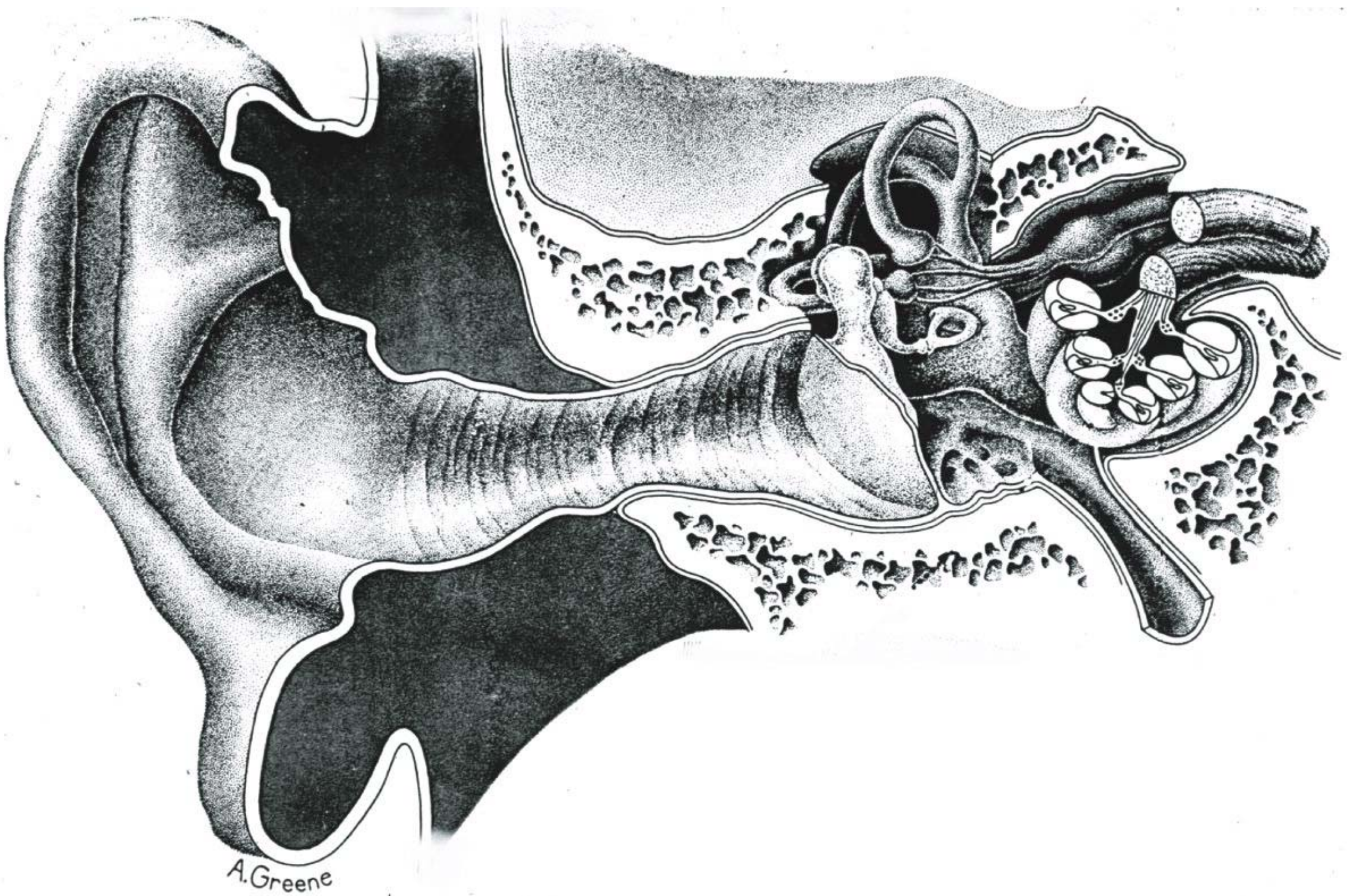
It is absolutely impossible to give too elementary a [*math*] talk. Every talk I have ever attended in four decades of lecture-going has been too hard. There is therefore no point in advising you to make your talk clear and comprehensible.

Tip #1 (of 2)

But suppose you do remember why you got into your current line of research. If you succeed in conveying that early freshness and excitement to somebody else, your talk will be an unqualified success, even if you never manage to describe a single one of the splendid things you uncovered when the project was well under way.

Question: Can a series of (linear) coupled oscillators exhibit large group delays across a wide frequency range as seen in otoacoustic emissions (OAEs)?

Means: Use the (relatively simple) lizard ear as a basis for modeling the inner ear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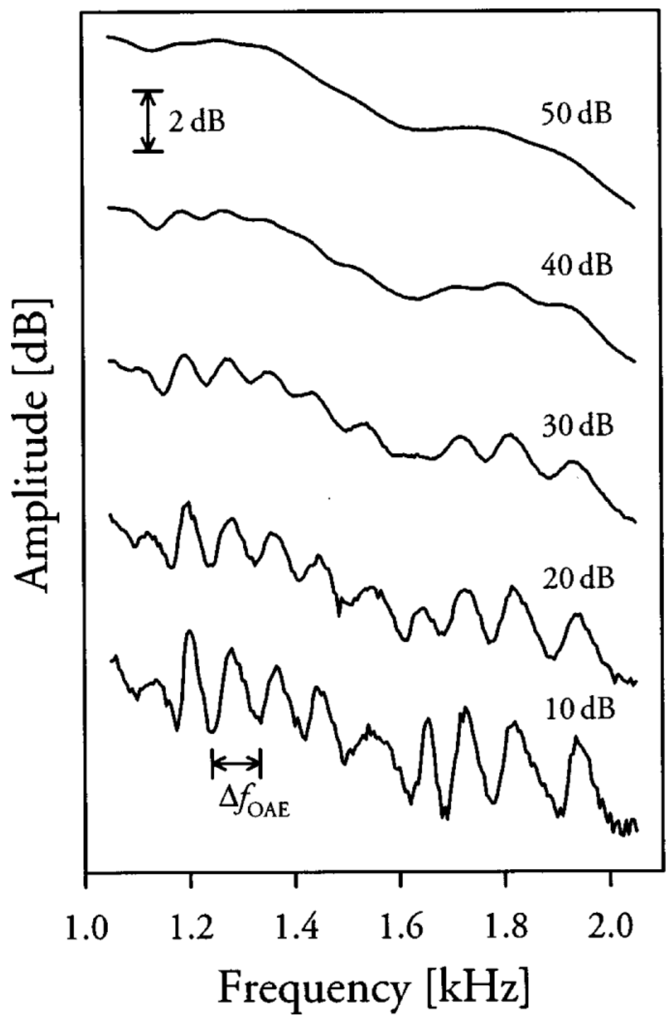
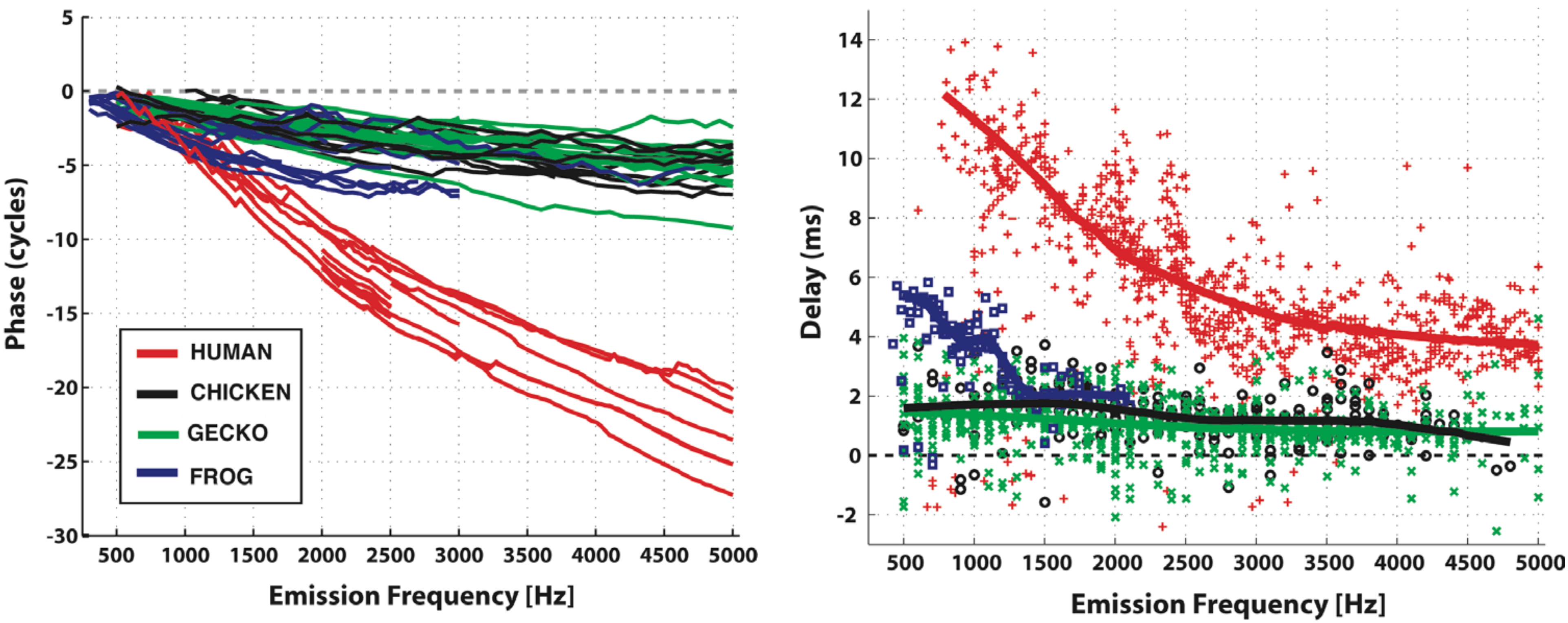


Shera and Zweig (1993)

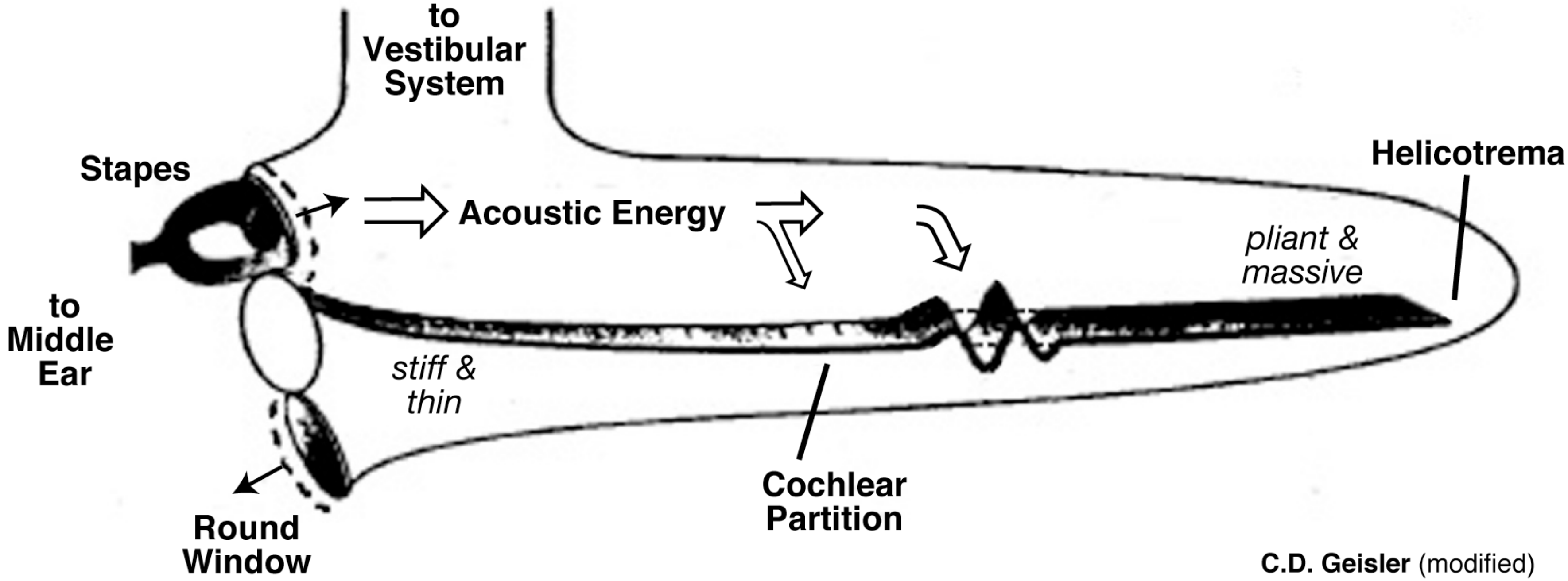
SFOAEs

Lp=40 dB SPL, Ls=55 dB, fs=fp+40 Hz



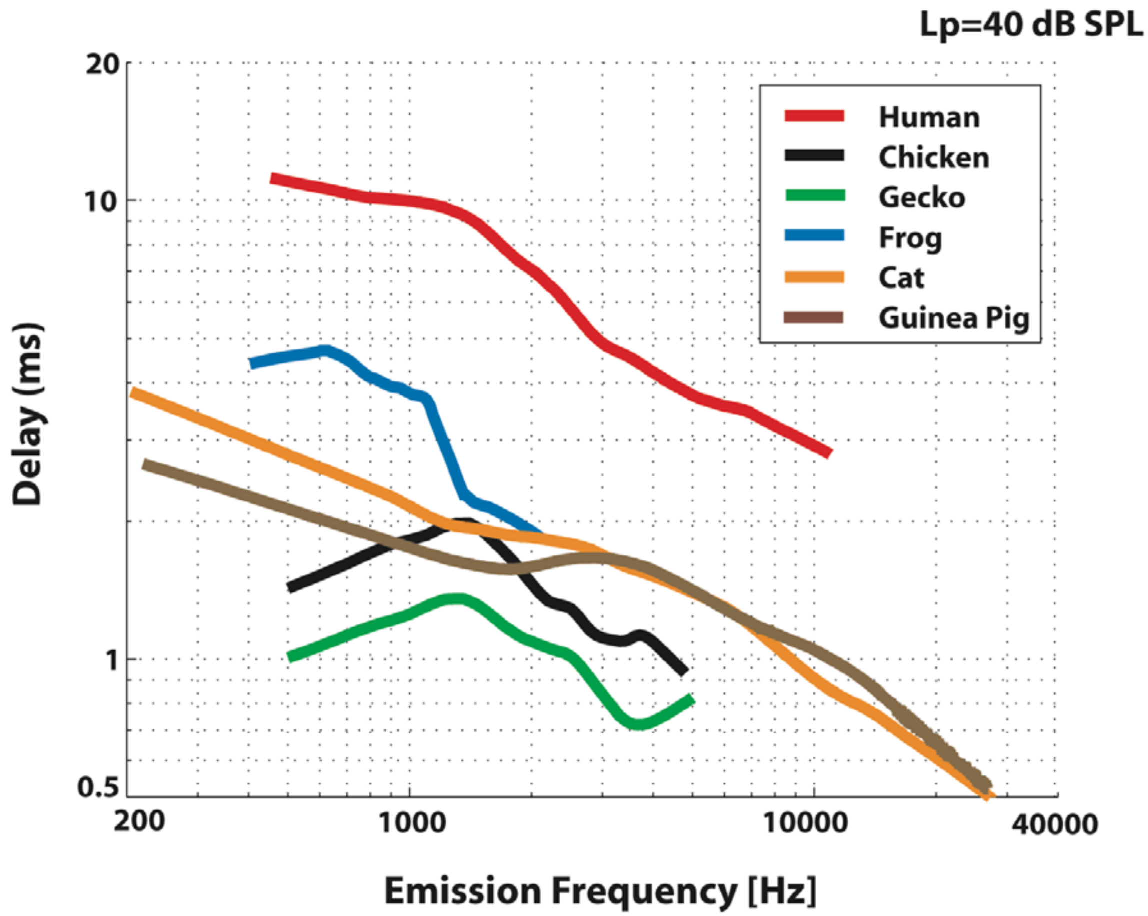
Bergevin et al. (2008A)

Mammalian Cochlea Uncoiled



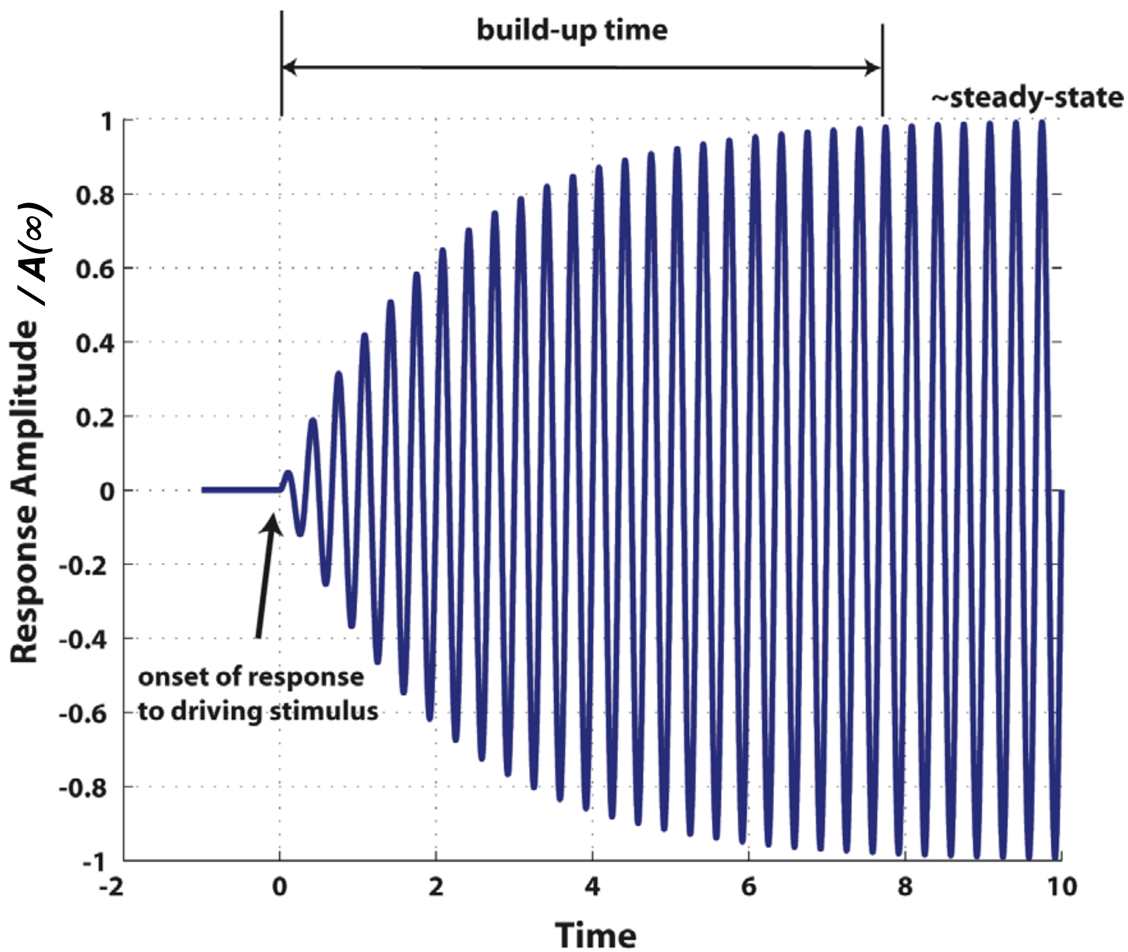
C.D. Geisler (modified)

Not due to differences between mammals and non-mammals nor size



[cat and guinea pig data from Shera and Guinan, 2003]

Tuned Responses Take Time



Second Order System
(resonant frequency ω_o)

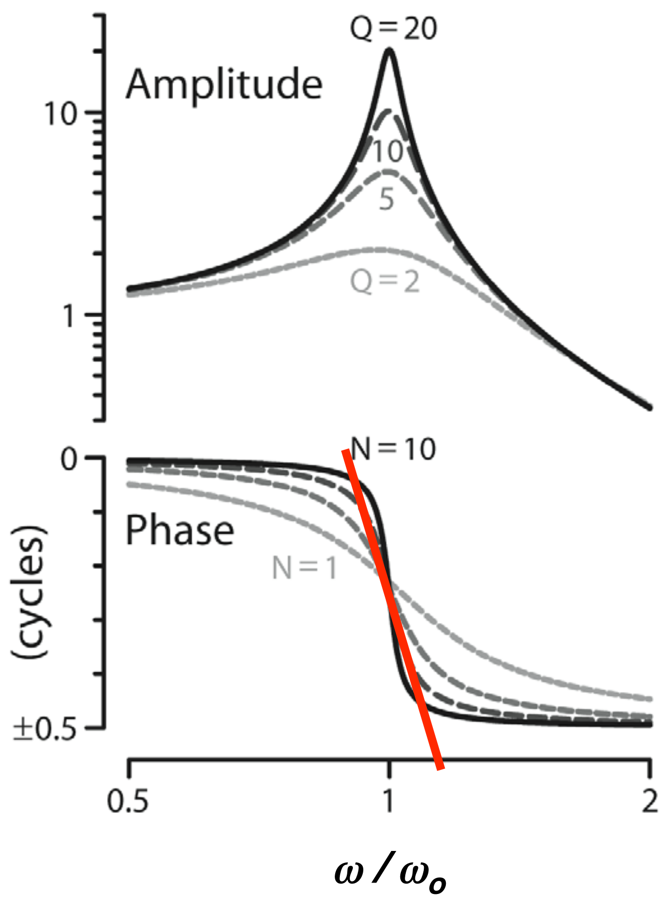
$\Rightarrow$ **External driving force at frequency ω**

$$x(t) = A(\infty)\,[\,1 - e^{(-t/\tau)}\,]$$

$$\boldsymbol{\tau = Q / \omega_o}$$

Q and Phase Gradients Co-vary

Second Order System
(resonant frequency ω_o)



$$Q = \omega_o / (2\pi \text{ x BANDWIDTH})$$

$$N = \omega_o \text{ x Phase Gradient} / 2\pi$$

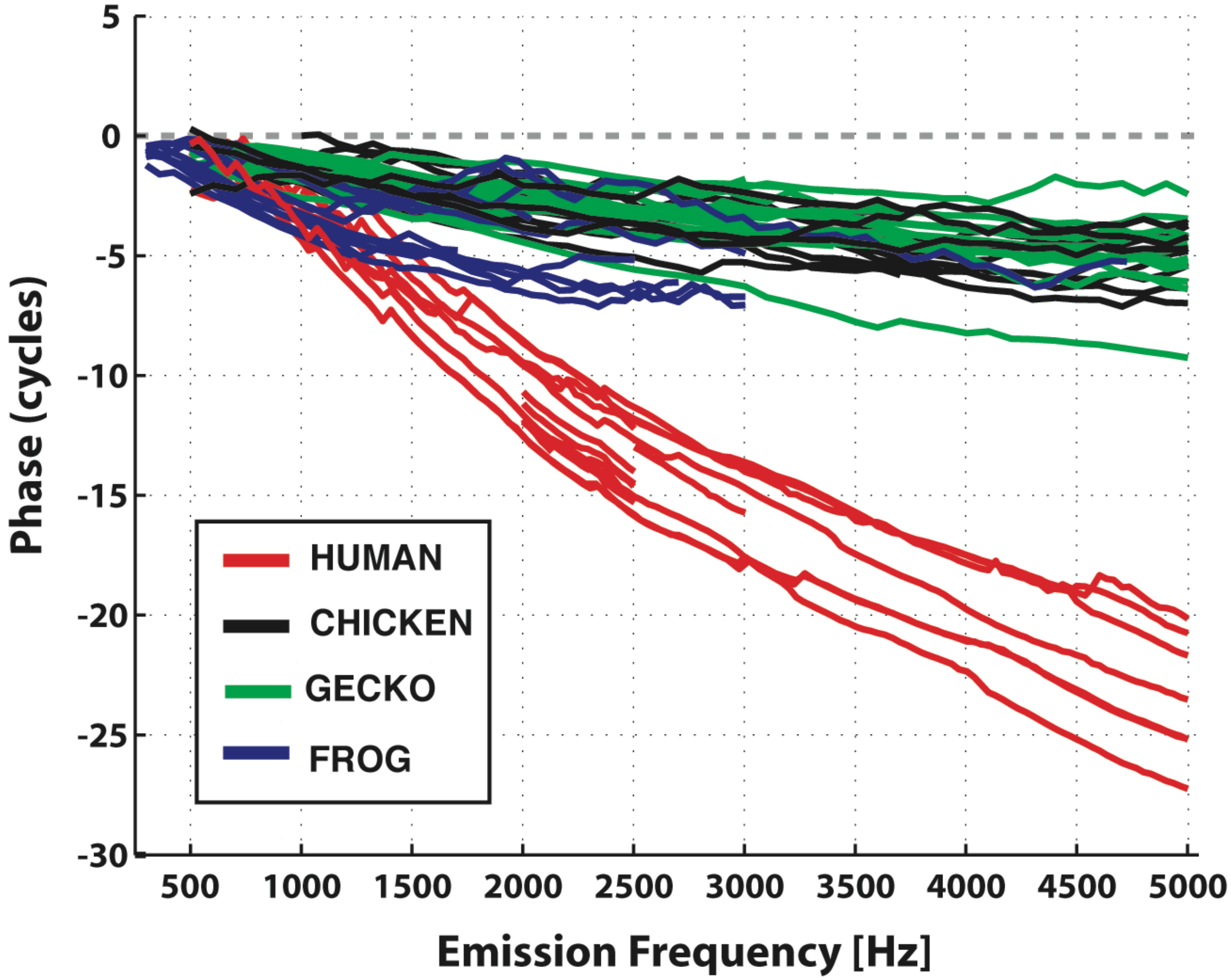
(at ω_o)

$$Q \; \alpha \; N$$

Shera, Oxenham and Guinan (2007)

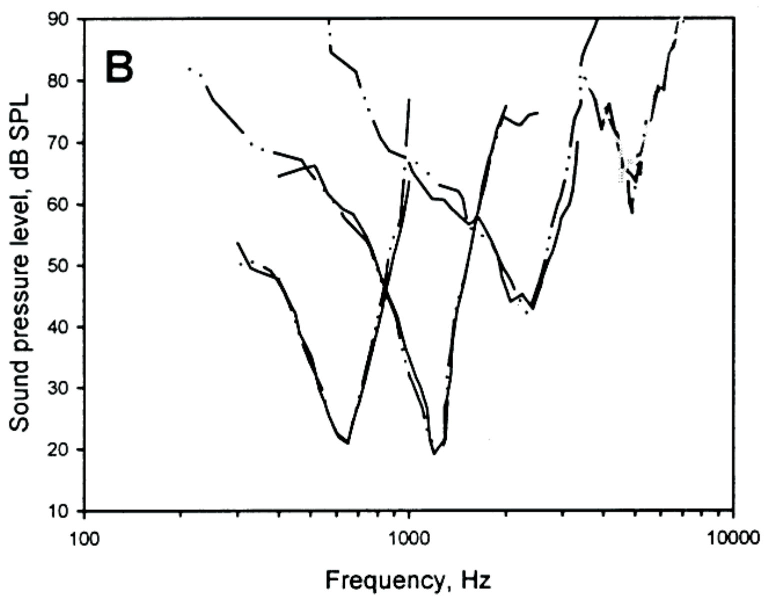
Hypothesis: SFOAE group delays* reflect tuning mechanisms in the inner ear

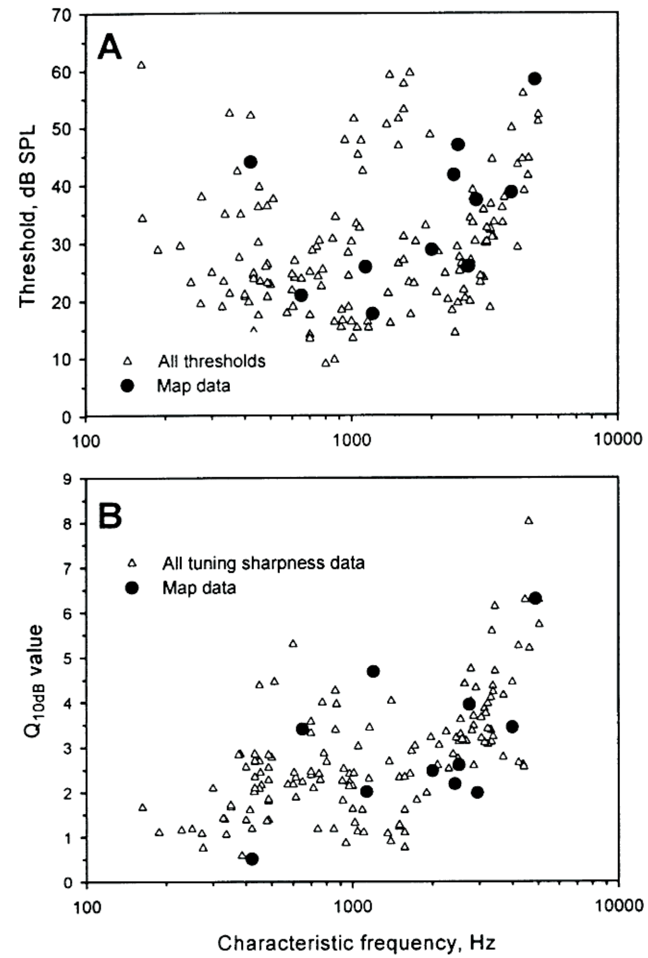
* group delay = phase-gradient delay (for the purpose of the talk)



Bergevin et al. (2008A)

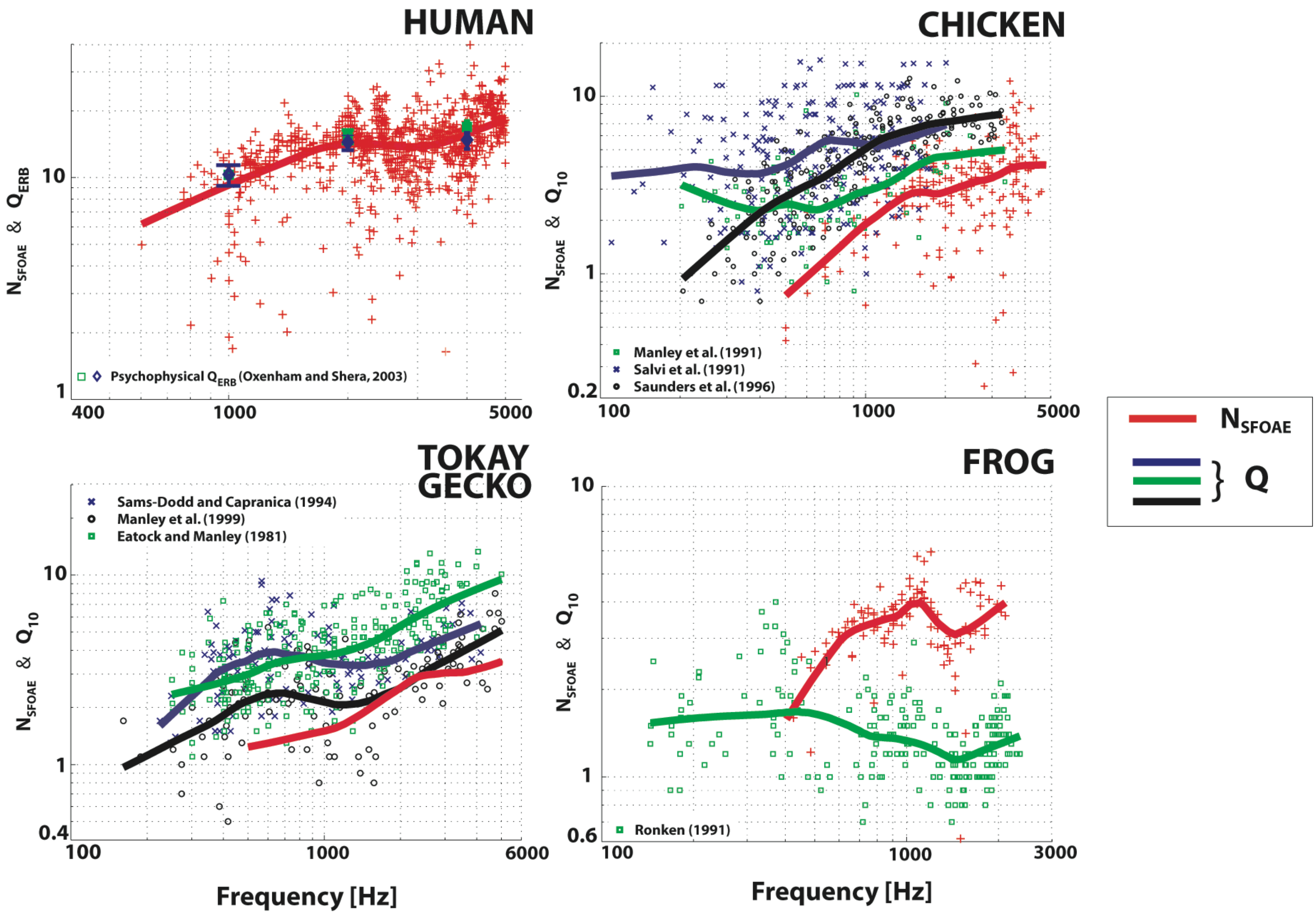
Tokay Gecko Auditory Nerve Fiber Responses





Manley et al. (1999)

Comparison of N (SFOAE) to Q-value (ANF)



Bergevin et al. (2007)

Gecko Inner Ear

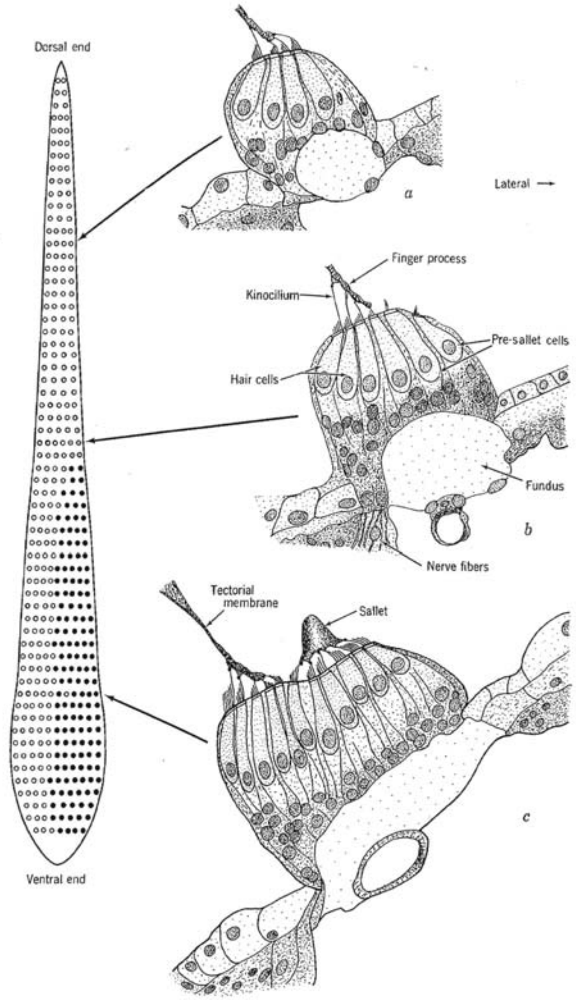
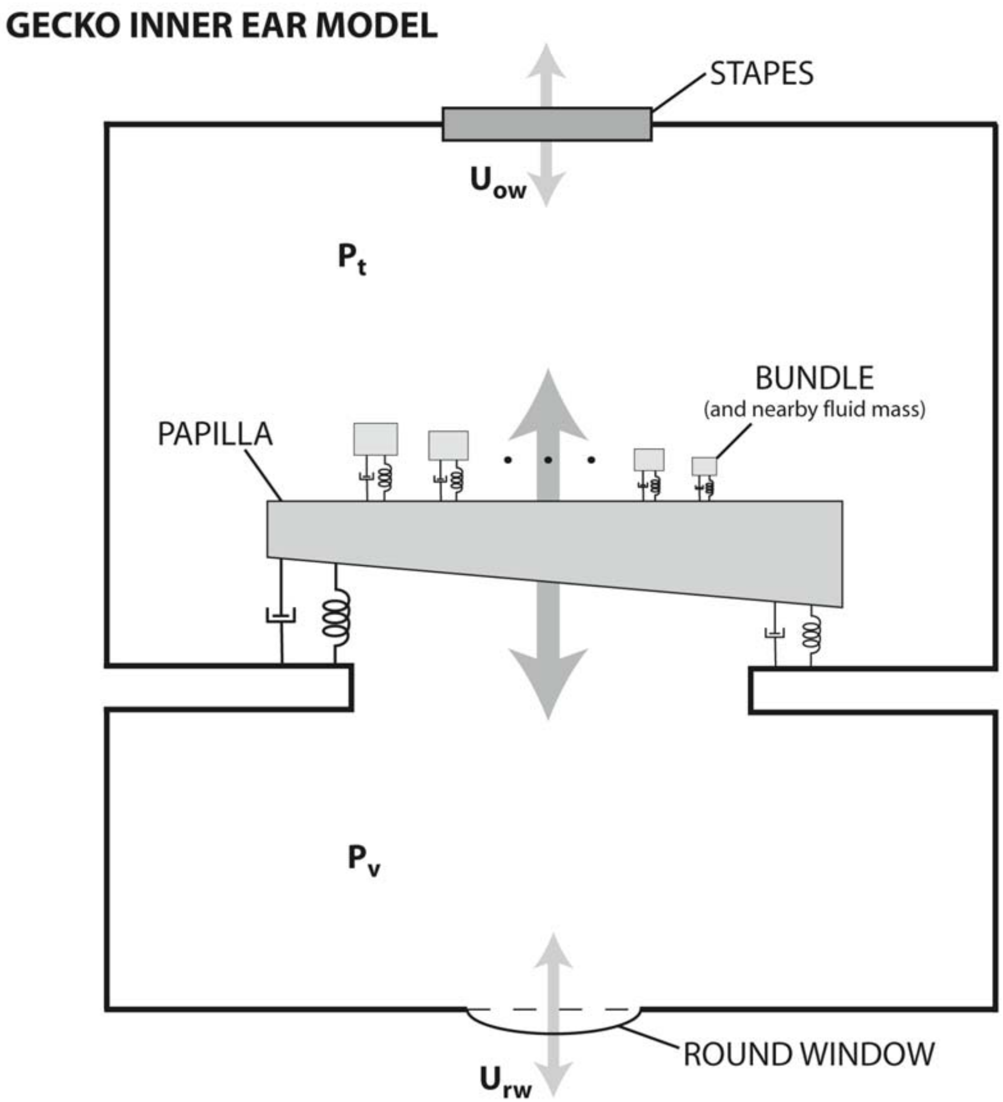


Fig. 14-3. The auditory papilla of *Eublepharis macularius*. On the left is the basilar membrane in outline showing the row structures of the hair cells; and on the right are three cross-sectional views of the auditory papilla at three cochlear regions. Scale for outline, 100×; for cross-sectional views, 400×. From Wever, 1974b.

Wever (1978)



⇒ **Coupled resonators**

Assumptions

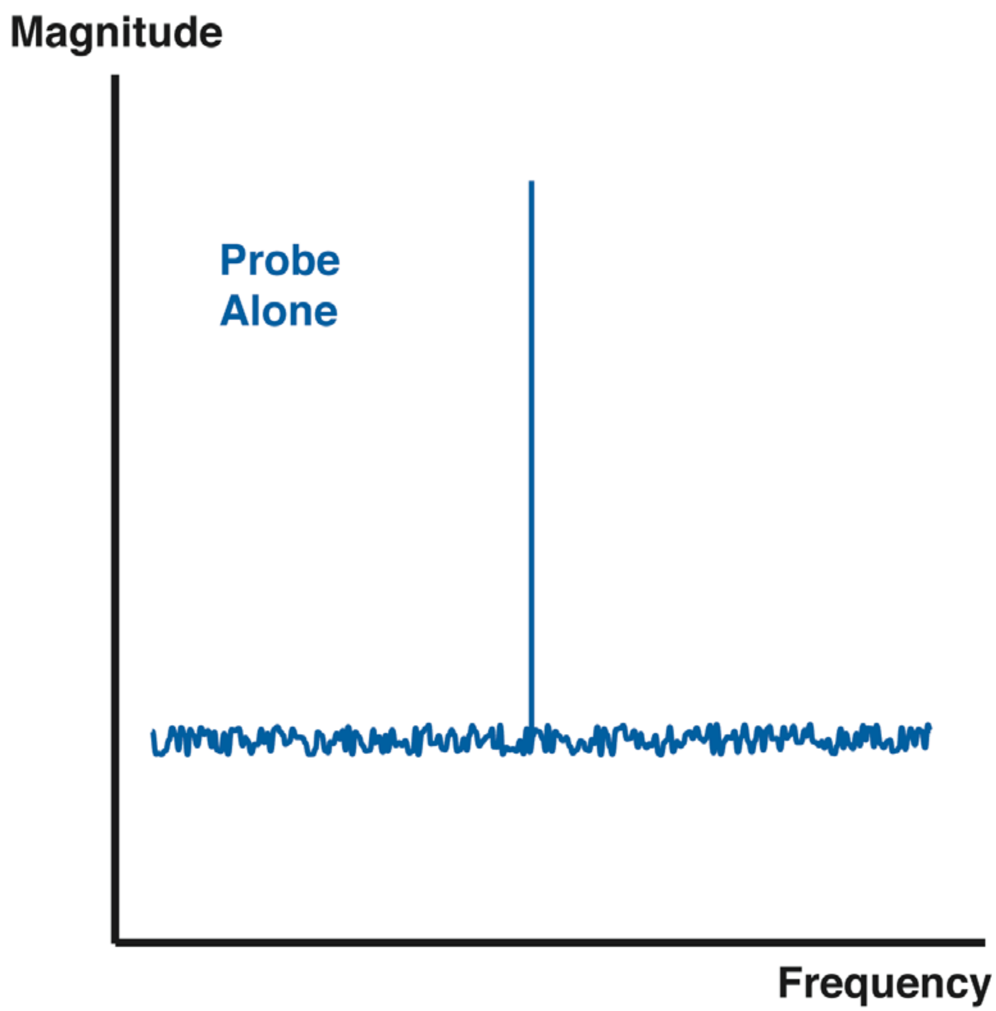
- middle ear delays are negligible

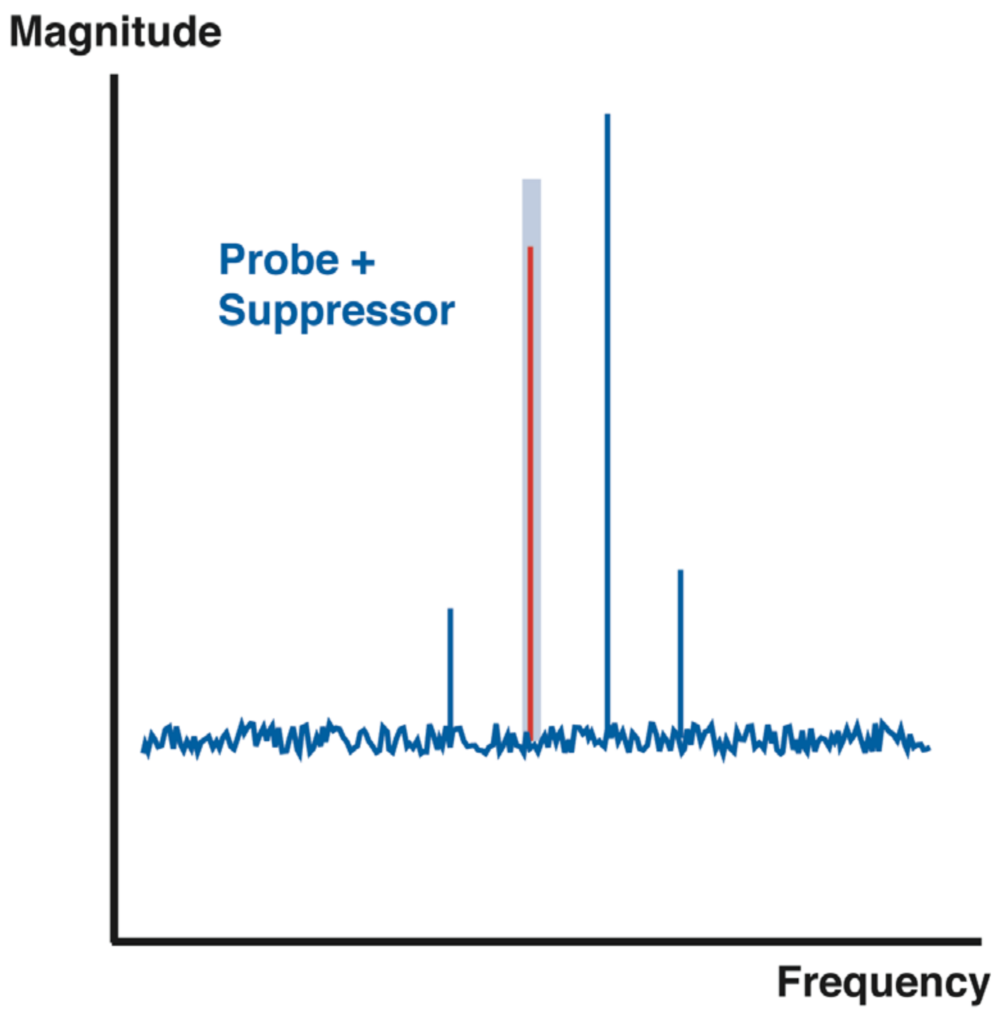
- papilla moves as rigid body ⇒ *one-dimensional motion*

- sinusoidal steady-state response

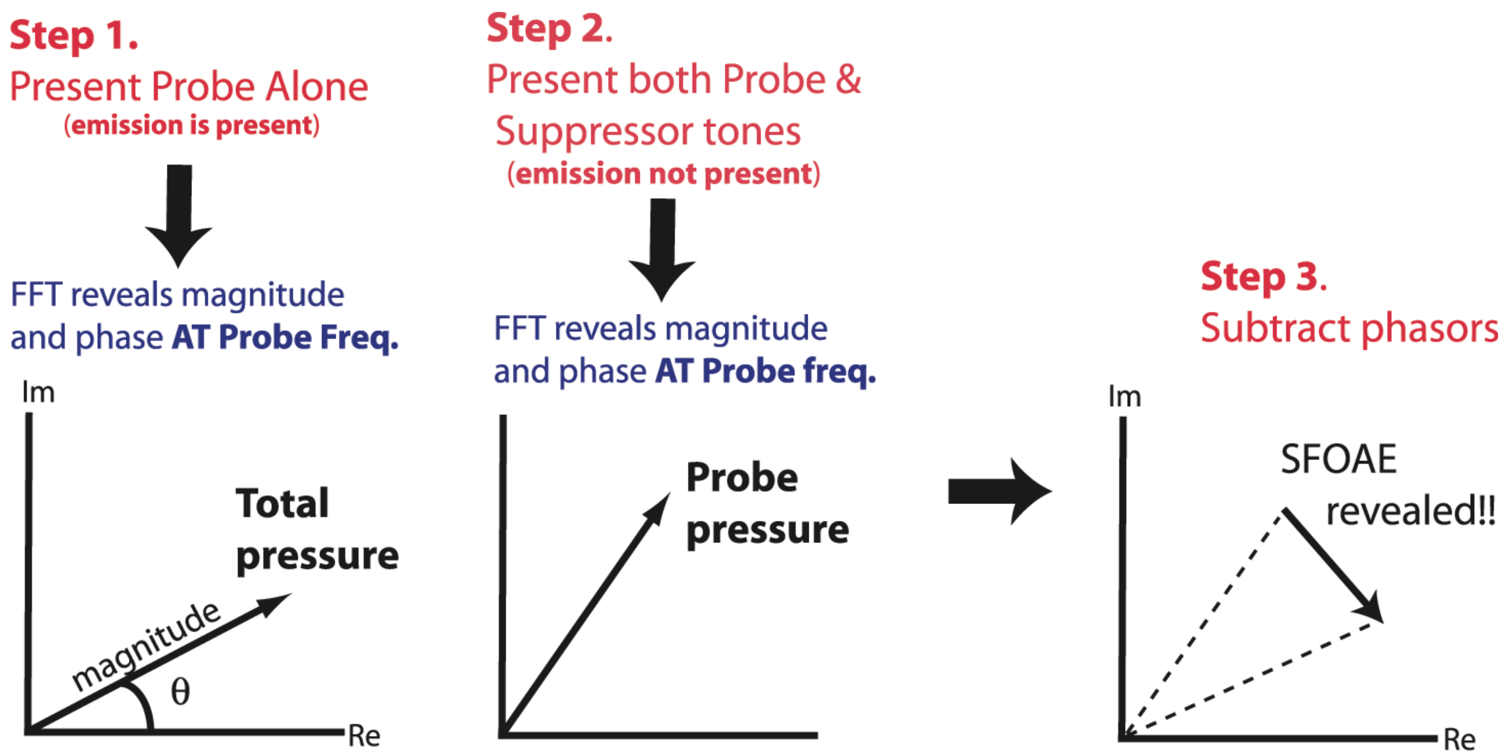
- exponential tonotopic map

- linearity


Magnitude
Probe
Alone
Frequency

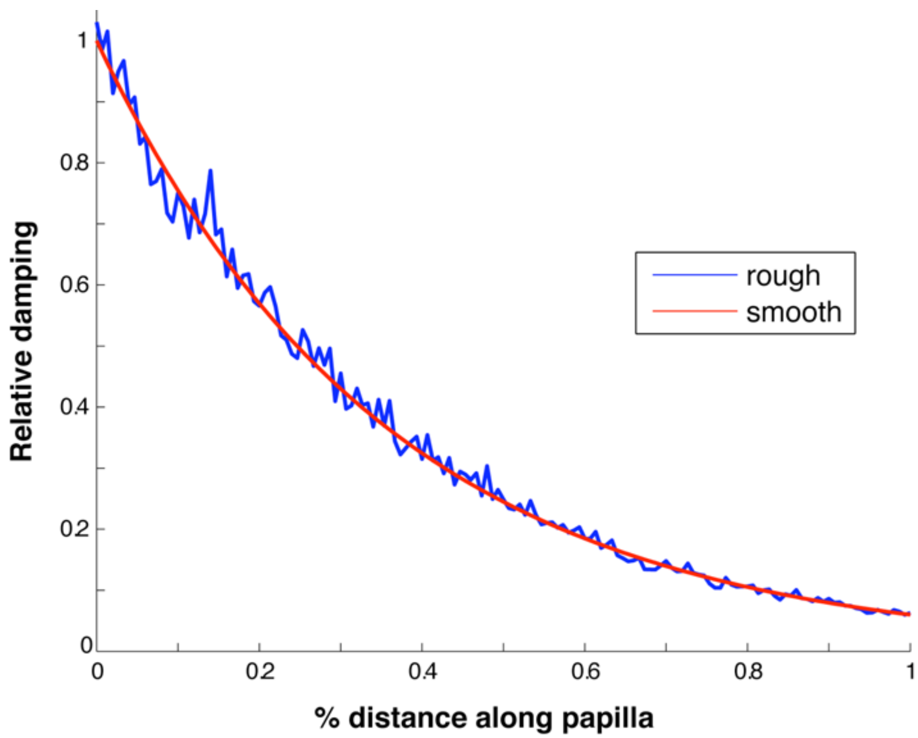

Magnitude
Probe +
Suppressor
Frequency

SFOAEs: Nonlinear suppression paradigm



Assumptions II

- irregularity in damping along papilla



- OAE is complex difference between ‘smooth’ and ‘rough’ conditions

Motion of the papilla:

$$m_p \ddot{y}_p = -k_p y_p - r_p \dot{y}_p + A(p_v - p_t) + \sum_n k_b^{(n)} (y_b^{(n)} - y_p)$$

Motion of an (*n*'th) individual bundle:

$$\ddot{y}_b^{(n)} = -{\omega_{b,o}^{(n)}}^2 \left[y_b^{(n)} - y_p \right] - \gamma_b^{(n)} \dot{y}_b^{(n)}$$

Sinusoidal steady-state:

$$y_b^{(n)}(t) = \mathbf{Y}_b^{(n)}(\omega)e^{i\omega t} \qquad\qquad y_p(t) = \mathbf{Y}_p(\omega)e^{i\omega t}$$

$$\mathbf{Y}_p k_b^{(n)} = \mathbf{Y}_b^{(n)} \left[-\omega^2 m_b^{(n)} + k_b^{(n)} + i\omega r_b^{(n)} \right]$$

$$\mathbf{Y}_p \left[-\omega^2 m_p + k_p + i\omega r_p + \sum_n k_b^{(n)} \right] = A(p_v - p_t) + \sum_n k_b^{(n)} \mathbf{Y}_b^{(n)}$$

Change of Variables (dimension-less):

$$\chi = x/L \qquad\qquad \beta_n = \omega/\omega_b^{(n)} = \omega/\omega_b(\chi_n)$$

$$\delta_o^{(n)} \equiv r_b^{(n)}/\sqrt{k_b^{(n)} m_b^{(n)}} = \frac{1}{Q}$$

$$\mathbf{Y}_b^{(n)} = \frac{\mathbf{Y}_p}{\left[1 - \beta_n^2 + i\beta_n \delta^{(n)}\right]}$$

Roughness:

$$\delta^{(n)} = \delta_o^{(n)} + \rho$$

(where ρ represents the irregularity)

Conservation of Mass:

$$\dot{\mathbf{Y}}_p A = U_{ow} \qquad \Longrightarrow \qquad \mathbf{Y}_p = \frac{U_{ow}}{i\omega A}$$

Impedance:

$$I_c \equiv \frac{p_v - p_t}{U_{ow}}$$

Impedance (smooth and rough conditions):

$$I_o(\chi,\omega) = \frac{-\beta^2 + i\beta\delta_o}{1 - \beta^2 + i\beta\delta_o} \qquad\qquad I(\chi,\omega) = \frac{-\beta^2 + i\beta\delta}{1 - \beta^2 + i\beta\delta}$$

Impedance (summing effect of all bundles):

$$Z_o(\omega) = \int I_o(\chi,\omega)d\chi \qquad Z(\omega) = \int I(\chi,\omega)d\chi$$

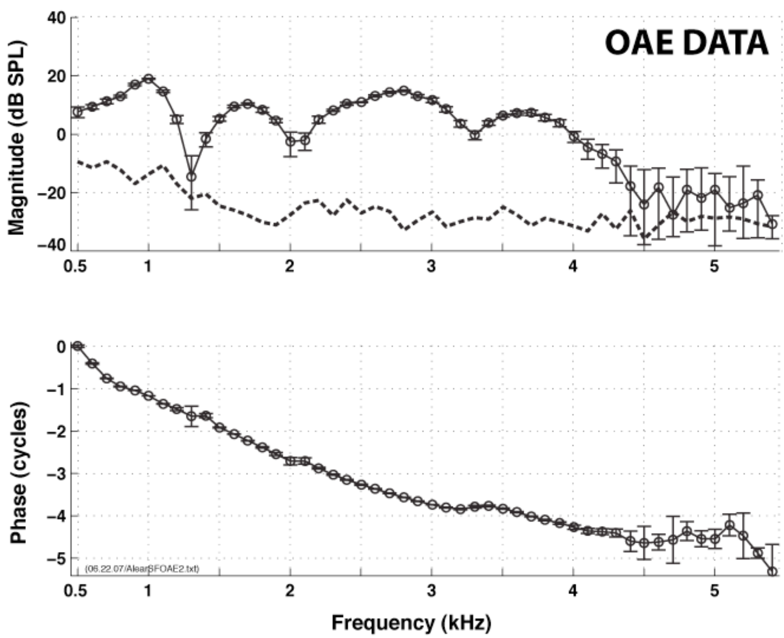
Finding the 'Emission':

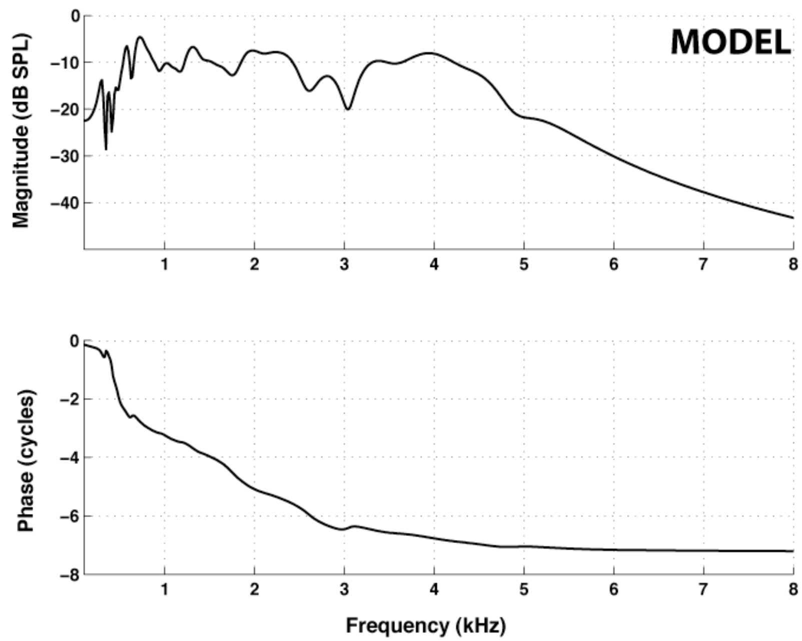
Complex Ratio: $z = Z/Z_o$

Reflectance:
(ignoring higher order terms)

$$\boxed{R(\omega) \equiv \frac{z-1}{z+1}}$$

<u>Comparison: Empirical Data and Model Results</u>



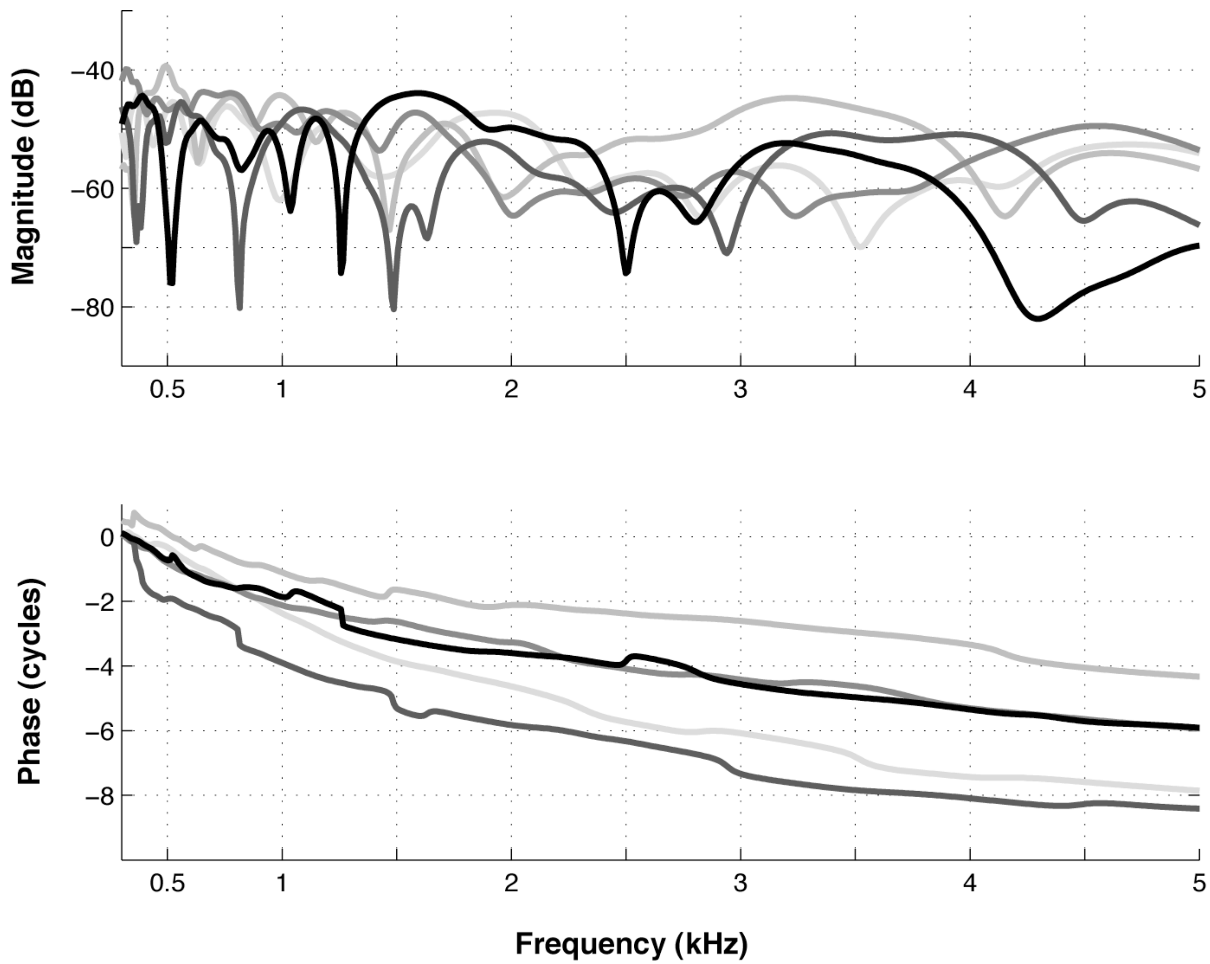


150 oscillators

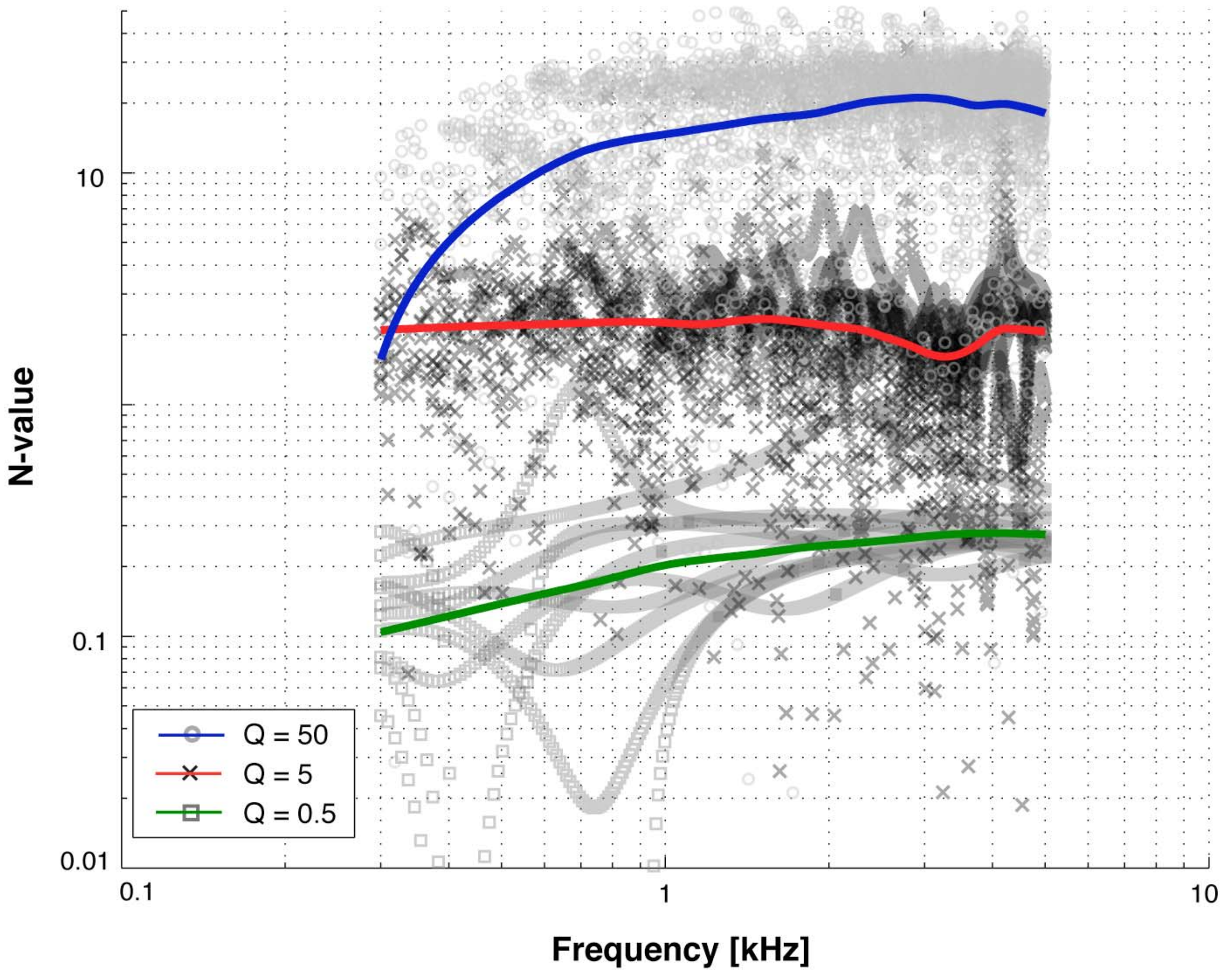
CF range 0.3-5 kHz

Q = 0.2 (uniform with frequency)

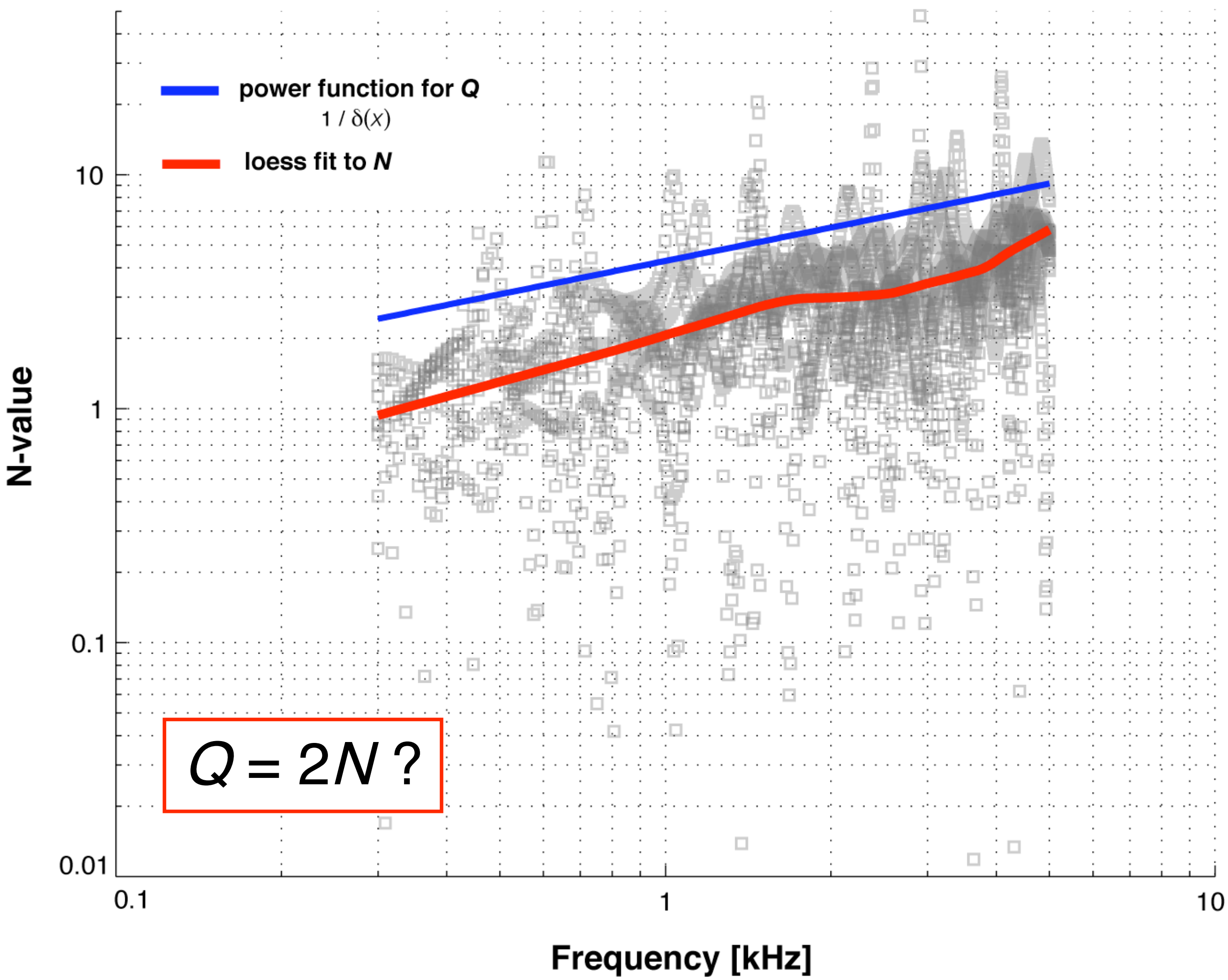
Different Irregularity Patterns ($\delta(x)$)



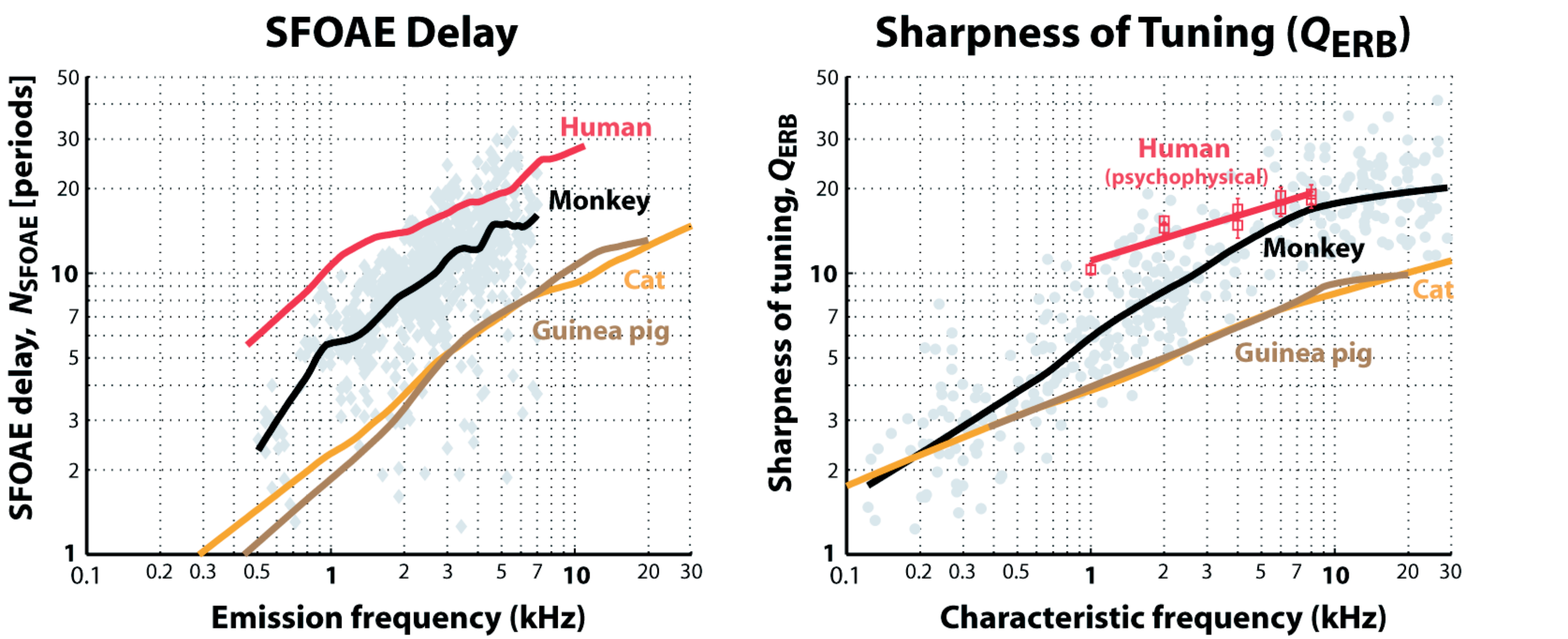
<u>N Increases with Q</u> (10 different 'ears')



<u>Let Q Vary with Frequency</u> (10 different 'ears')



Comparison of SFOAE Delays and ANF Tuning Across Species



Bergevin et al. (2008B)

Tip #2 (of 2)

The ubiquitous heavy-handed concluding summary should be omitted; a talk should tell such a good story that a summary is uncalled for. Imagine War and Peace ending with a summary. There is no better way to make an audience happy than briskly finishing a talk five minutes earlier than it expected you to. Like this.

the project was well under way. Those interested in such technical matters will ask you questions in private. For no matter how detailed you might be tempted to make your talk, it cannot possibly be detailed enough for those few who are knowledgeable enough to appreciate such refinements. And no matter how basic and elementary you make your treatment of those fascinating technical accomplishments, virtually none of them will penetrate the minds of the overwhelming majority of your audience. Your only goal must be to furnish ordinary physicists with some modest glimpse of what sustains your own interest in your subject.

What brings even well-intentioned efforts to grief is the misconception that it is necessary for speakers to talk about their own contributions. There is no need to say anything whatever about what you did yourself. Your personal work in the field qualifies you to give a talk only because it may have led you to discover how to break through the formidable barriers preventing the subject from engaging the interest of outsiders. If you can manage to do this *and* encompass a contribution or two of your own, that is fine. But if your own contributions are unfit for public display in such a forum, that too is fine, provided you do not persist in displaying them anyway. This should be kept in mind even when designing "job talks" or presentations at specialized conference sessions. Sometimes you have no choice but to speak of your own work, but even then it is best to devote the greater part of your talk to giving the clearest possible context for that contribution.

Never, ever, have I heard anybody complain about a talk on the grounds that "I understood everything in it." People feel good after talks they understand. Even those few people who hear nothing they didn't already know can derive substantial enjoyment from hearing their subject presented well. The most important thing your talk can do for such experts is to give them an opportunity to learn how to do better in their own talks.

Other points to keep in mind:

▷ Humanists, who take words more seriously than physicists do, often read their talks from a prepared text. When the talk is delivered with animation and impromptu asides, the results can be spectacular, for the written language is more powerful and concise than informal speech, and a richer and more attractive medium. Most physicists deem it undignified or unsporting to read a prepared text. Rubbish!

▷ The physics talk has, in any event, evolved toward the reading of a prepared text, but in an entirely unsatisfactory way. Many physicists do read their talks, not from a paper text, but from a sheet of transparent plastic projected on a screen. This combines the worst of both approaches: The spontaneity of improvisation is lost, but the elegance of writing is not achieved, since the verbal contents of the plastic sheet are fragmentary stammerings, not written language. To make things worse, text on plastic sheets can be read by an audience faster than the speaker can anticlimactically deliver it, unless the abominable practice is employed of covering up most of the plastic until the moment of revelation. Sheets of plastic must never be used to convey the purely verbal, which should be either spoken extempore or read aloud from a paper text.

▷ Sheets of plastic are only for illustrative figures, graphs or data, and unavoidable elementary mathematical analysis in the absence of a blackboard. Even when so used they almost always have too much on them. Many in your audience will have an unobstructed view of only the upper half of the screen, and many will be seated quite far from it. You must therefore put very little on each sheet, leave the lower half empty and make everything extremely large and uncluttered. If your analysis or diagram is too intricate to present in this way, it is too intricate to be in a talk at all. Just as one should go through a manuscript many times, ruthlessly cutting the redundant, so too should one keep redesigning a plastic sheet to reduce its contents to the bare minimum. You will be present when the sheet is on display. Most details are better supplied orally.

▷ We are fortunate to live in an age of informal dress. When giving a talk, wear whatever makes you comfortable, remembering only that a filthy or outlandish costume may be viewed by your audience as a sign of disrespect or incipient lunacy. Do not worry whether all your buttons are buttoned. Once you start down that perilous path you can wonder whether there is ketchup on your nose, a large chalky smudge on your back or a piece of stickum with a coarse message maliciously affixed to an inaccessible part of your person. Assume that if you are in disrepair somebody in your audience will have the kindness to call it discreetly to your attention, permitting you to fix the problem on the spot. If it's not called to your attention, it's not a problem. If it is, simply say, "Ah, mustard on my ear? Sorry about that," wipe it off and continue.

▷ On those few occasions when a physics talk delves into the history, sociology or social psychology of the subject, the audience wakes up and listens. Though most professional journals frown on such digressions, they are entirely appropriate in a lecture. Reading aloud from the reports of hostile referees, for example, almost invariably rouses an audience from its stupor as well as giving you a rare opportunity to make it vividly and painlessly aware of your own contributions.

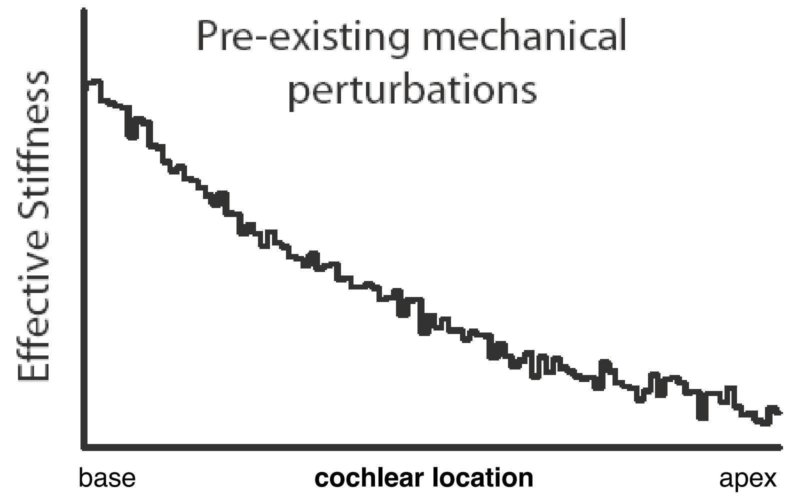
▷ The ubiquitous heavy-handed concluding summary should be omitted; a talk should tell such a good story that a summary is uncalled for. Imagine *War and Peace* ending with a summary. There is no better way to make an audience happy than briskly finishing a talk five minutes earlier than it expected you to. Like this. ■

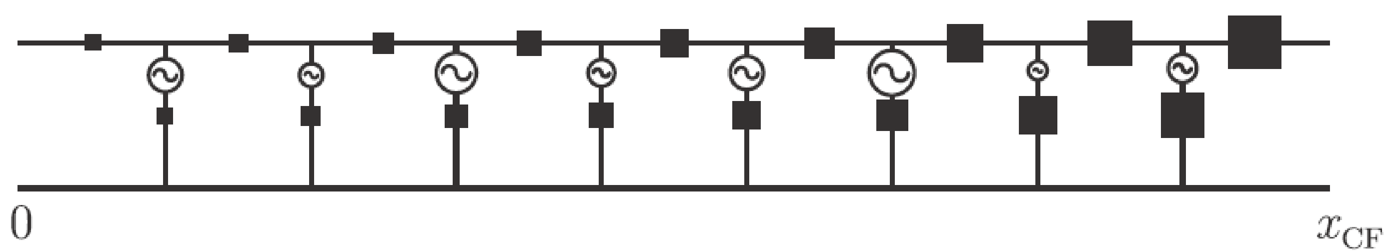
THEORETICAL PHYSICIST WITH POWERS OF ESP STEALING A THOUGHT EXPERIMENT FROM A COLLEAGUE

Fini

Current Models for Mammalian SFOAE Phase-Gradient Delays

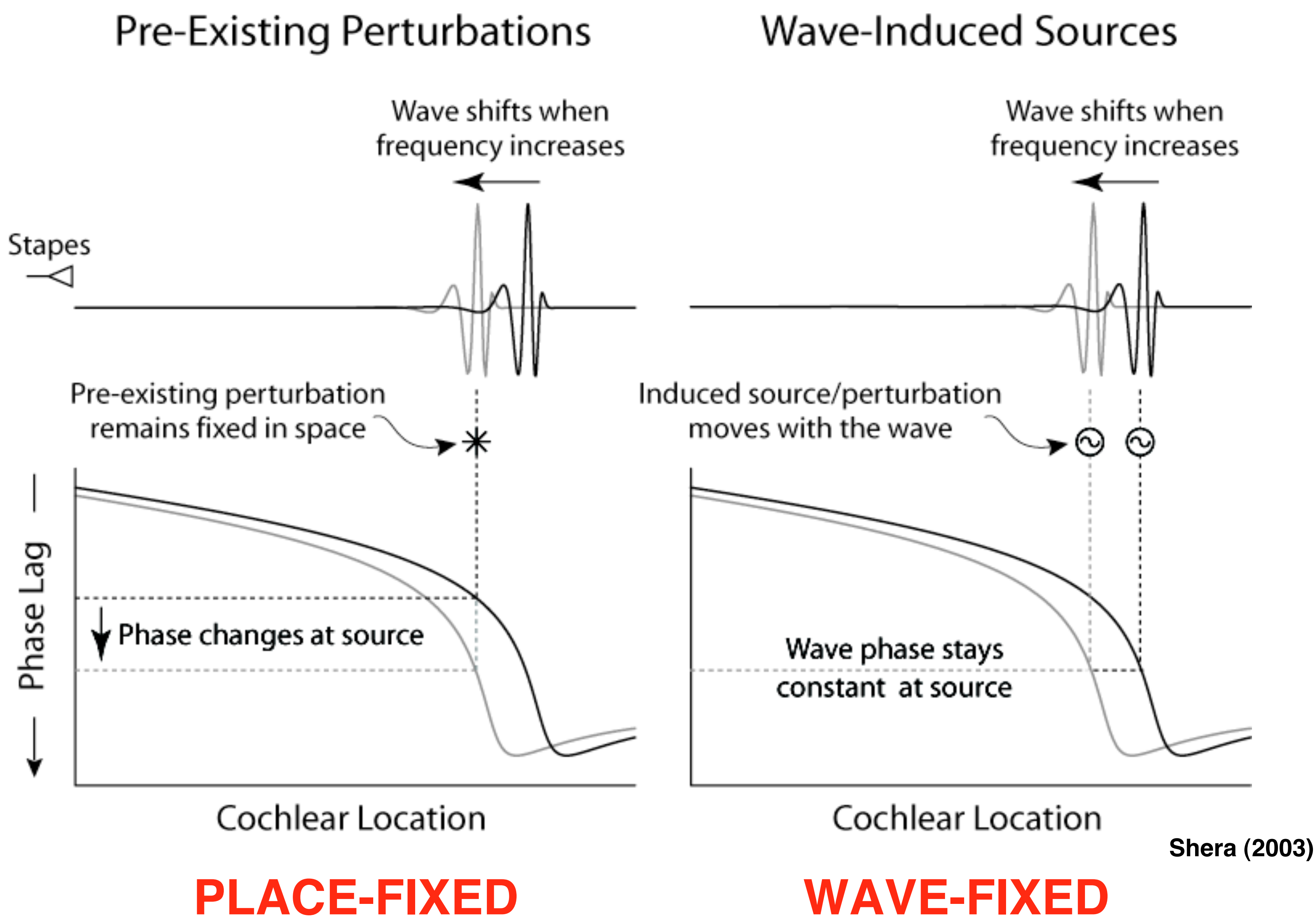
Reflection of energy?





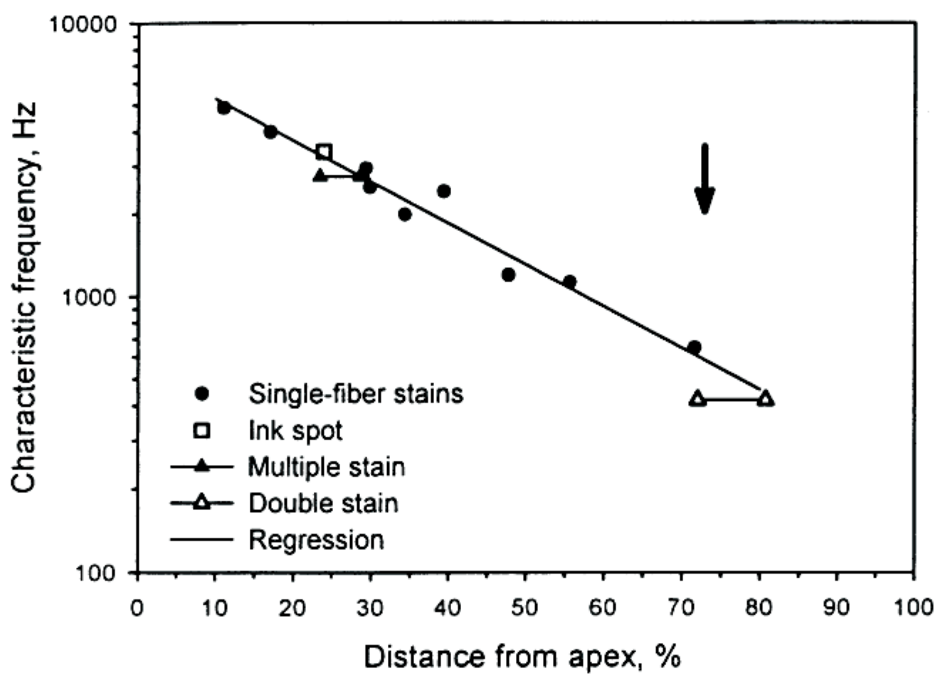
Transmission line with random irregular ‘sources’

Shera and Guinan (2007)



Pre-Existing Perturbations
Wave-Induced Sources
Wave shifts when frequency increases
Wave shifts when frequency increases
Stapes
Pre-existing perturbation remains fixed in space
Induced source/perturbation moves with the wave
Phase Lag
Phase changes at source
Wave phase stays constant at source
Cochlear Location
Cochlear Location
Shera (2003)
PLACE-FIXED
WAVE-FIXED

Tokay Gecko Auditory Nerve Fiber Responses



Manley et al. (1999)