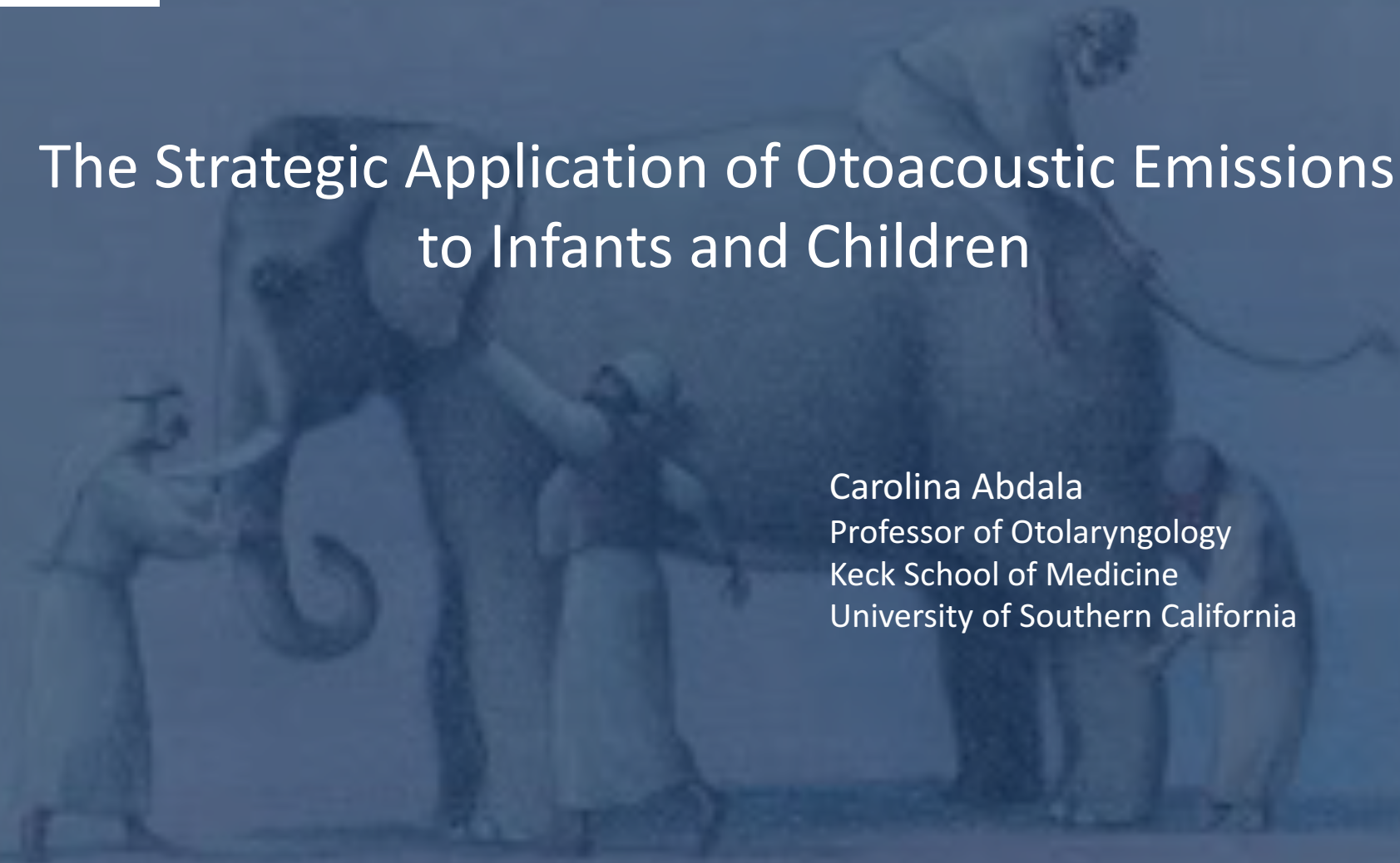


# The Strategic Application of Otoacoustic Emissions to Infants and Children

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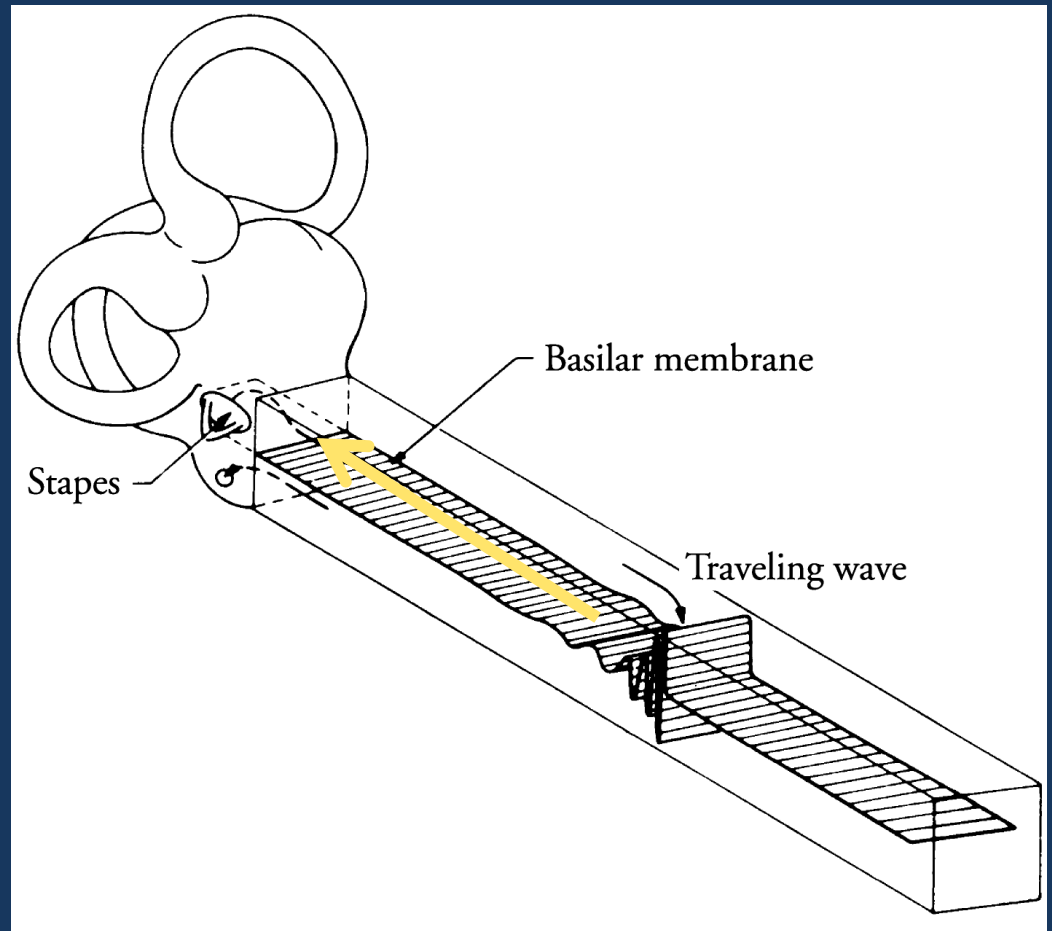
A little background...

# What are otoacoustic emissions?

Low-level sounds produced in the cochlea as a by-product of normal cochlear mechanics and transduction

OAEs travel in reverse from their site of origin in the cochlea back into the ear canal and our microphone

OAEs require normal (or near normal) outer hair cells – OHCs power the “cochlear amplifier”



When first discovered, we thought all OAEs were alike and they could be used interchangeably.

OAEs are not all alike! (Shera & Guinan, 1999)

They arise through at least two distinct processes in the cochlea:  
reflection & distortion

Reflection and distortion OAEs are sensitive to different cochlear properties, just as the behavioral audiogram is different from the ABR in its sensitivity to hearing loss.

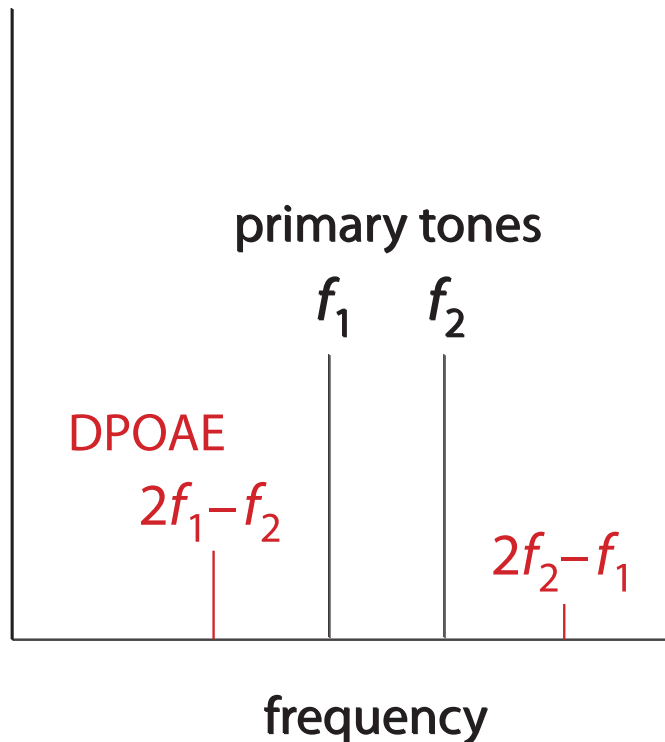
**Distortion** is generated by two simultaneously presented pure tones at the overlap of traveling waves produced by these tones.

Distortion product OAEs gauge cochlear nonlinearity.

DPOAE

$$2f_1 - f_2$$

Level (dB SPL)

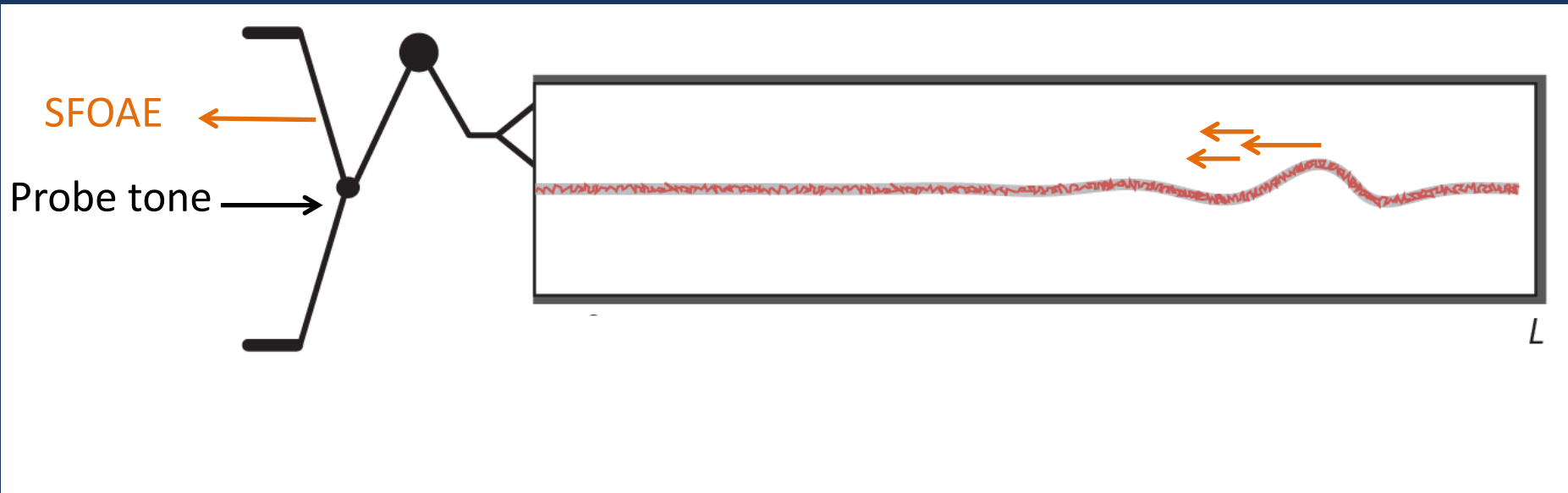


*Nonlinearity can manifest in various ways. The healthy cochlea creates combination tones (like DPOAEs) which is one example of nonlinearity.*

apex

$f_2$   $f_1$

Reflection emissions require natural biological irregularity or “roughness”



Energy from a stimulus is backscattered as the traveling wave encounters roughness along the cochlear spiral - like swells in the ocean that run into a pier piling and reflect backwards.

# *Taxonomy for Evoked OAEs*

*Two basic types*

Distortion-type OAEs



DPOAE

Reflection-type OAEs



Transient or Click-evoked OAE (TEOAE)

Stimulus-frequency OAE (SFOAE)  
(one single pure tone)

*\*DPOAEs are a mixed emission and include a reflection part too*

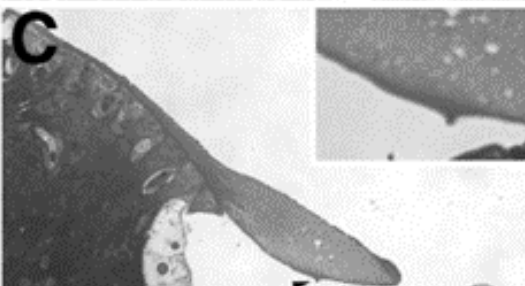
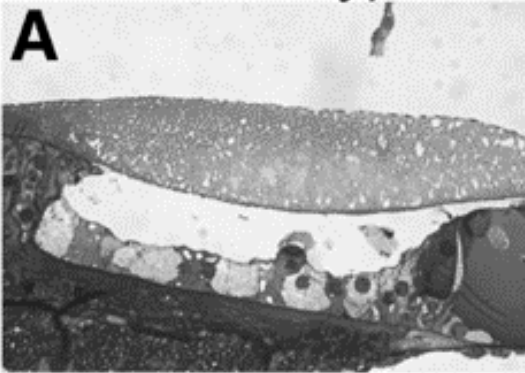
## Reflection and distortion OAEs can be independently affected

- Both the **medial efferent reflex** and **salicylates (aspirin)** produce a stronger effect on reflection compared to distortion OAEs.
- **Development** impacts each OAE differently: distortion OAE phase is NOT adult-like in newborns; reflection OAE phase is adult-like (when middle ear effects are considered)
- **Aging** reduces distortion emissions more than reflection OAEs.



- **Gene mutations** producing very specific damage can independently alter distortion and reflection OAEs.

Wild type

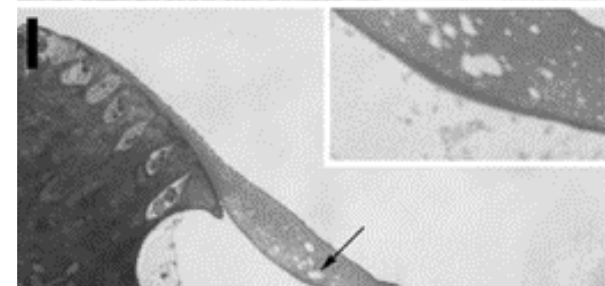
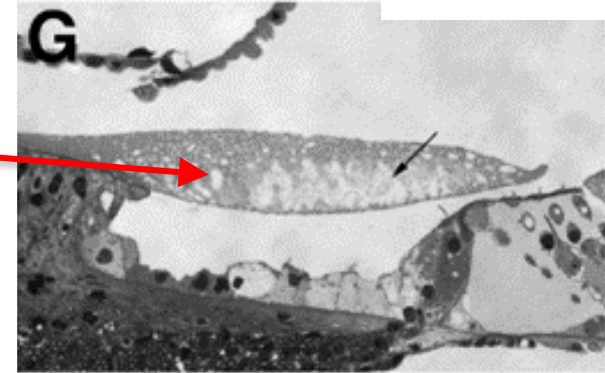


The Ceacam16 mouse has holes in its tectorial membrane.

Hearing is impaired as a result

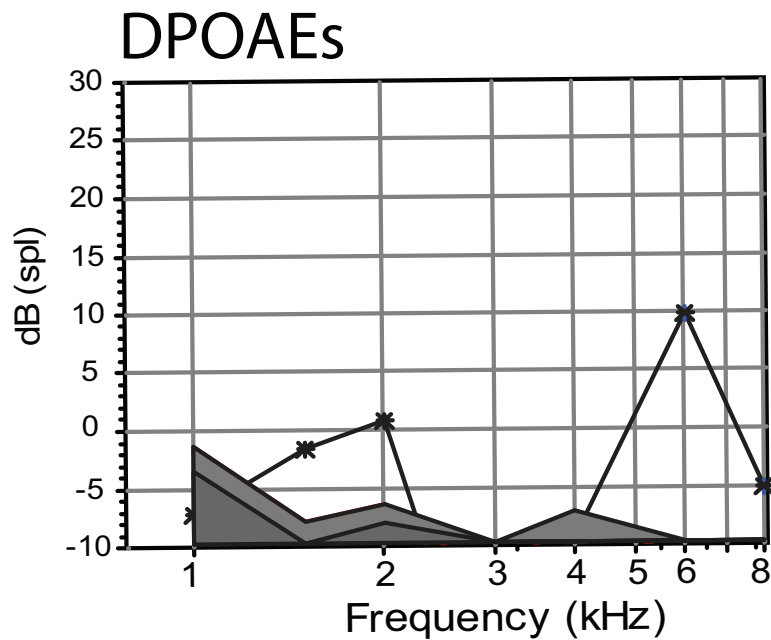
SFOAEs (reflection) are abnormally large in this mutation while DPOAEs are normal.

Ceacam<sup>-/-</sup>

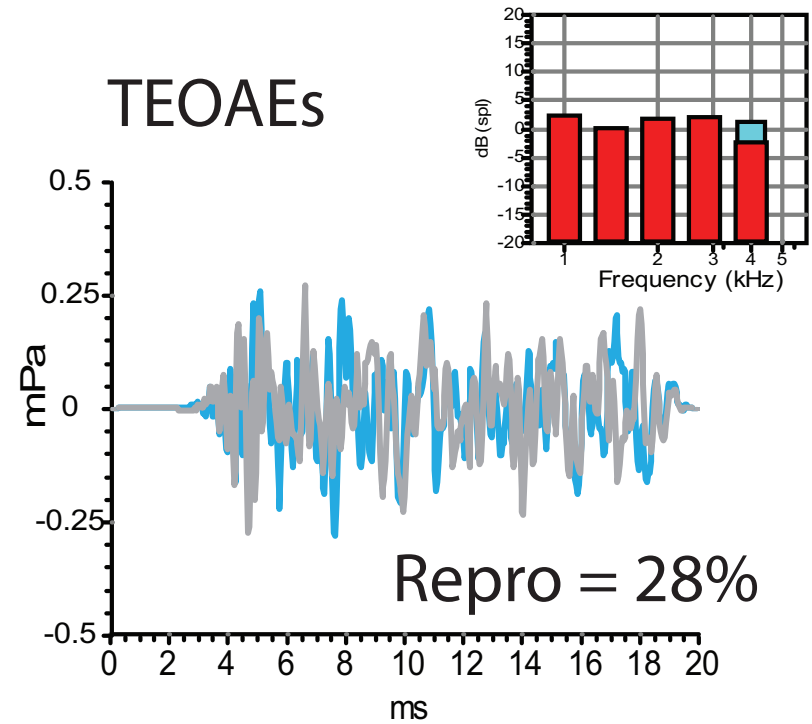


- Slight-mild hearing loss impacts TEOAEs (reflection) more than DPOAEs

A



B



*Why record only one OAE if we can learn about different aspects of hearing from each?*

More than a decade ago we did not understand why we would want to do both ABR and OAEs to test hearing. Yet without this combination, we would not have come to recognize auditory neuropathy (ANSD).

The field *shaped* the test battery for ANSD based on diagnostic tests required for its detection.

# Strategic Application of OAEs



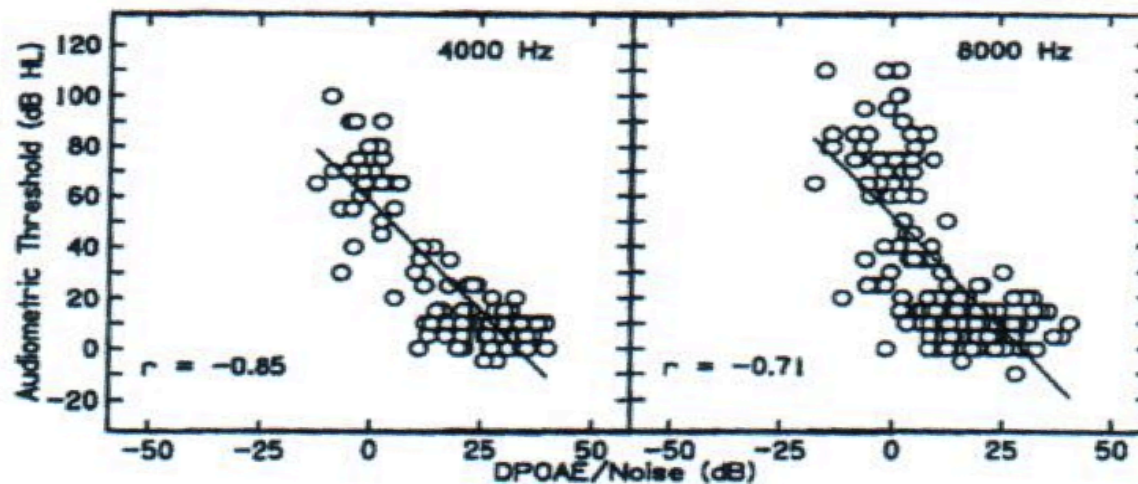
# Typical default OAE Protocol

*Goal: To **detect** hearing loss*

- One or the other OAE is measured –DPOAE or TEOAE—but not both.
- One fixed stimulus level is presented (typically the equipment default): 65-55 or 60-50 dB SPL primary tones for DPOAEs; and 82-86 dB pSPL clicks for TEOAEs.
- OAE is measured at a few frequencies only, e.g., 2, 4 and 8 kHz for DPOAEs and maybe 2-4 or 5kHz for TEOAEs
- The OAE is judged as either present or absent based on a SNR criterion

These default levels and frequencies have been found to be most effective and diagnostic in separating normal-hearing from hearing-impaired ears

When a narrow range of optimal stimulus parameters are used, OAEs have a nearly 90% hit rate for detecting hearing loss if it is beyond approximately 40 dB HL.



Gorga et al., 1993

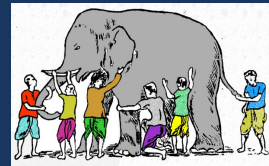
Several large-scale studies with clinical populations have shown the clear link between OAEs and hearing loss (Gorga et al., 1993ab, 1996, 1997, 1999, 2000)

# Strategic Application of OAEs

*What do I mean by “strategic”?*

- When the goal is *not* just detecting hearing loss but learning about the total deficit (i.e., elephant)
- When you venture outside of the limited role OAEs play
- When you move beyond the default parameters the equipment has “suggested” for you
- When your awareness of how OAEs are generated can influence the test session if needed

# Three suggestions to use OAEs strategically



## #1 - Consider recording both TEOAEs and DPOAEs.

### Why? (theoretical reasons):

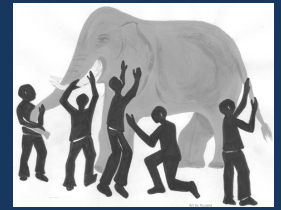
- TEOAEs and DPOAEs are not identical markers of the same cochlear processes.

*Reflection emissions come from the peak of the traveling wave (which is the most sensitive, tuned part) so they are sensitive to slight-mild SNHL.*

*Distortion emissions (DPOAEs) are indicators of cochlear nonlinearity which is a hallmark of the healthy ear.*



## *Why record both ? (Practical Reason #1):*



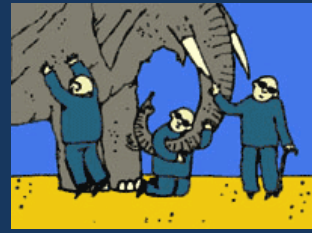
Genetic manipulations in mouse have led to the discovery of mutations presenting atypical auditory profiles (like the mouse with holes in its tectorial membrane. Ceacam16; and the stereocilin-deficient mouse).

*Many of these deafness genes have been identified in human families!*

Without a comprehensive approach to OAES, we will miss undefined forms of hearing loss and simply group it with all other SNHL.

...Just like we did with auditory neuropathy for decades.

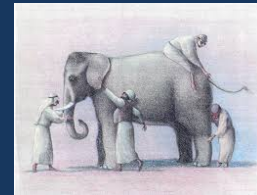
## *Why record both?* (Practical reason #2)



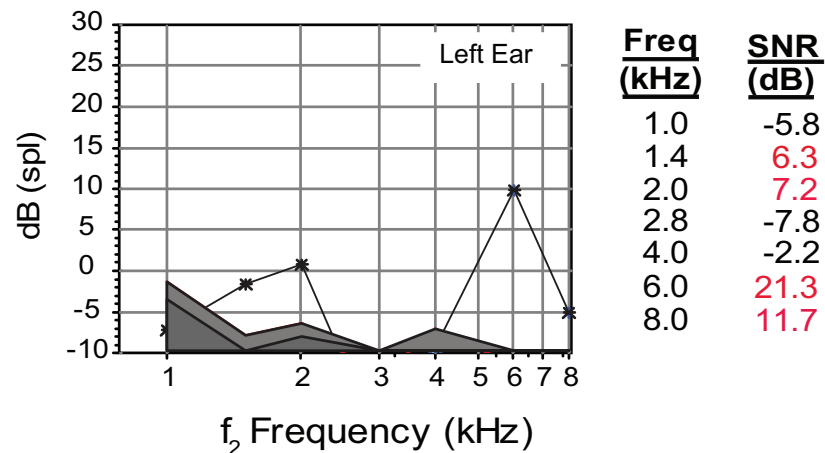
Because an absent TEOAE by itself is non-discriminating and can indicate anything from a mild to profound SNHL.

An absent TEOAE with a present DPOAE is not normal (normal ears have both types) – it is likely to indicate mild-moderate SNHL and effectively rules out a profound SNHL. *Deaf ears do not generate DPOAEs.*

Present DPOAE (though not normal: low in amplitude and present at only 4/7 frequencies). *Do you send this child along his way? Re-evaluate in a year?*



Standard DP-gram: 65-55 dB SPL



Absent TEOAE (more sensitive to slight HL) confirms abnormal hearing. Present DPOAE suggests it is on the mild side.

Suggestion #2 - If DPOAEs at default primary tone levels (65-50 dB SPL) are absent, use higher stimulus levels.



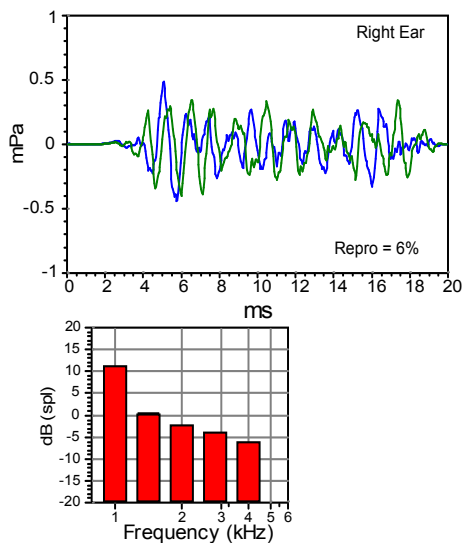
*Why?*

Even if TEOAEs are absent (because they are so sensitive to slight-mild loss) an ear can generate distortion. Give yourself every chance to measure present DPOAEs if they are there!

This combination of findings (absent TEOAE and present DPOAE) is valuable because it gives a clue to the degree of hearing loss: mild not profound.



## TEOAE



## Absent TEOAE

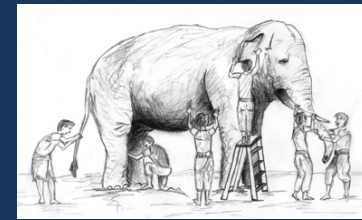
Absent DPOAE using default primary tone levels

Present DPOAE at low-mid frequencies when higher-level primary tones are used.

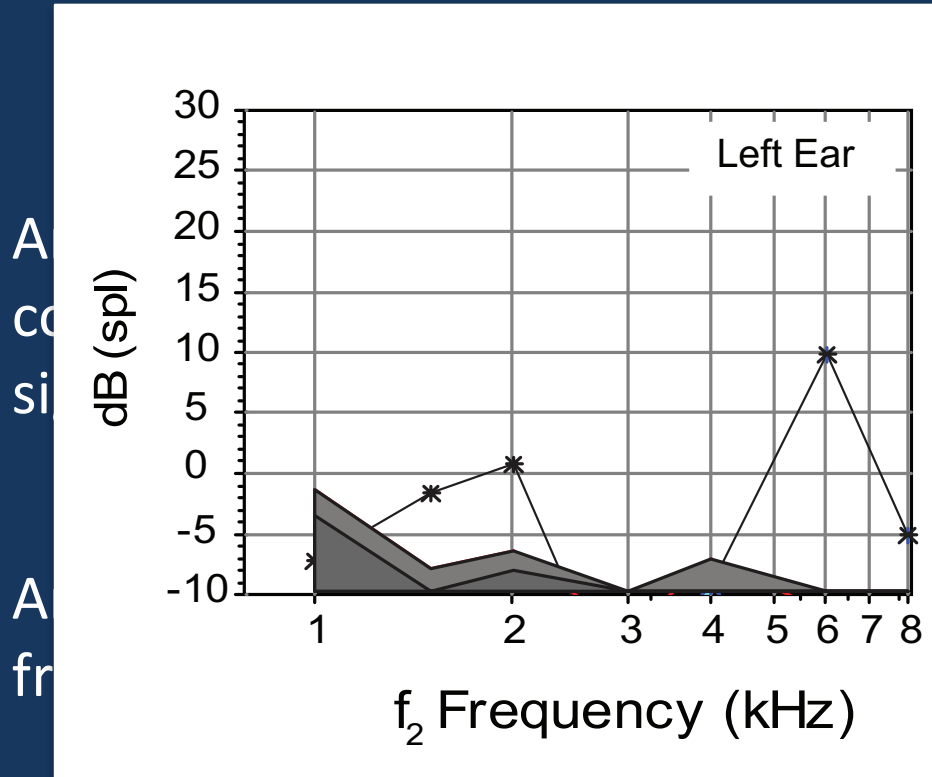
NOTE: ABR confirmed normal tone-pip thresholds at 500 and 1000 Hz and mod-severe SNHL at high frequencies.

# Suggestion #3 - Move beyond absent/present

Ask yourself whether an OAE is *normal*.



Why?



If you are satisfied with a low-amplitude emission, designating the OAE as absent or present, there is a greater chance of missing mild hearing losses only in limited segments of the signal a non-flat audiogram.

# On the Horizon: Be Aware

Sweeping Tones in the clinic

Unmixing of the DPOAE

The Stimulus-Frequency emission (SFOAE) in the clinic

The use of OAE Phase and delay in the clinic

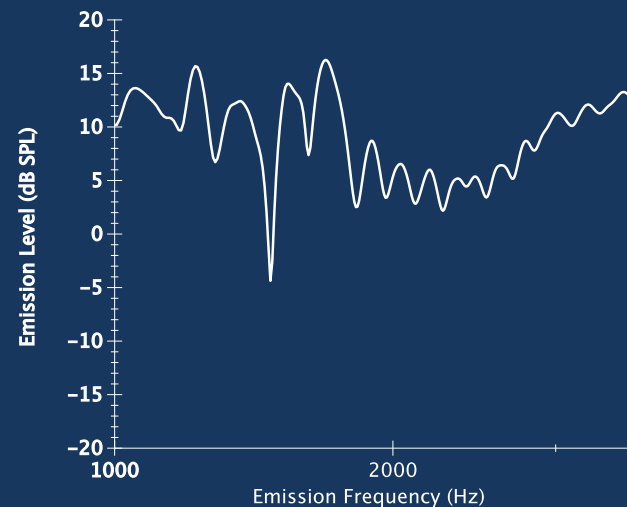
## Recording OAEs with sweeping tones



Sweeping tones make it feasible to quickly measure both SFOAEs and DPOAEs in the same ear.

They save time by smoothly sweeping the stimulus across frequency rather than presenting individual tones or tone-pairs.

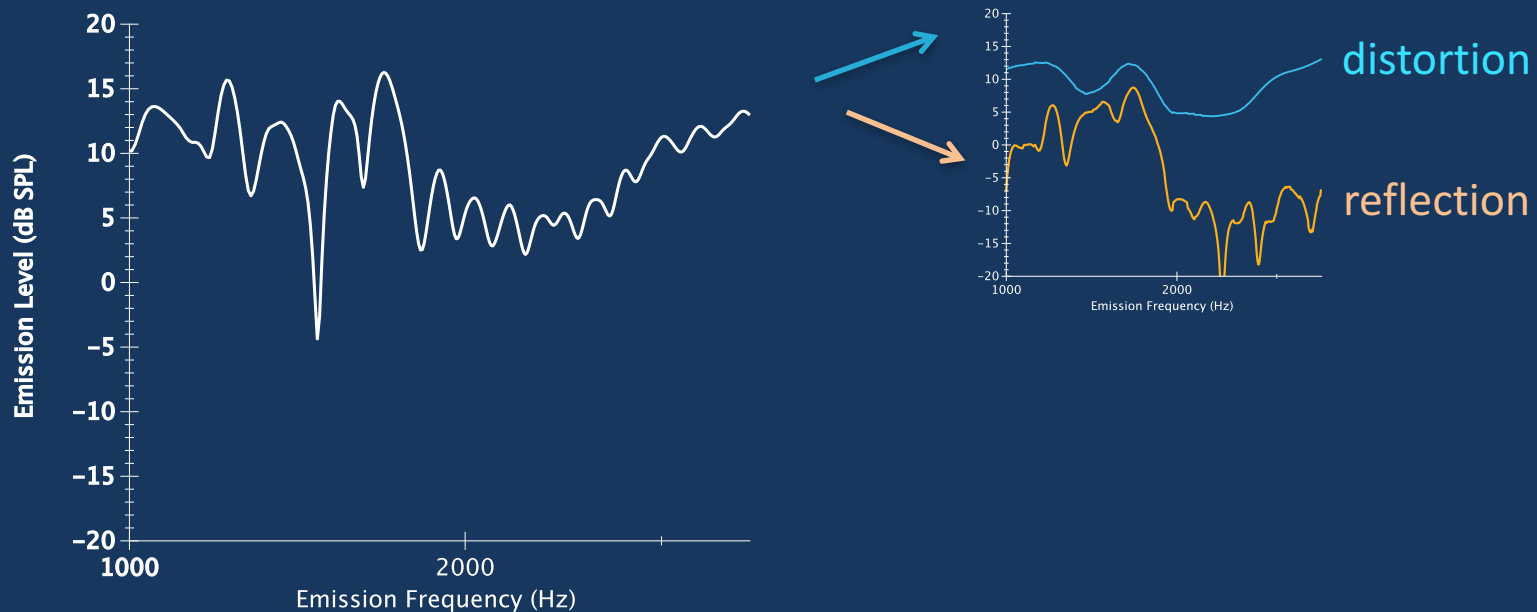
The resulting OAEs are the same as those collected with conventional stimuli but provide much higher resolution.





## *Unmixing the mixed-up DPOAE*

DPOAEs are a mixed emission composed of reflection and distortion components. Signal processing can 'unmix' or separate the DPOAE into its constitutive parts: reflection and distortion.



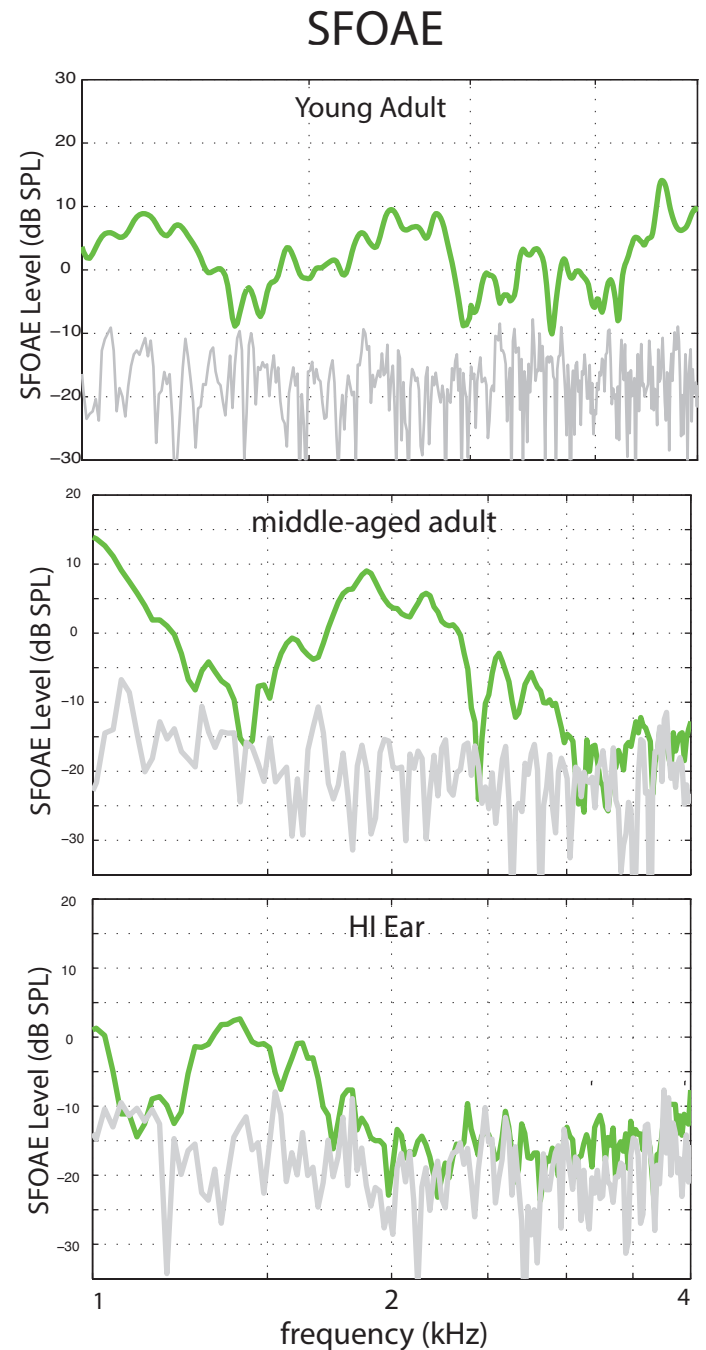
The potential for extracting both types of information with one measure would be helpful in the context of Suggestion #1.

# Stimulus-frequency OAEs

Reflection emissions can also be evoked by single pure tones: SFOAEs.

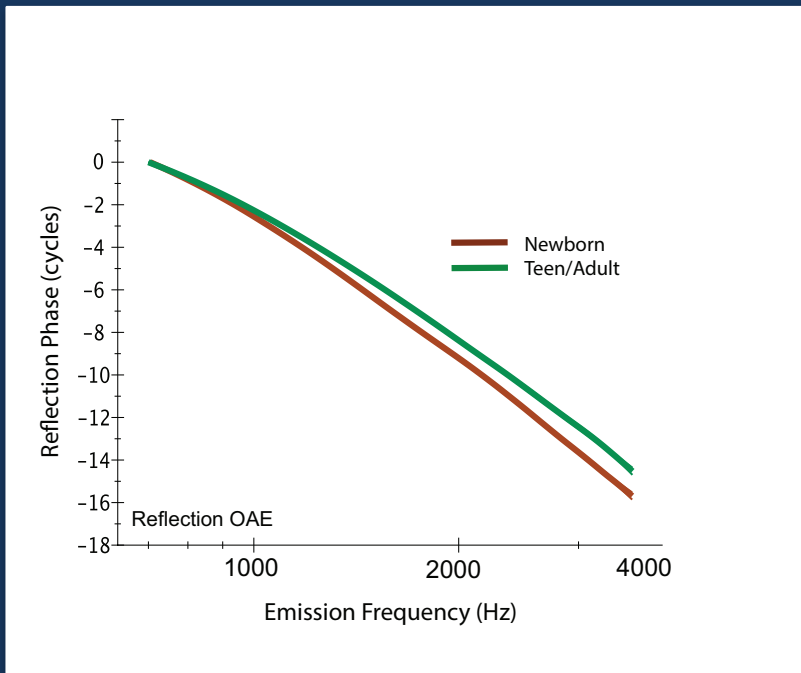
They eliminate problems with click stimulus artifact and can be measured at higher frequencies.

SFOAEs are linked to cochlear tuning - it might one day offer a new tool for assessment of frequency tuning.



## Using OAE phase and delays

Research has shown that one can infer the sharpness of tuning from SFOAE delay; Some deafness mutations produce abnormally sharp cochlear tuning; these might be identified with the SFOAE.



DPOAE phase is also being studied to detect dangerous build-ups of intra-cranial pressure.

Certain SNHLs might show aberrations in OAE phase that are not present in amplitude.

## Conclusions

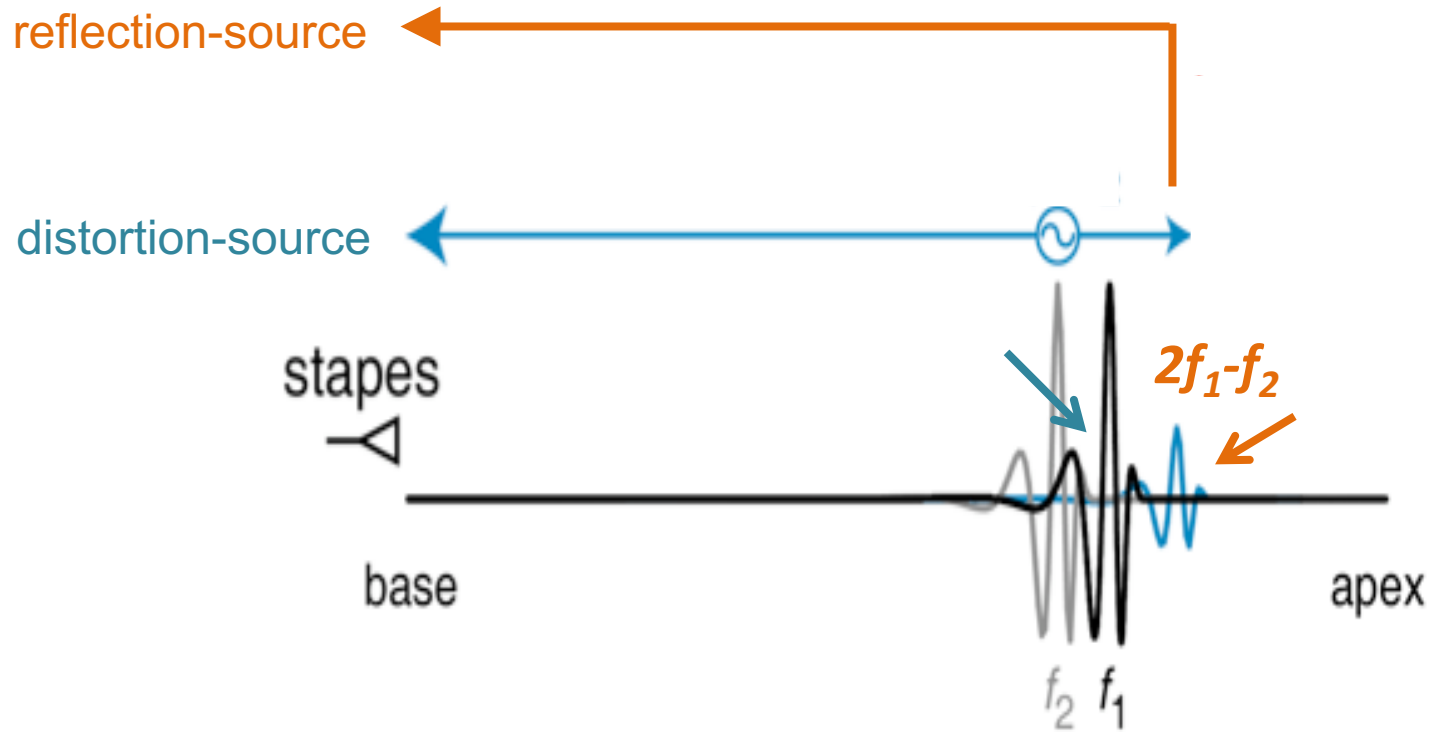
*Hearing loss is a puzzle in the pediatric population; and audiologists use the tools at their disposal to put together the puzzle; that is, to understand the whole elephant.*

*Be strategic! Reflection and distortion OAEs are two informative tools to detect and learn about hearing loss in infants and children.*



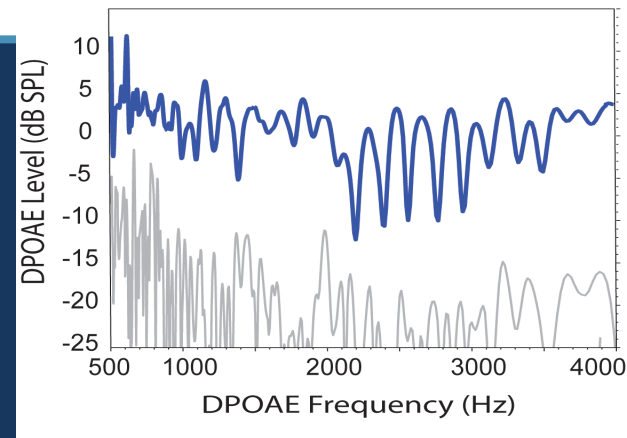


# The mixed-up DPOAE



Distortion between the two primary tones

Reflection at the  $2f_1 - f_2$  site



*Considering the bits of information gathered from all OAE sources to understand the big picture of hearing loss.*

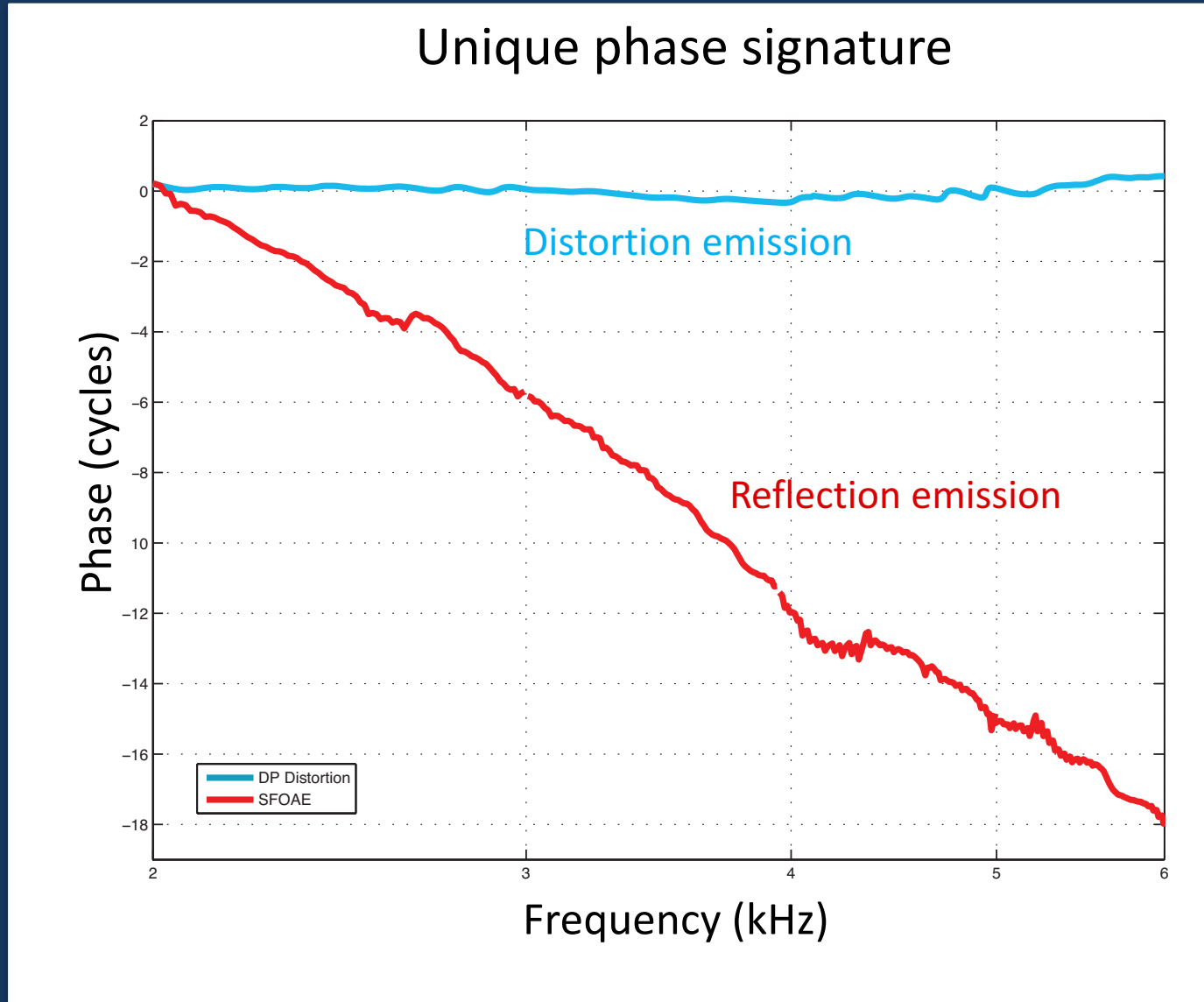




The two types of OAEs –**reflection** and **distortion**— really provide different and unique information about the cochlea and hearing, like an audiogram and the ABR provide different views of hearing and hearing loss.

Further Evidence: Can reflection & distortion OAEs change independently or do they always change in tandem?

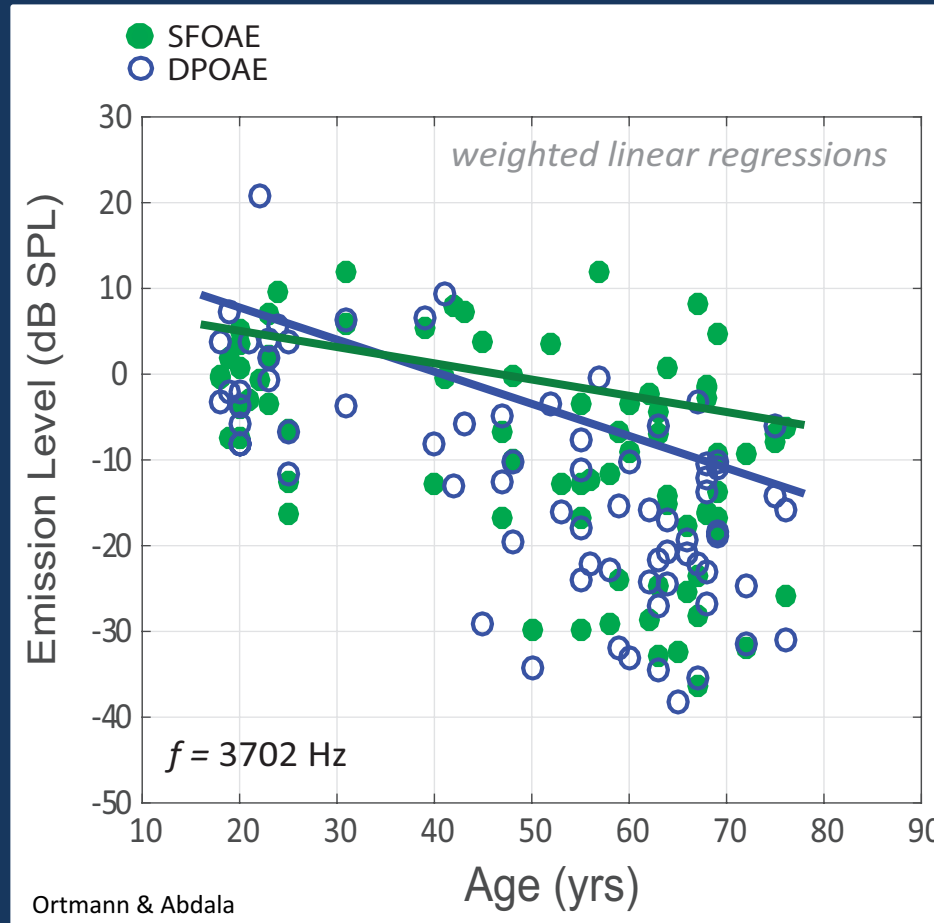
We know the two OAEs arise in the cochlea through distinct processes because they show grossly distinct *phase* behavior across frequency.



*Improving the detection of slight and mild hearing loss appears to be a realistic goal for OAEs if we are strategic*

- Do both TEOAEs and DPOAEs if necessary to distinguish between a HL that is mild vs. severe-profound: An absent TEOAE and present DPOAE often suggest mild HL (Note: elicit the DPOAE with higher primary tone levels if necessary).
- Go beyond absent/present distinctions to catch OAEs that are present (i.e., have sufficient SNR) but have low amplitude (for patient age). This finding suggests mild hearing loss.

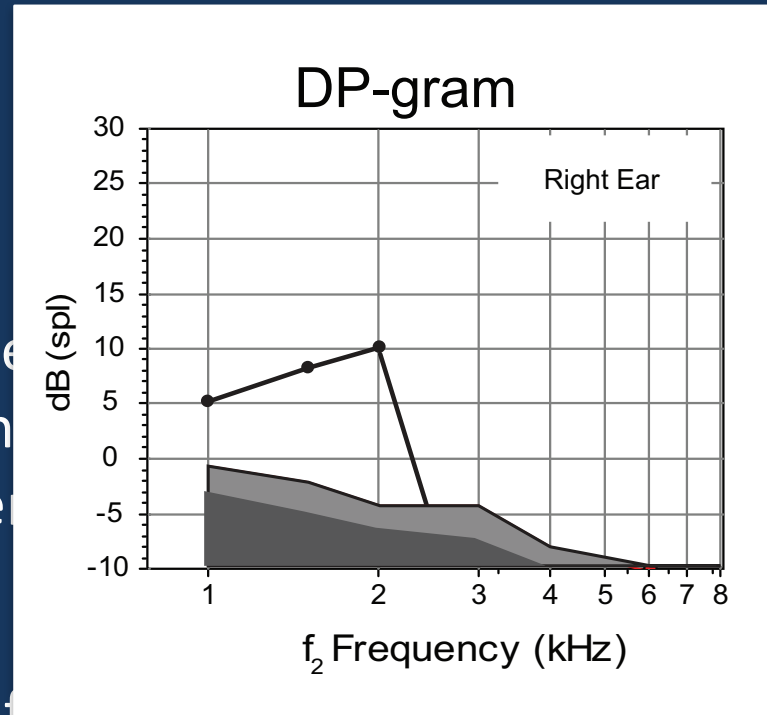
# DPOAE level decreases more rapidly with aging than SFOAE (reflection OAE) level



## Suggestion #3: Test across a broad frequency range.

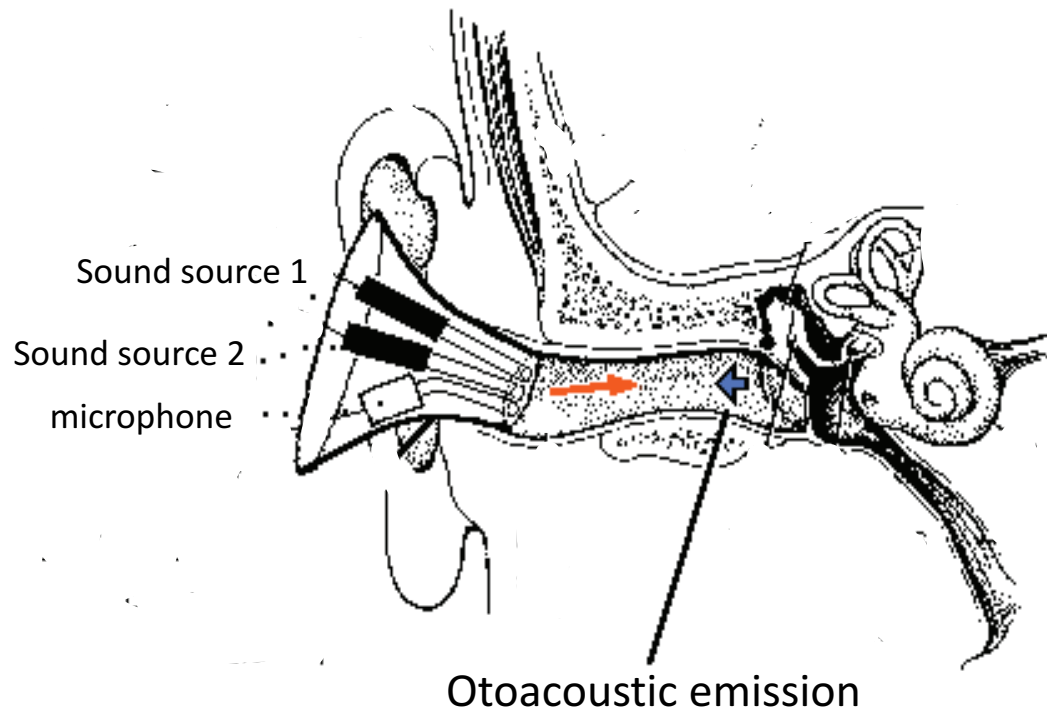
*Why?*

Diagnostic TEOAE test  
recording epoch, and  
test only 2-3 frequen



mode restrict the  
screening DP-grams

Hints as to the configuration of the hearing loss, if present, will be derived from recording as broad a frequency range as possible.



To record OAEs, one needs a sound source and a microphone (along with an amplifier, a filter and signal processing).

## The Cochlear Amplifier

Although they arise from two different mechanisms in the cochlea, the two emission types share a common dependence on outer hair cells, the mechano-transducer sensory cells that respond to sound vibration by moving. OHCs provide amplification and sharp tuning to the healthy cochlea

OHCs form the core of the *Cochlear Amplifier*.

Why do linear reflection OAEs (which only require biological roughness) need OHCs?

Because both OAEs produce tiny backward traveling waves that need to be amplified for us to record them in the ear canal.

Therefore, when the cochlear amplifier is weak or dysfunction (i.e., SNHL), OAEs are no longer measureable.

# What do distortion and reflection OAEs measure?

**Distortion OAEs** - Likely originate in the nonlinear opening and closing of the gating channels on the OHC stereocilia. *Distortion OAEs are especially sensitive to cochlear nonlinearity.*

*Strongest at moderate-high levels*

**Reflection OAEs** - Back-scattering action comes mostly from the peak of the traveling wave, which happens to be where the cochlear amplifier is most active. *As such, reflection OAEs are especially sensitive to loss of gain and frequency tuning.*

*Strongest at low stimulus levels*



*If we want to record both types of emission, why not just use the DPOAE since it is “mixed” and includes both types within it (good question)?*

Un-mixing the DPOAE is not that simple just yet (though labs do it all the time); it renders a small, somewhat confounded reflection emission.

To record both emission types, it is best to record two separate emissions: SFOAEs/TEOAEs and DPOAEs.

# NOTE: TEOAEs must be recorded in the nonlinear mode

- TEOAEs are reflection OAEs so they arise by a linear back-scattering process (they do not technically arise due to nonlinearity like distortion)
- When we record TEOAEs in **nonlinear mode**, it eliminates the artifact induced by the stimulus, which can be mistakenly considered response. It does this by eliminating linear response from the cochlea (This strategy was developed because we used to think that all OAEs came about by cochlear nonlinearities).
- So, even our common reflection emission – the TEOAE- is diminished by the need to rid it of stimulus artifact.