(almost) Everything I know about hearing loss

Mead C. Killion,

CAA 2015 Conference, Niagra

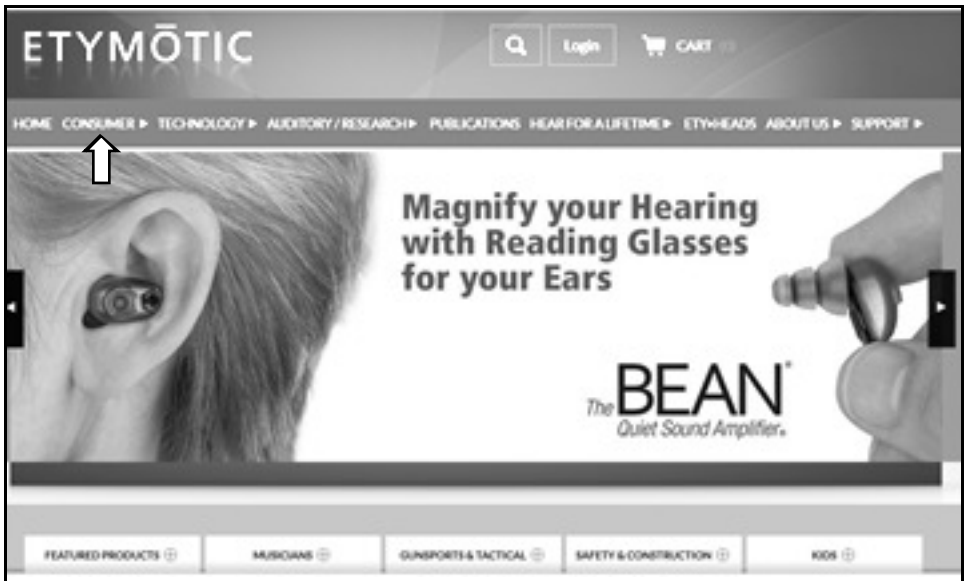
Part 2

1. **Typical loss among musicians and normal people**
2. **Hear for a Lifetime (how to)**
3. **Supra Threshold Hearing Loss**
   a. Diplacusis,
   b. SNR loss and the Magic Formula

Before I forget –

The etymotic.com website contains a wealth of information. More than 100 scientific reprints (including my 1979 PhD thesis), research tools, and products to help prevent hearing and help people who have lost some (the Etymotic Research mission in life).

The next screen capture examples honestly happened by chance to be the flash screen showing our Quiet Sound Amplifier the BEAN®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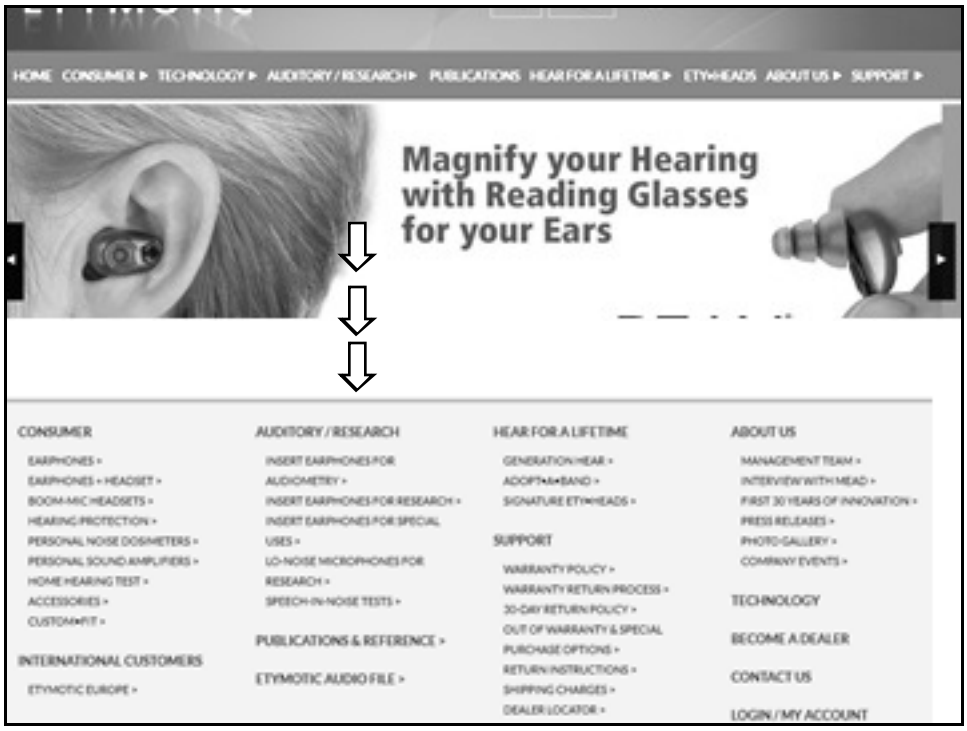
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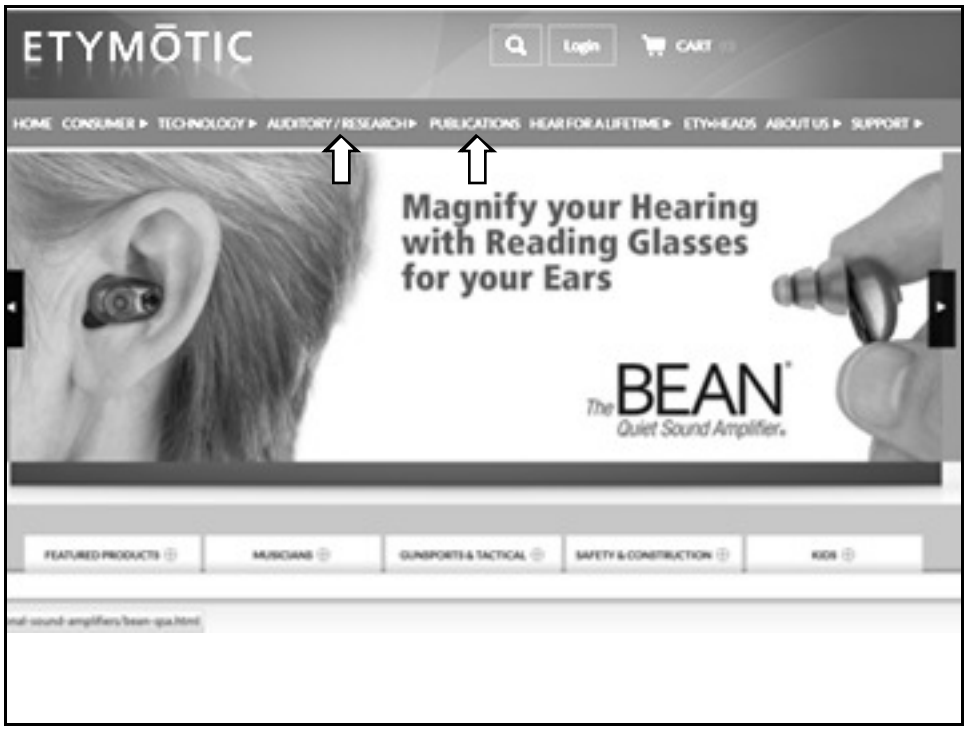
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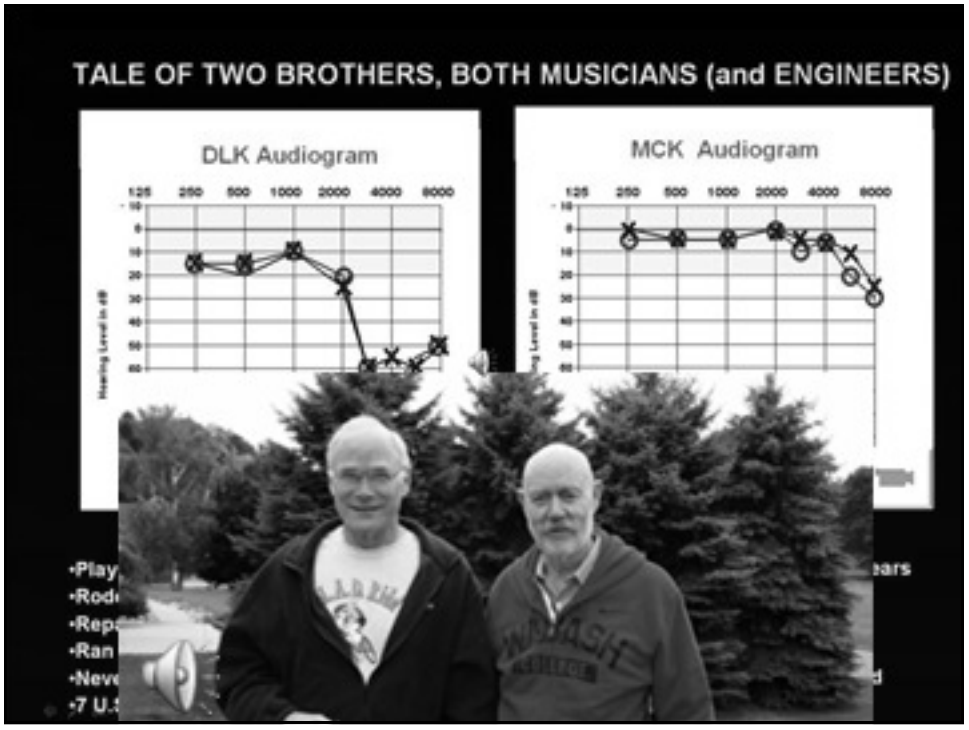

TALE OF TWO BROTHERS, BOTH MUSICIANS (and ENGINEERS)
DLK Audiogram
MCK Audiogram
125 250 500 1000 2000 4000 8000

The best paper title of this century (so far):

"Age Related Hearing Loss: Evidence of a Misspent Youth"

Kujawa and Liberman (2006)

Permanent hearing loss can happen in a very short time.

- **Drummer for New Orleans band: Two hours to a complete loss of hearing**

- **Tossing firecrackers in cars years ago in Nashville**

More commonly, hearing loss accumulates over time, as with my brother

Pete Townshend: "The real reason that I haven't performed for a long time is ... I've shot my hearing."

Ted Nugent: "Pete Townshend has good hearing compared with me. My left ear is there just to balance my face, because it doesn't work at all."

Ears ring, then they stop. Years later, ears ring but don't stop

Beginning, ➔ 2:03-2:26 3:34-4:19

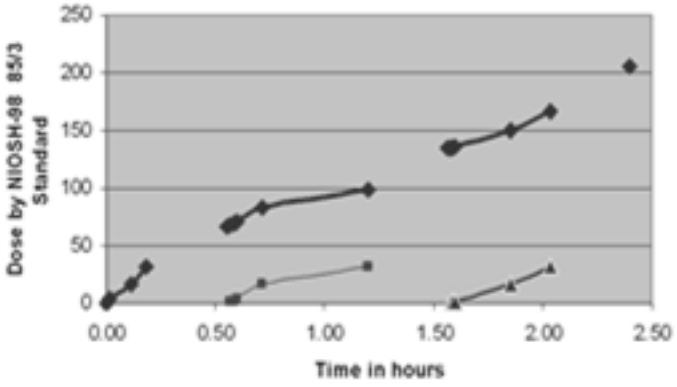
Etymotic Research personal noise dosimeter

- Blinks green at 25% of allowable exposure
- Blinks green at 50% of allowable exposure
- Blinks red at 100% exposure: You should put in earplugs or leave the Blues Bar!

It blinked red after the first 30 seconds of a recent Paul McCartney concert!

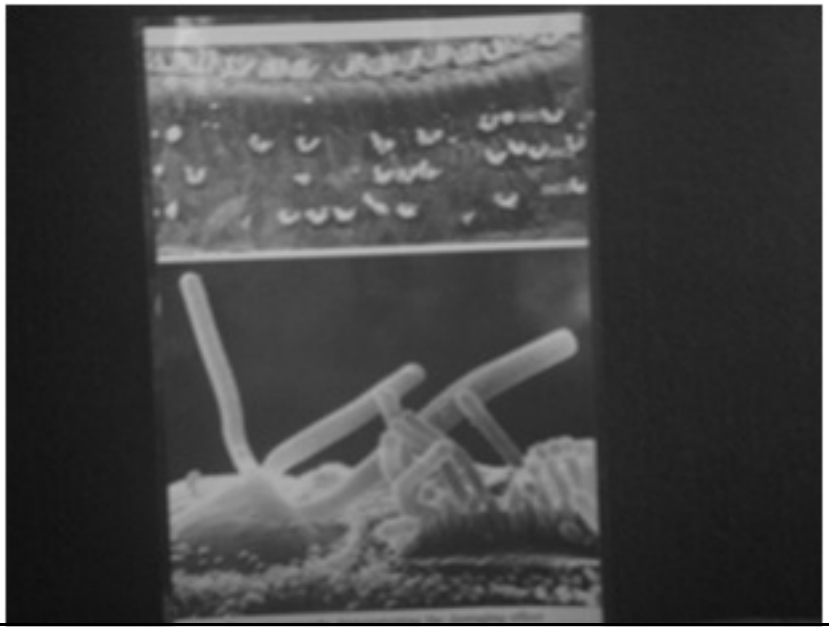
We sat in 3rd row seats at a Paul McCartney concert in Chicago Cubs Wrigley Field. We took earplugs, sound level meter, and an ER-200D data logging dosimeter.

The levels varied between 110 and 120 dBA for most of 2.4 hours, ending with 9 cannons firing off at goodness knows what SPL.



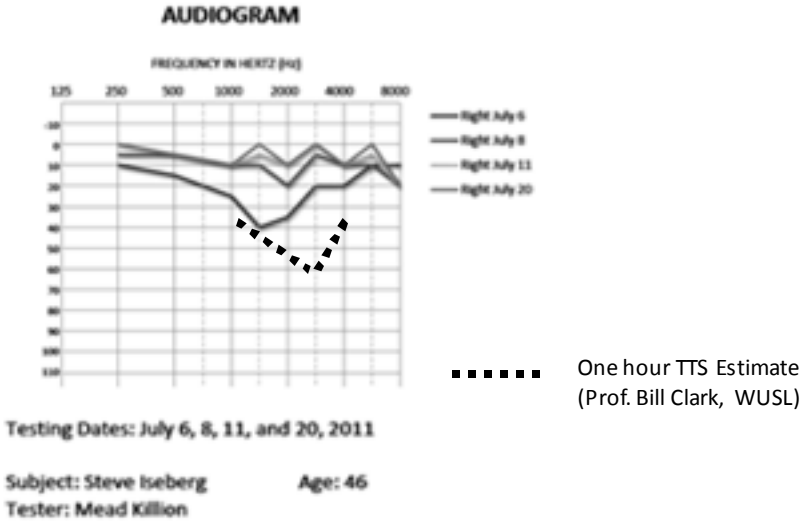
At 210X allowable dose per concert, three Paul McCartney concerts ➔ 1 DB PTS, 30 concerts ➔ 10 dB PTS at 4 kHz

What happens to the tiny "hair cells" in the inner ear when they are exposed to those sound levels?



Steve Iseberg, Project Leader on the ERO-SCAN and the new 10X OAE research probe for the Navy,

went to a U2 concert but forgot his earplugs.



Most musicians gradually lose hearing over many years.

The President of Vandercook College of Music recently sent me a copy of a MS thesis of one of their students.

"Noise Doses of Five High School Band Directors in Northeast Illinois" Hayes (2010)

Average daily music dose ranged from **3.4X to 20X allowable dose**, predicting 25-40 dB PTS over 30 years ***if they had median susceptibility.***

Average Daily Dosimeter Readings for Five Chicago Area High School Band Directors : 4, 7, 11, 14 and 20 X NIOSH-97

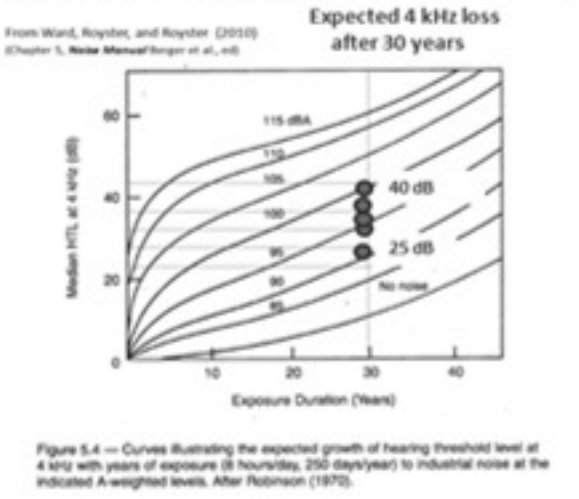
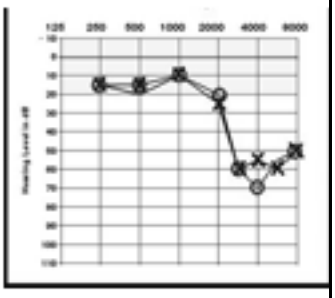
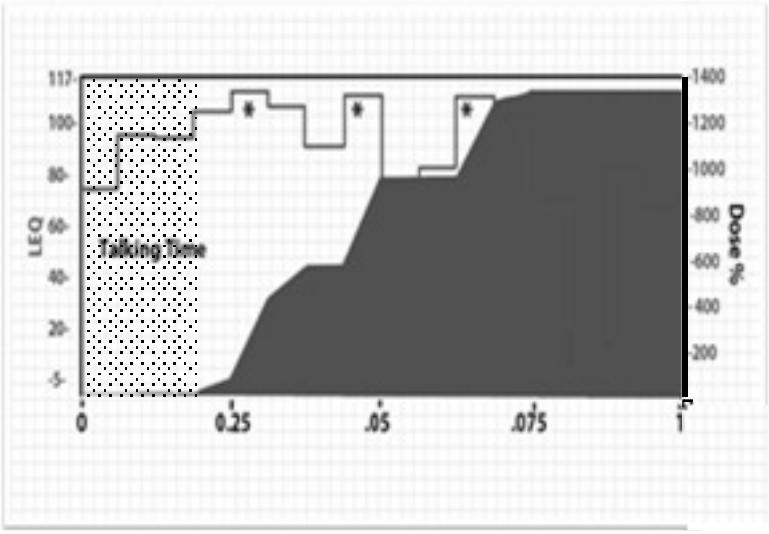


Figure 5.4 — Curves illustrating the expected growth of hearing threshold level at 4 kHz with years of exposure (8 hours/day, 250 days/year) to industrial noise at the indicated A-weighted levels. After Robinson (1970).



➔ **In 12 years standing at the Etymotic Research booth at the Midwest Clinic, I have met only two band directors past the age of forty who did not have a significant hearing loss.** Virtuoso CM 70 dB –like my brother

One Hour with a Drummer Rehearsing



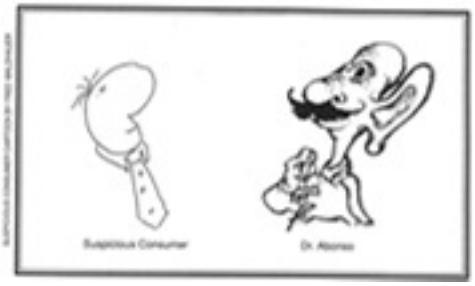
Hoffman Estates H.S. Drumline

Keeps a lot tighter

Speaking of virtuoso trumpet players, Charlie Geyer, then professor of music at Northwestern University, was 4th trumpet in the Chicago Symphony Orchestra for 12 years – sitting right next to the percussion section.

He told me (with permission to tell his story):

"It happens so slowly that you don't notice it is happening until one day you discover you can't carry on a conversation with the telephone on your right ear."

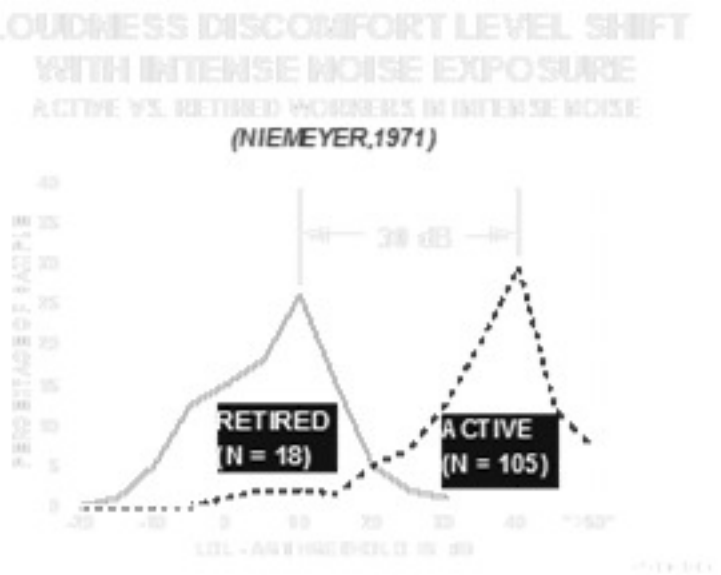


Q: Don't my ***ears*** tell me when it is too loud??

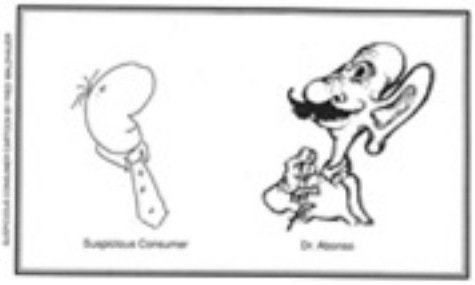
A: Yes indeed – for the ***first few times*** loud sounds will be very uncomfortable.

Q: Then what happens to my safety warning signal?

A: It becomes muted. There was a famous study of German factory workers in the 1970s



Foreman Sherman Williams Factory

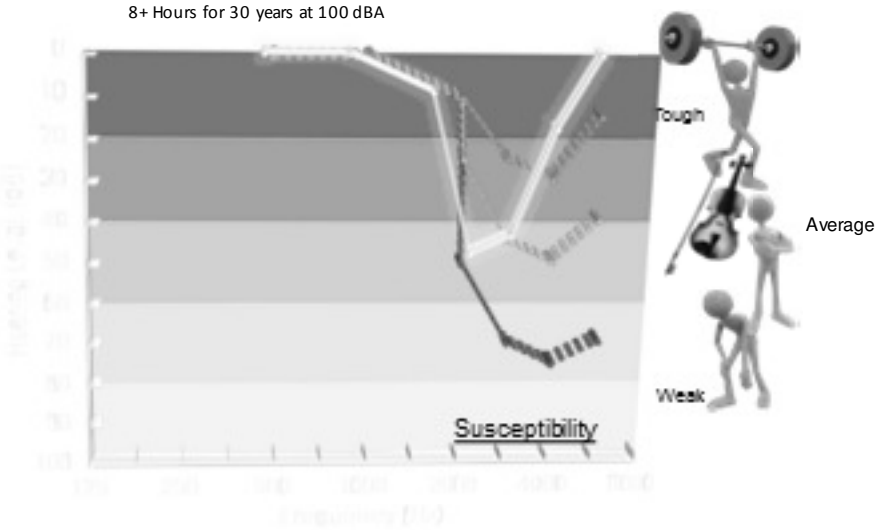


Q: Aren't you being an alarmist? I know some musicians that have been around ***really loud*** sounds for many years and they still hear pretty well. What do you say about that?

A: The best answer came from the shipbuilders in WWII, down inside steel reverberation chambers pounding and scraping. Some came out after 30 years with profound hearing loss, others still had good hearing.

How Tough Are Your Ears?

Exposure Impacts People Differently



Ruben Gonzales LE

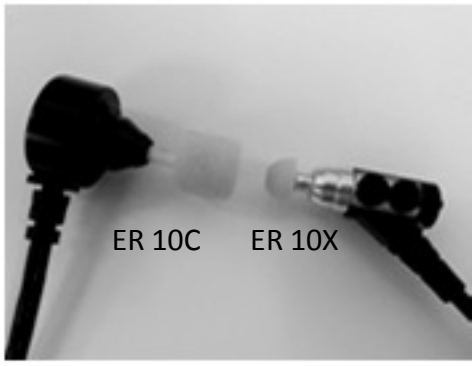
Q: How can I tell how tough ***my*** ears are?

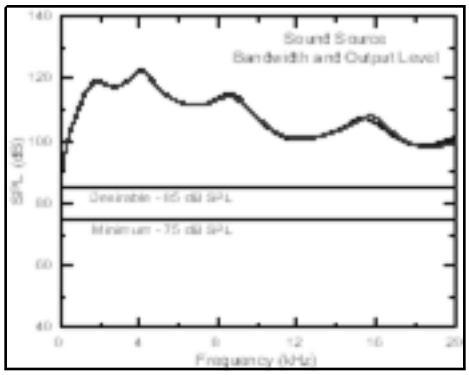
A: You can't. **The only safe thing to do is <u>assume they are highly susceptible</u> to hearing damage.**

After nearly 100 years of scientific investigation, we still don't know how to predict which sailors can safely work on the deck of an aircraft carrier (with earplugs, of course) and which sailors should stay down below.

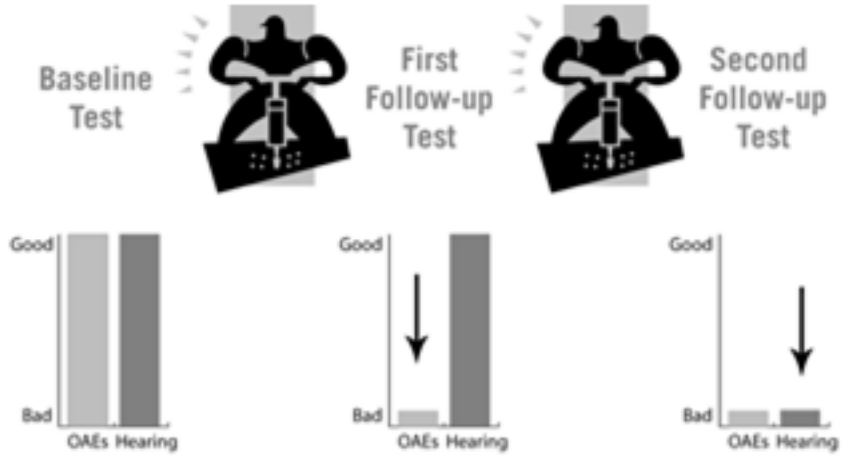
Q: Is there any hope for finding out in the future?

A: Yes. Etymotic Research and Northwestern University are part of a Navy-sponsored team investigating the use of OAEs to give an early warning that you are heading toward permanent hearing loss even though you still have normal hearing thresholds.





Preliminary results published by the Navy's Lynne Marshall (2011) suggest that a drop in the level of the "Tartini Tone" (OAEs) occurs well before hearing loss is apparent. (Like the canary in the mines.) She made a wonderfully simple graph that shows the idea.

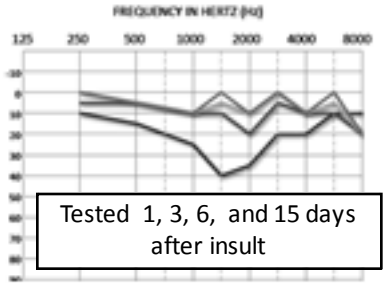


Anecdotal (One Jazz Pianist): OAES dropping wi normal thresholds, after 20 years playing, asking abut HAs

But preparing for this talk, I realized there *already is* a way to know today and forever that you are saving your ears:

1. **Avoid exposures that cause ringing in your ears (tinnitus) and**
2. **Avoid exposures that cause temporary threshold shift.**

Remember our engineer whose sequence of audiograms we showed? Even without a " before" audiogram, we see he had a serious TTS, even though the first post-insult test was almost 24 hours later.



Tested 1, 3, 6, and 15 days after insult

This won't protect you from an explosion, but most noise- or music-induced hearing loss occurs slowly over 30 years. You can protect against that!

Most people can keep their hearing into their 70s and 80s by protecting their hearing. Kujawa & Liberman

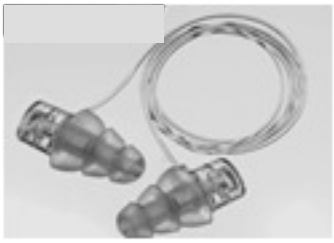
Our message for musicians: "Play Safer Longer"

Our Adopt-A-Band program has several national drum corps whose members' ears are now safer:
Cavaliers, RhythmX Phantom Regiment
DCI (Drum Corps International)
has endorsed Etymotic's ER-20 Earplugs

A REPEAT:
Our message for musicians: "Play Safer Longer"

- Use of 20 dB earplugs will extend your safe playing time by a factor of 100
- From 1 minute to 100 minutes, for example

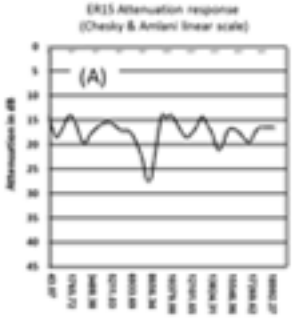
ER-20

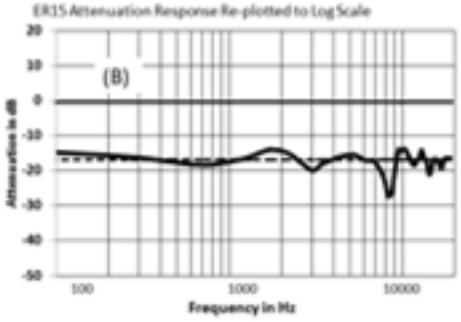


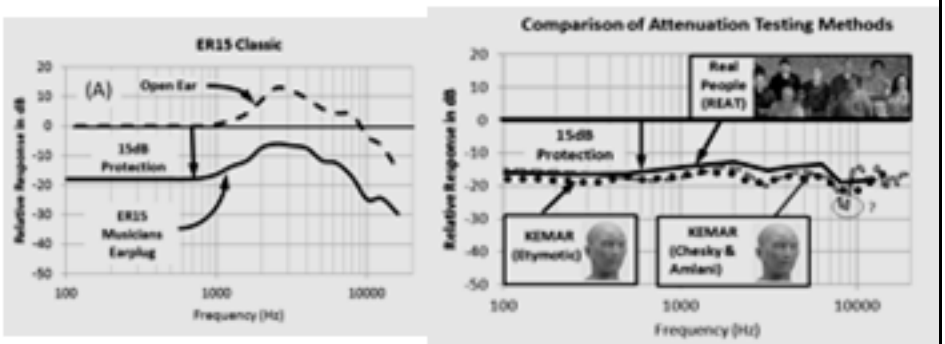
ER-20XS

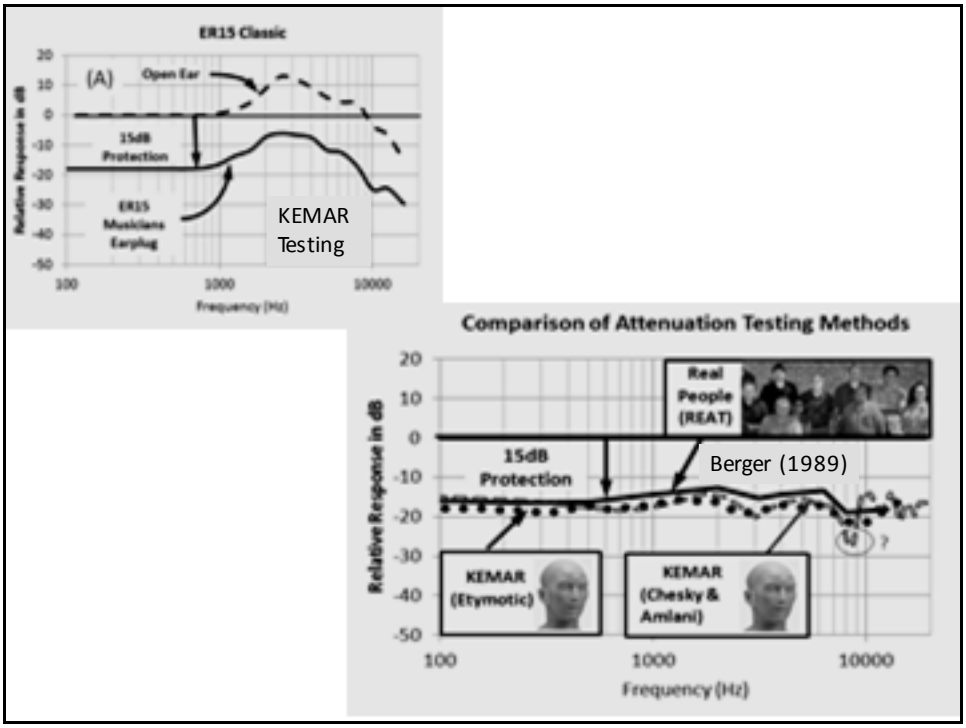
An uncomfortable topic: Claims that Etymotic's earplugs don't work as stated, and are not high fidelity at all.

Chesky and Amlani (2014) state that: "*...the claims used to market [Musicians Earplugs] to musicians and music schools are misleading and the discrepancies for claiming attenuation characteristics in response to musical stimuli are related, in part, to the use of the REAT testing procedure.*"






ER15 Classic
(A)
Open Ear
15dB Protection
ER15 Musicians Earplug
Relative Response in dB
Frequency (Hz)
Comparison of Attenuation Testing Methods
Real People (REAT)
15dB Protection
KEMAR (Etymotic)
KEMAR (Chesky & Amlani)
Relative Response in dB
Frequency (Hz)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Berger (1989)
KEMAR (Etymotic)
KEMAR (Chesky & Amlani)
Relative Response in dB
Frequency (Hz)

Original Design

New Design "The Bean"

Music•PRO

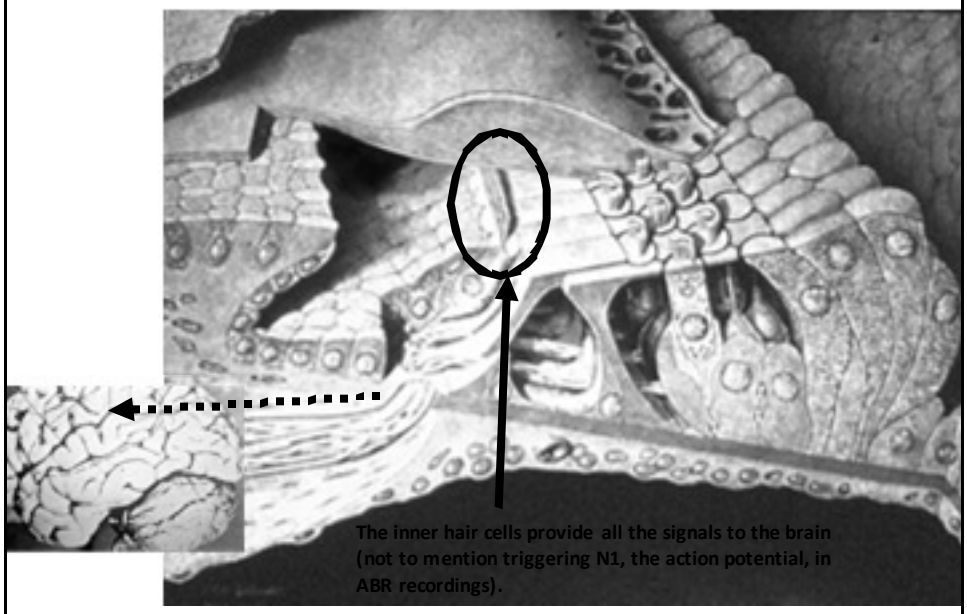
Snap-on Foam Windscreen
➔ Same as Open Ear

I'd love to have two IU recordings of the same tune: ears open, and with ER20 earplugs

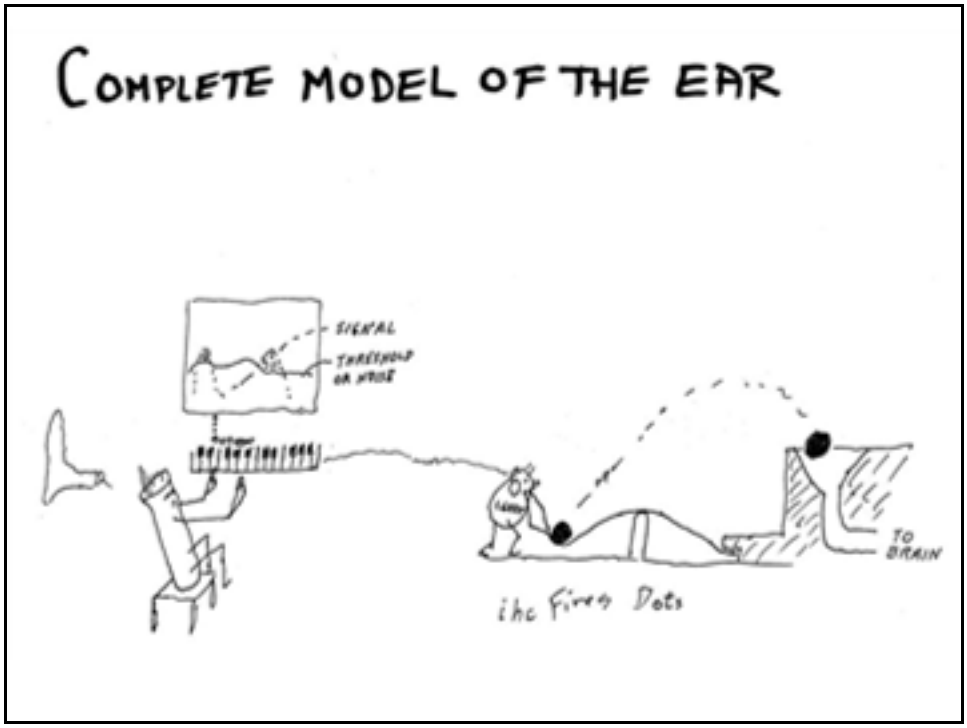
2. Supra Threshold Hearing Loss: Hearing loss that doesn't show up on the audiogram

A short review of the physiology of hearing loss

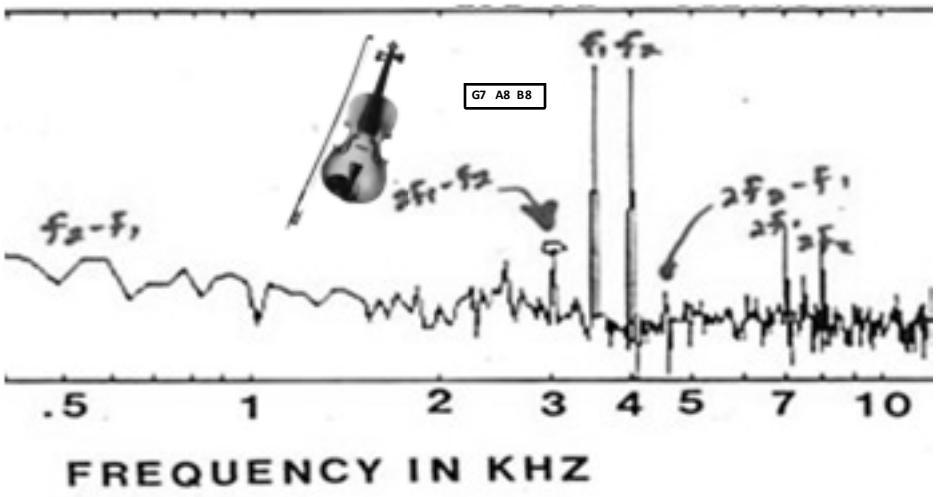
The magic formula that ties it together

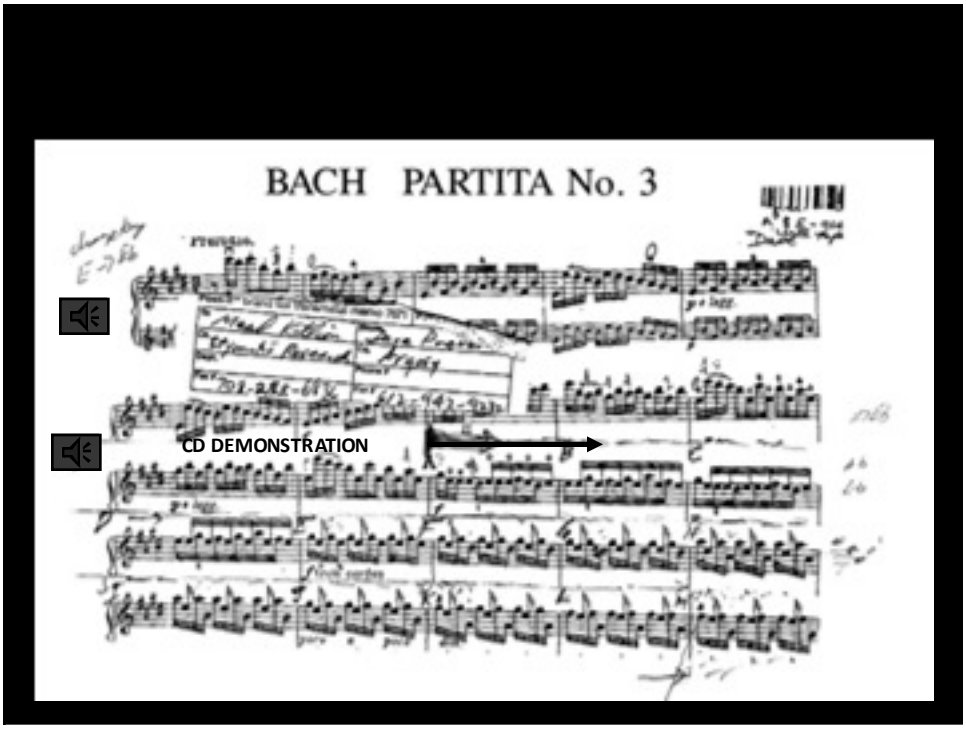

The inner hair cells provide all the signals to the brain
(not to mention triggering N1, the action potential, in
ABR recordings).

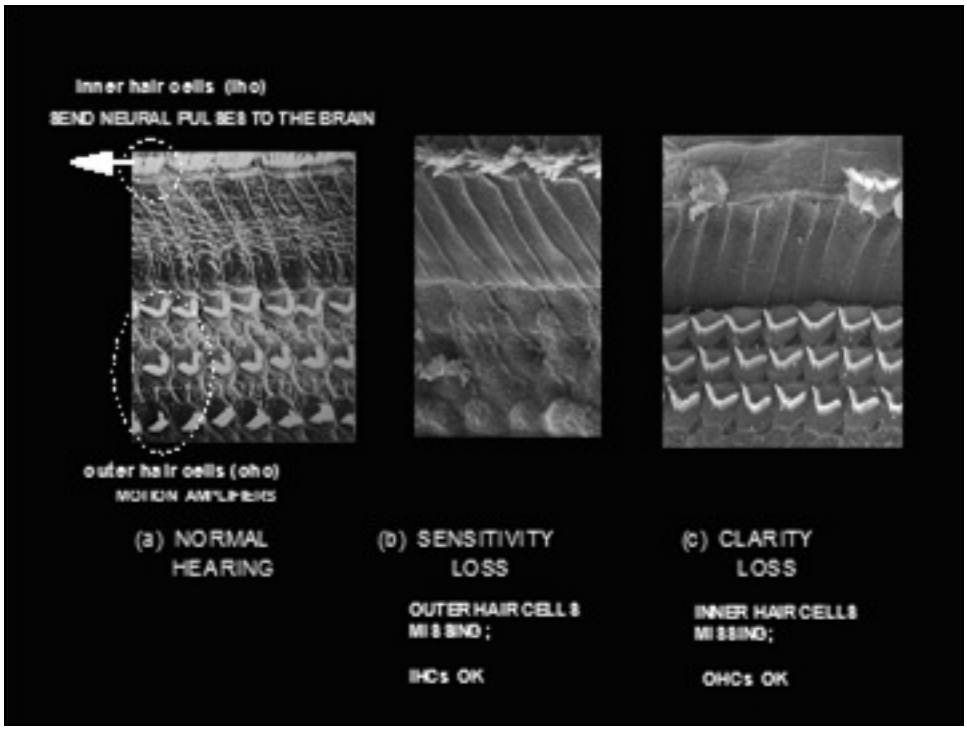
➔ cib demos ➔

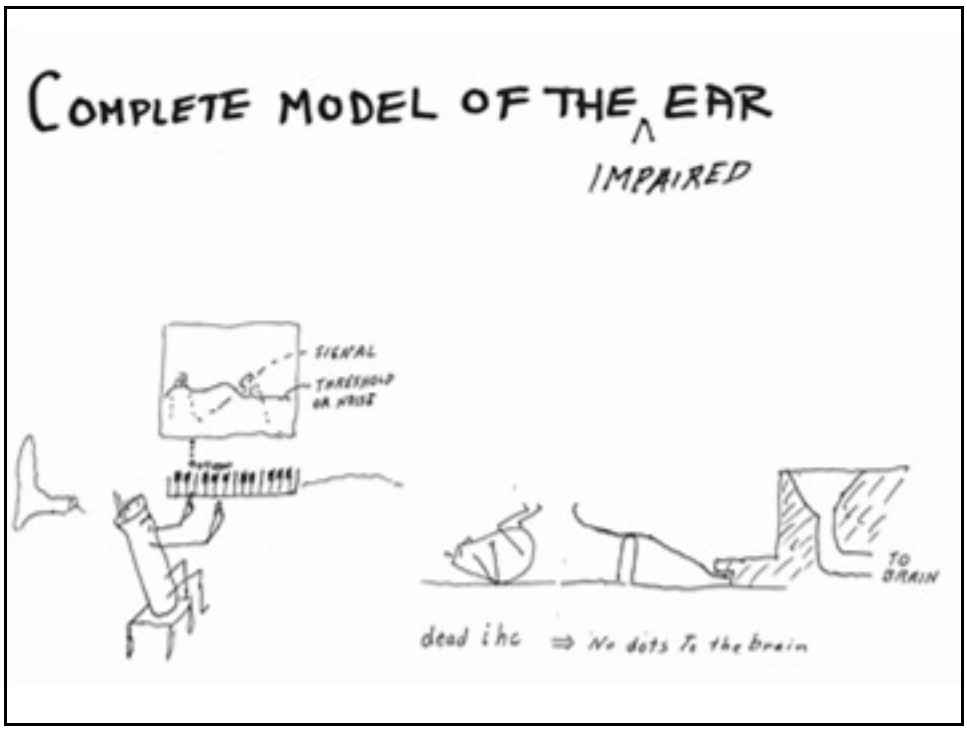

COMPLETE MODEL OF THE EAR
SIGNAL
THRESHOLD OR NOISE
TO BRAIN
the Firing Dots

In additional to taking an audiogram, we can make objective measurement to deduce the activity of the normal outer hair cells by detecting the *intermodulation distortion* products that arrive back in the earcanal from the cochlea. What we measure clinically is the "Tartini tone" he described in 1840 at the frequency 2f1-f2






inner hair cells (ihc)
SEND NEURAL PULSES TO THE BRAIN
outer hair cells (ohc)
(a) NORMAL HEARING
(b) SENSITIVITY LOSS
OUTER HAIR CELLS MISSING;
IHCs OK
(c) CLARITY LOSS
INNER HAIR CELLS MISSING;
OHCs OK


COMPLETE MODEL OF THE EAR
IMPAIRED
SIGNAL
THRESHOLD OR NOISE
TO BRAIN
dead ihc ⇒ No dots To the brain

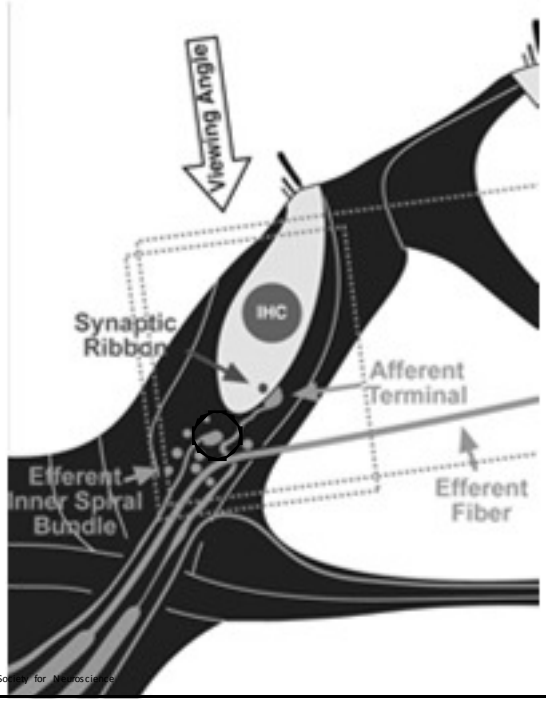
That was pretty much the complete story until Kujawa and Liberman made another surprising discovery

2009 – "Adding Insult to Injury: Cochlear Nerve Degeneration after "Temporary" Noise-Induced Hearing Loss

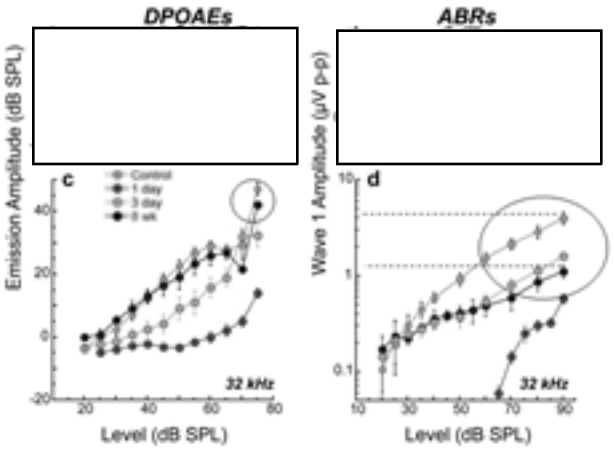
Mice experiments summary:

1. Exposure to produce 40 dB TTS 2 hours post exposure (2 hours 100 dB 8-16 kHz)
2. Complete hair cell, DPOAE, and ABR recovery in 8 days (except N1 @32kHz)
3. Loss of ≈ 50% of cochlear synaptic terminals at one day (!)
4. Loss of ≈ 50% of ganglion cells at 64 weeks

➔ Thresholds (DPOAE, not paw raising) still normal at 64 weeks



Despite threshold recovery, suprathreshold neural responses at high frequencies were permanently attenuated, although recovery of otoacoustic emissions suggests cochlear sensory cells are normal.



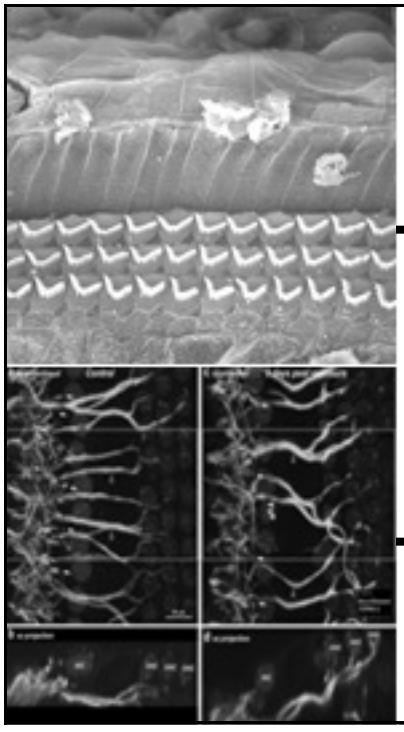
Kujawa S G , Liberman M C J. Neurosci. 2009;29:14077-14085

The Journal of Neuroscience

~30% N1

Most of the lost neurons are the high-threshold (high-SPL) fibers

A "Squeek in Noise" test might show SNR loss at a mouse social gathering.

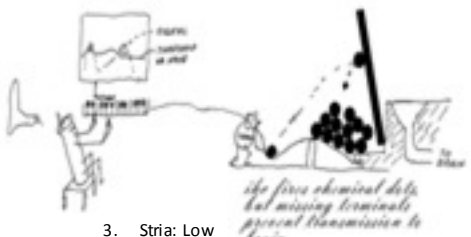


Two common causes of SNR loss:

1. Inner hair cell loss: (No ihc chemicals to fire)

(NHCA)

2. Neural loss: (The ihc chemicals fire but nothing happens)



(Kujawa & Liberman, 2009)

3. Stria: Low battery

But even that isn't the whole story

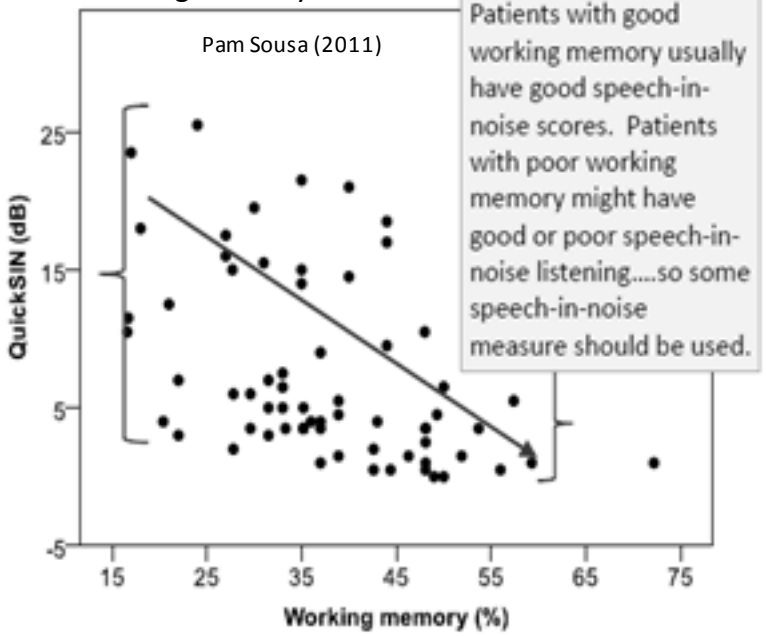
The stria battery can run down

Short term memory loss can cause SNR loss

#4 Atrophy of the stria vascularis as a cause of sensorineural hearing loss.
Pauler M[1], Schuknecht HF, White JA.

24 subjects who had reliable audiometric records. The criterion for selection was strial atrophy as the predominant pathological change in 17 experimental ears and normal hearing for seven control ears. Losses in the summed cross-sectional areas of stria vascularis showed a direct correlation with hearing loss.

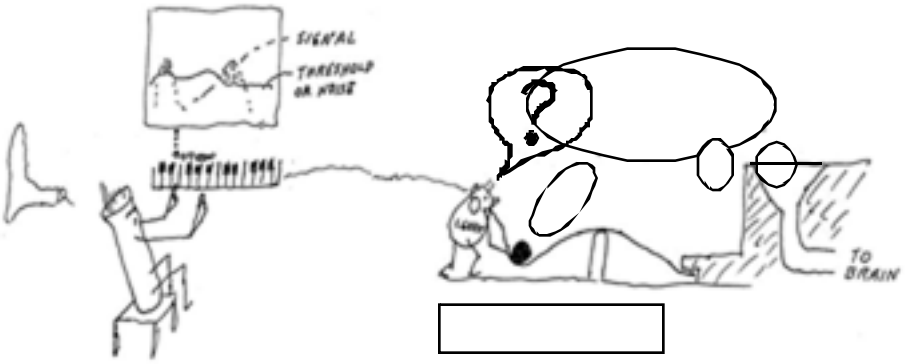
#3. Working-memory loss



COMPLETE MODEL OF THE EAR

FORGETFUL

#3. Working-memory loss (The ihc hears speech cue but forgets what to do with it) cf. Souza



Everything I know about hearing loss

Mead C. Killion, PhD ScD(hon)
CTO, Etymotic Research
October 17, 2014 CAA Whistler, BC

1. **Hearing loss from identifiable sources**
2. **Supra Threshold Hearing Loss**
   a. **Dead Patches and Diplacusis (learning from musicians)**
   b. SNR loss and the Magic Formula,

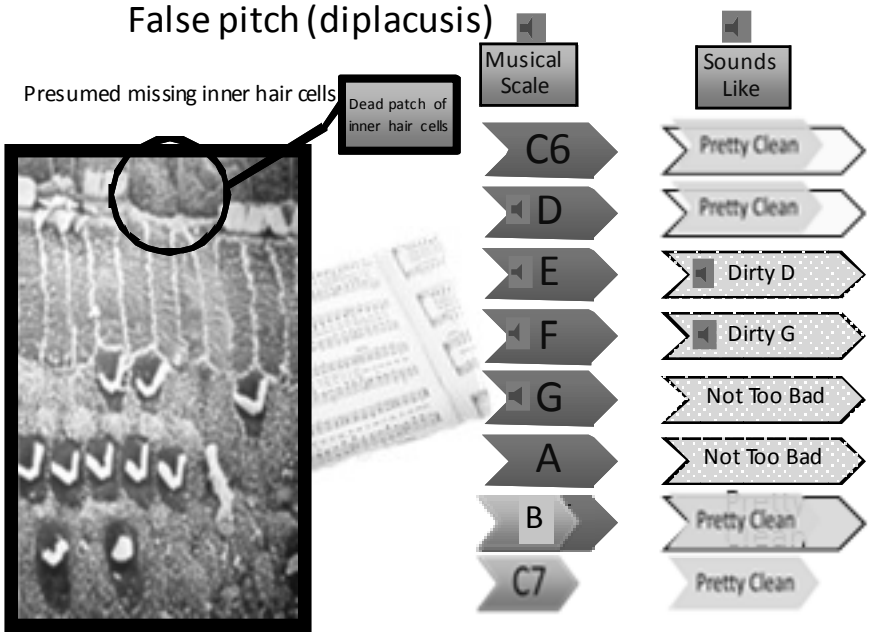
https://dl.dropboxusercontent.com/u/12584972/14CAA-Whistler-What%20I%20knowAboutHearing.pptx

I once had a violin lesson from Yehudi Menuhin, one of the greatest violinists of the last century. He told me he could no longer play the violin because he had false pitch.

I have a neighbor, Bob Boss, who can no longer play the harmonica because of his false pitch.

I believe these two diplacusis stories are linked to a similar cause

False pitch (diplacusis)



How We Hear Pitch: Cochlear Tuning

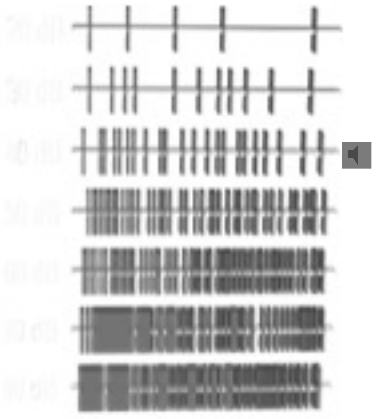
Animation Courtesy of Howard Hughes Medical Institute

How We Hear Pitch: Cochlear Tuning

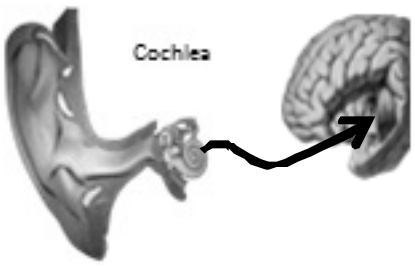
Your Brain's Interpretation of Sound

The Only Thing your Brain Hears are Clicks -- Out of waves of clicks we hear tones!

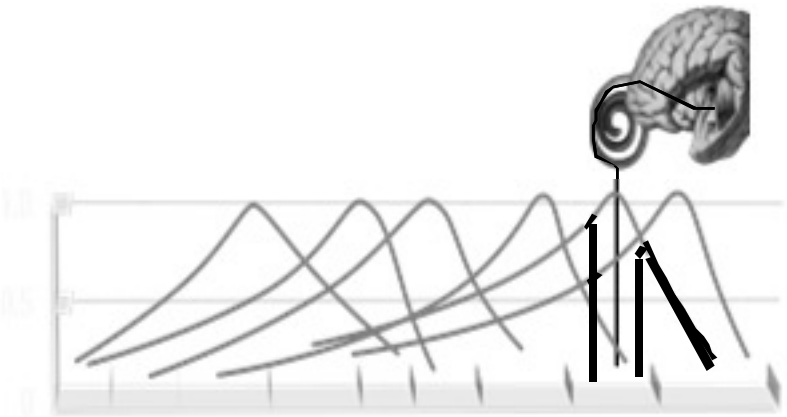
Rate Coding



The interpretation of these (thousands of) click trains as speech, or C#, or a thunderstorm, is one of the miracles of our brains.

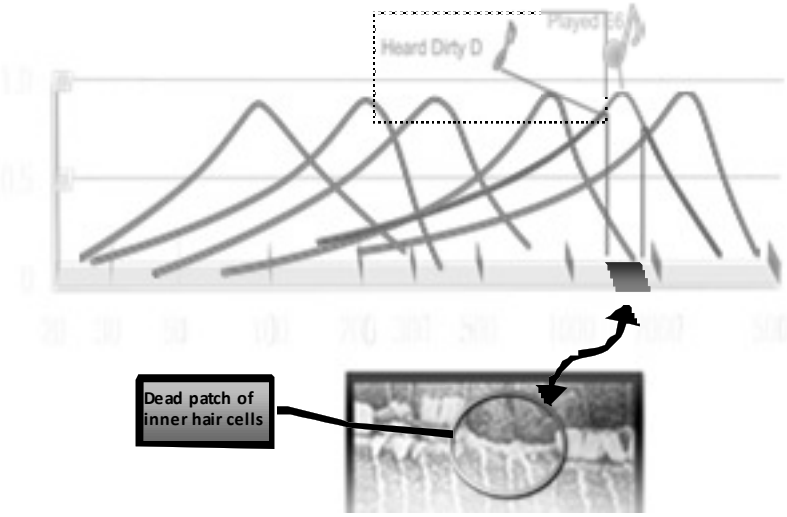


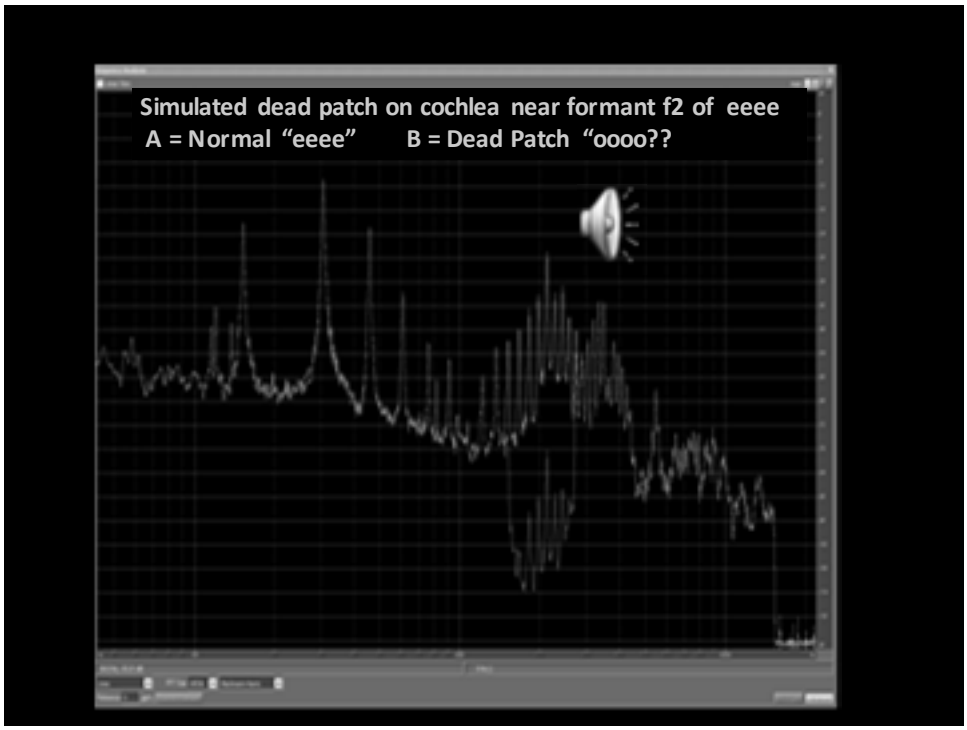
How We Hear Place Pitch



How We Hear With a Dead Patch

Patch of presumed missing inner hair cells





Why two pitches with Meniere's?

Presumably because the increased pressure (hydrops) causes a kettle-drum type stiffening of the highly-compliant apical (low frequency) end of the Organ of Corti more than the stiffer basal end.

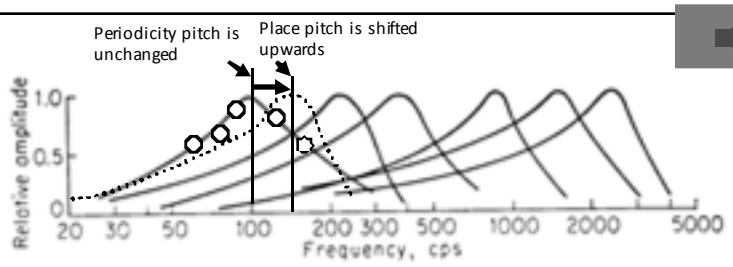


Figure 11-49 Forms of resonance curves for six positions along the cochlear partition.

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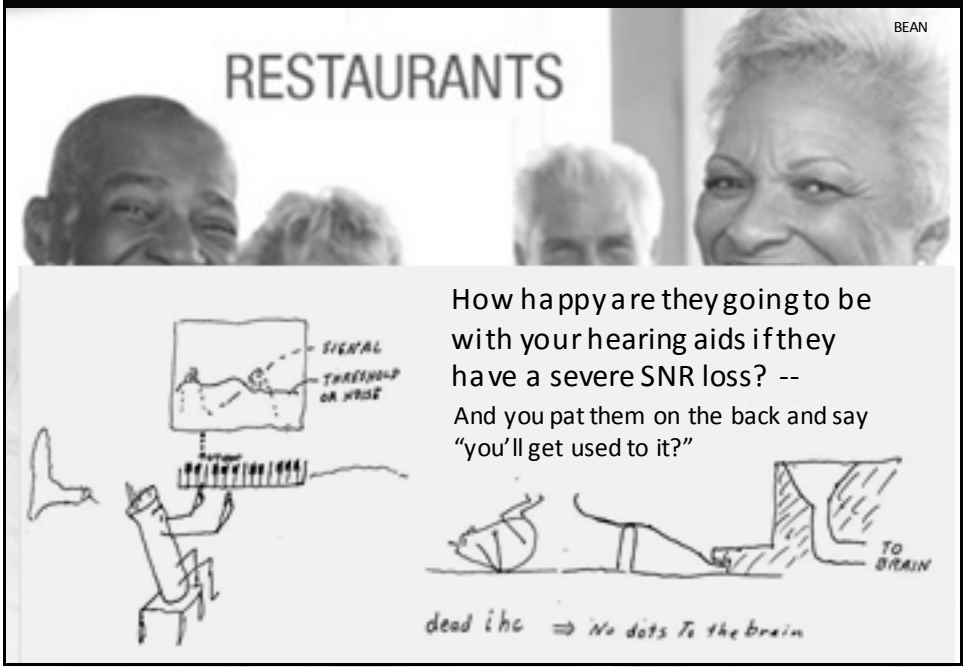
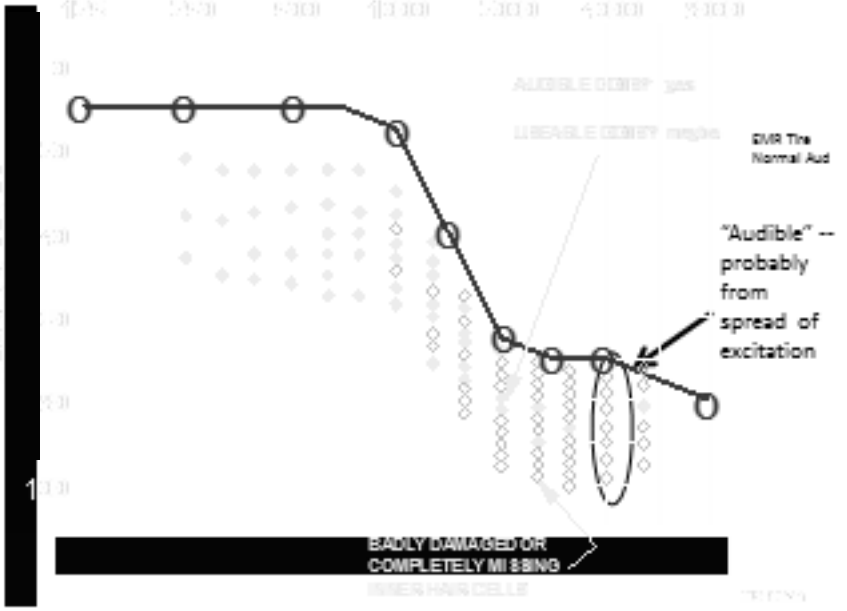
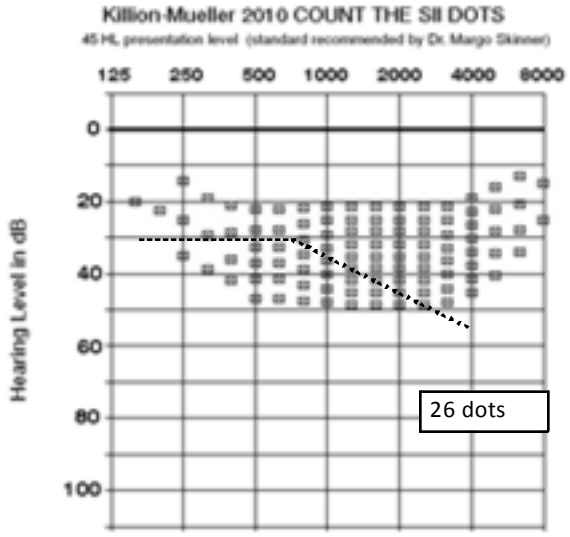
HAPPY WEARERS OF AMPLIFICATION

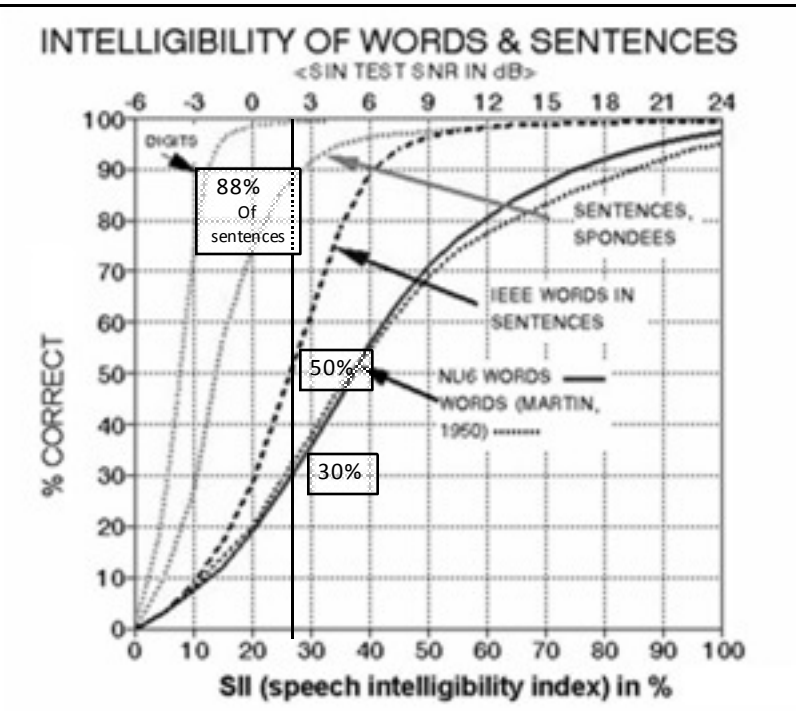


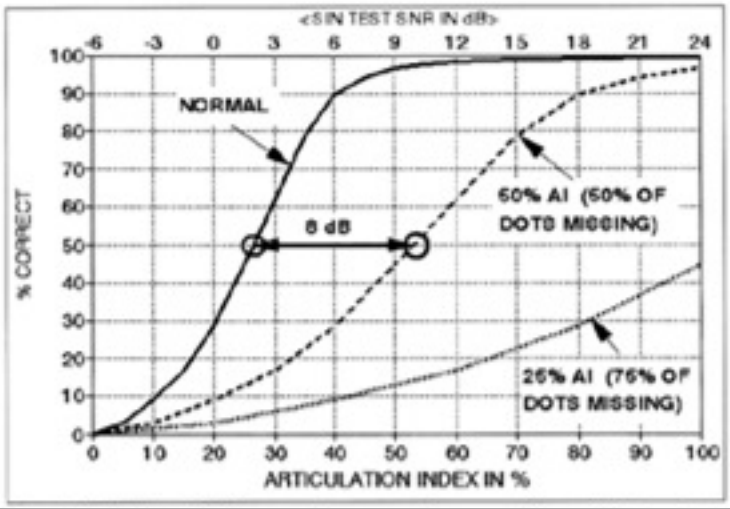
Q: When can speech-in-noise scores be low when everything is audible?
A: When half the "audible" dots don't reach the brain intact.



Some 20 years ago, Gus Mueller and I were sitting in a hot tub drinking Manhattans, and we decided that what the world needed was a simpler way to calculate Articulation Index. "Why don't we just count dots," we said!

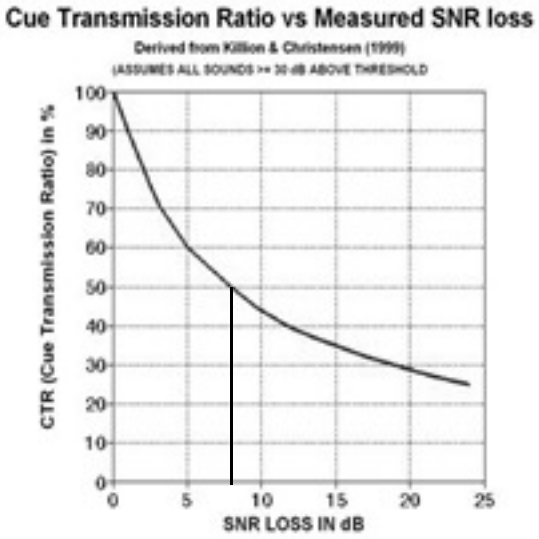






If only half the speech cues reach the brain, you have to start with twice as many audible. In the case of QuickSIN – IEEE words in sentences – that shows up as an 8 dB SNR loss.

By the same method shown in the previous slide, we can estimate the CTR corresponding to each SNR loss



If only half of the audible cues reach the brain, we say the

Cue Transmission Ratio

CTR = 0.5 (50%)

This cause an 8 dB SNR loss (QuickSIN)

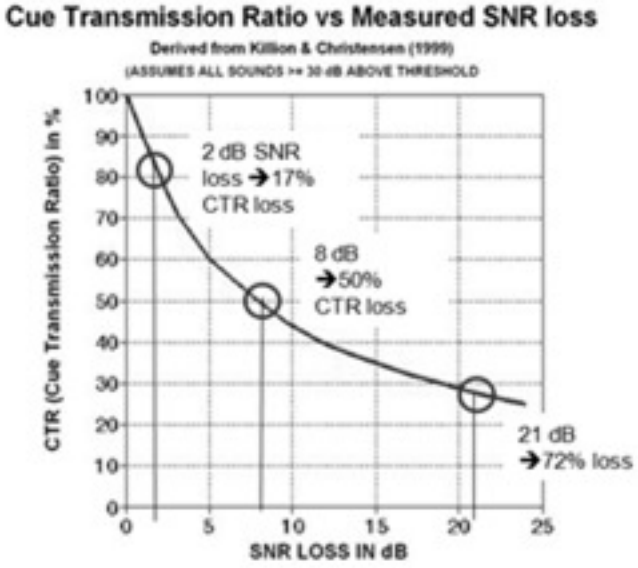
In other words, half the

Audible Dots

are not

Useable Dots

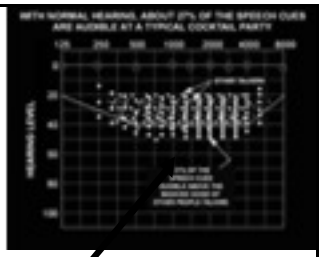
Examples



The

Magic Formula

that explains everything



perceived AI = AI * CTR

/\ % Dots reaching brain

/\ % Dots Audible

/\ Cue Transmission Ratio = % of ***Audible*** Dots which will reach the Brain

Party Example: 13% pAI <== 26% Audible AI * 0.5 CTR

What can you do if you suspect cochlear dead regions or dead zones?

1. **Ask what the 4 kHz (e.g.,) tone sounds like: Tone, buzz, screech?**
2. **TEN test**
3. **(Musicians) Pitch Errors (Diplacusis)**
4. **(Everyone) Find out if high-frequency information clarifies or degrades speech intelligibility.**

GUILT-FREE *QuickSIN* TEST: for ski-slope loss

High-Frequency Lists & Low-Pass-Filtered Lists

Figure 2 shows the high-frequency emphasis added to the ***QuickSIN*** lists to obtain the recordings labeled **HFE**. This frequency response was obtained from FIG 6 (1997) for 65 dB (normal speech) inputs for a patient with 60-70 dB ski-slope loss.

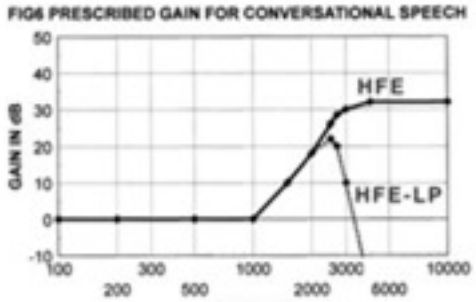
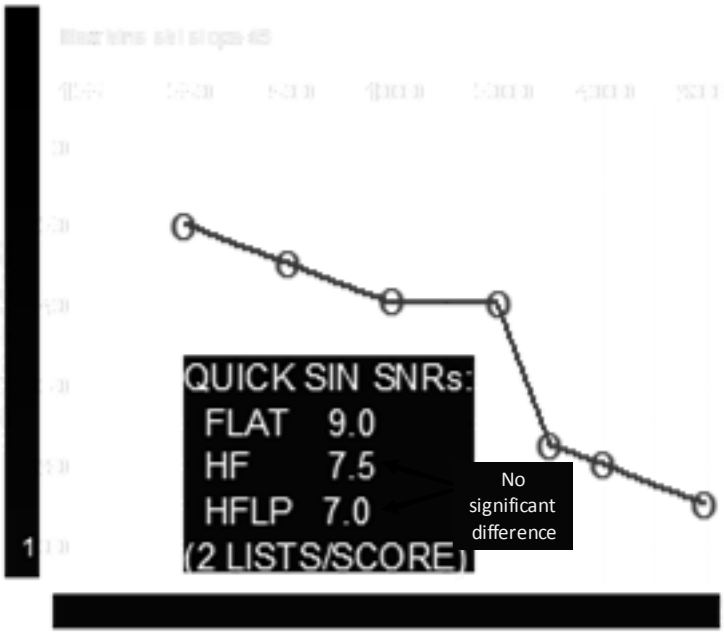


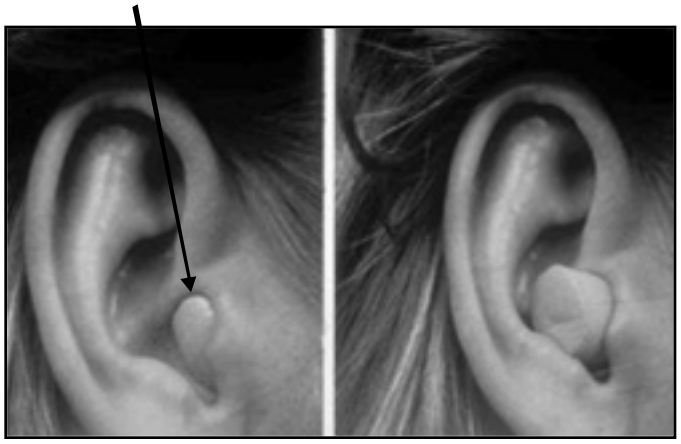
Figure 2

Data on ski-slope hearing loss from Skinner (1980), Rankovic (1991), and Turner and Cummings (1999) indicate that some patients do worse with the extended high frequency emphasis prescribed by popular formulae than if the emphasis is restricted to regions of better hearing. Other patients with similar audiograms seem to benefit from the extended high-frequency amplification.



If you play in a heavy metal band, the yellow foam E-A-R plugs can be your friend, but only if you put them in deeply enough.

(Also if your spouse snores: 40,000 marriages saved)

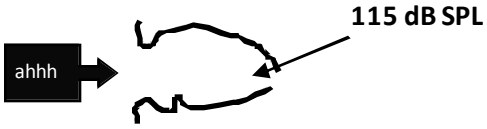


Occlusion effect quick review:

Explanation:

1. **Closed vowel (ee, oo) restricts mouth opening,**

2. **Open vowel (ah) lets sound spill out**



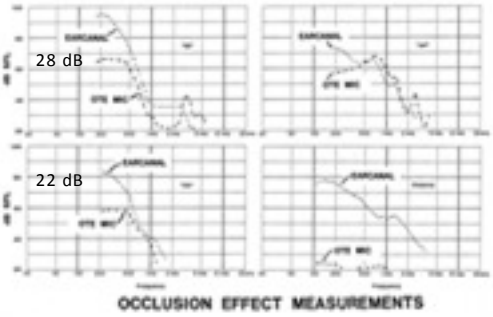
Do it yourself:

1. **Feel vibration of throat and jaw on "ee" and "ah"**
2. **Push tragus over to seal earcanal and hear the amplified "ee".**

Recorded Demonstration from Laura Wilber's earcanal:

1. **ee ah oo, shallow sealed earmold**
2. **Shallow vs. deep: Soft tip canal aid**

(From "Talking Hair Cells" CD)



(From Killion, Wilber and Gudmundsen; 1988)

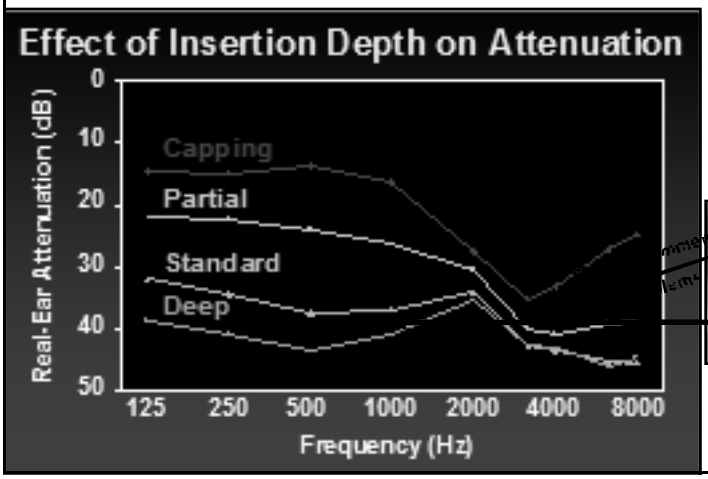
Another anecdote: Trombone player has tinnitus after wearing Musicians Earplugs on the job!

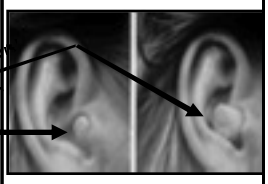
DEEP SEAL

The best universal solution is a deep seal in the earcanal. This blocks the canal wall vibration from making sound at the eardrum.

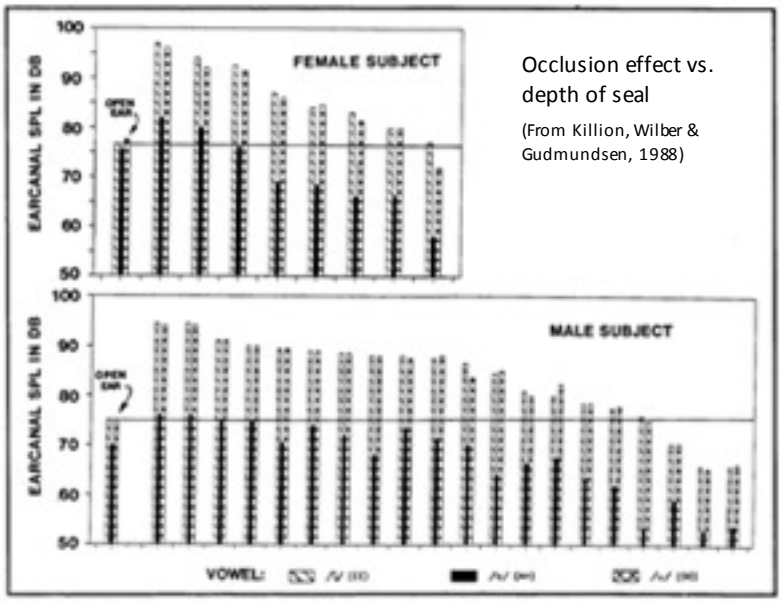
Shallow insertion risks wrist problems, but

Deeply inserted, they are a high-fidelity 40 dB earplug.





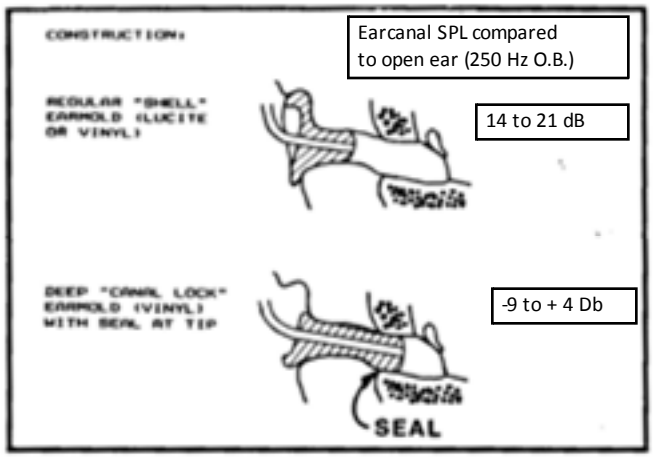
(Berger, 2003)



Occlusion effect vs. depth of seal

(From Killion, Wilber & Gudmundsen, 1988)

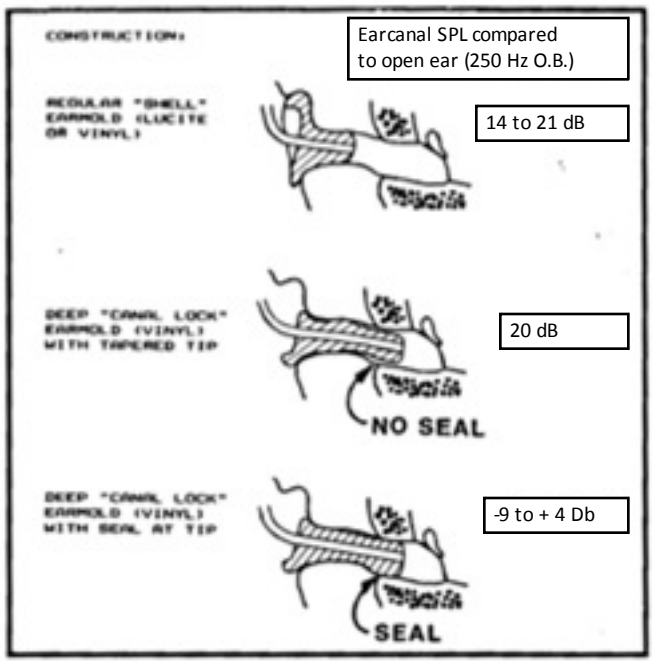
Fig. 4. Ear canal SPLs developed during vocalization behind a variety of unvented earmold constructions investigated in these experiments. Open ear SPLs shown for comparison.

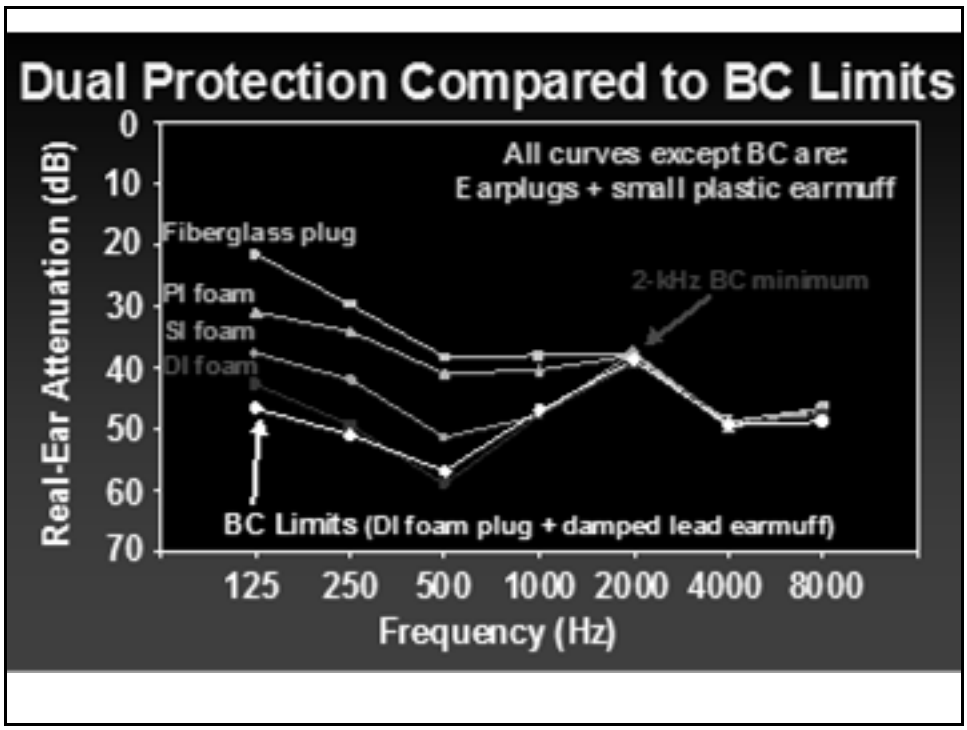


Earcanal SPL compared to open ear (250 Hz O.B.)

14 to 21 dB

-9 to + 4 Db


CONSTRUCTION:
Earcanal SPL compared to open ear (250 Hz O.B.)
REGULAR "SHELL" EARMOLD (LUCITE OR VINYL)
14 to 21 dB
DEEP "CANAL LOCK" EARMOLD (VINYL) WITH TAPERED TIP
20 dB
NO SEAL
DEEP "CANAL LOCK" EARMOLD (VINYL) WITH SEAL AT TIP
-9 to + 4 Db
SEAL


Dual Protection Compared to BC Limits
Real-Ear Attenuation (dB)
0
10
20
30
40
50
60
70
All curves except BC are:
Earplugs + small plastic earmuff
Fiberglass plug
PI foam
SI foam
DI foam
2-kHz BC minimum
BC Limits (DI foam plug + damped lead earmuff)
125
250
500
1000
2000
4000
8000
Frequency (Hz)

The rest of the time is
now reserved for Q&A