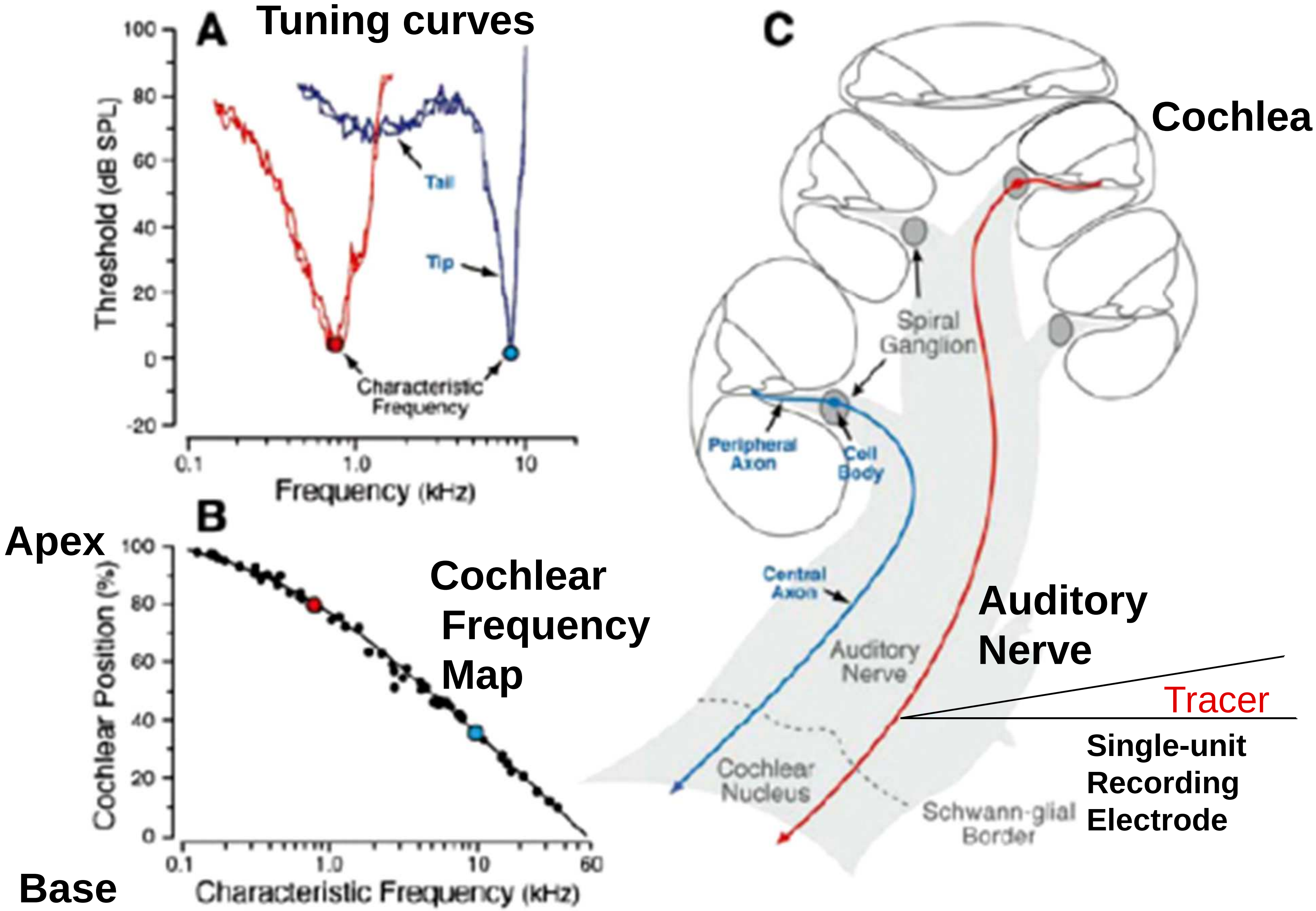
What do we know about physiological reflections of sensori-neural hearing loss?

focus on hair cell damage

Auditory Nerve Structure and Function



slide courtesy of Chris Brown, Mass Eye & Ear

Liberman (1982)

Outer Hair Cells are relatively vulnerable to damage, leading to ...

- Decreases in basilar membrane movement and hence increased thresholds to sound
  - *hearing loss*
- A loss of cochlear compression (a *linearised* input/output function)
  - *reduced dynamic range*
  - *loudness recruitment*
- Loss of frequency tuning (analogous to widened filters in an auditory filter bank).
  - *degraded frequency selectivity*

Input/ Output functions on the basilar membrane near CF in an impaired ear

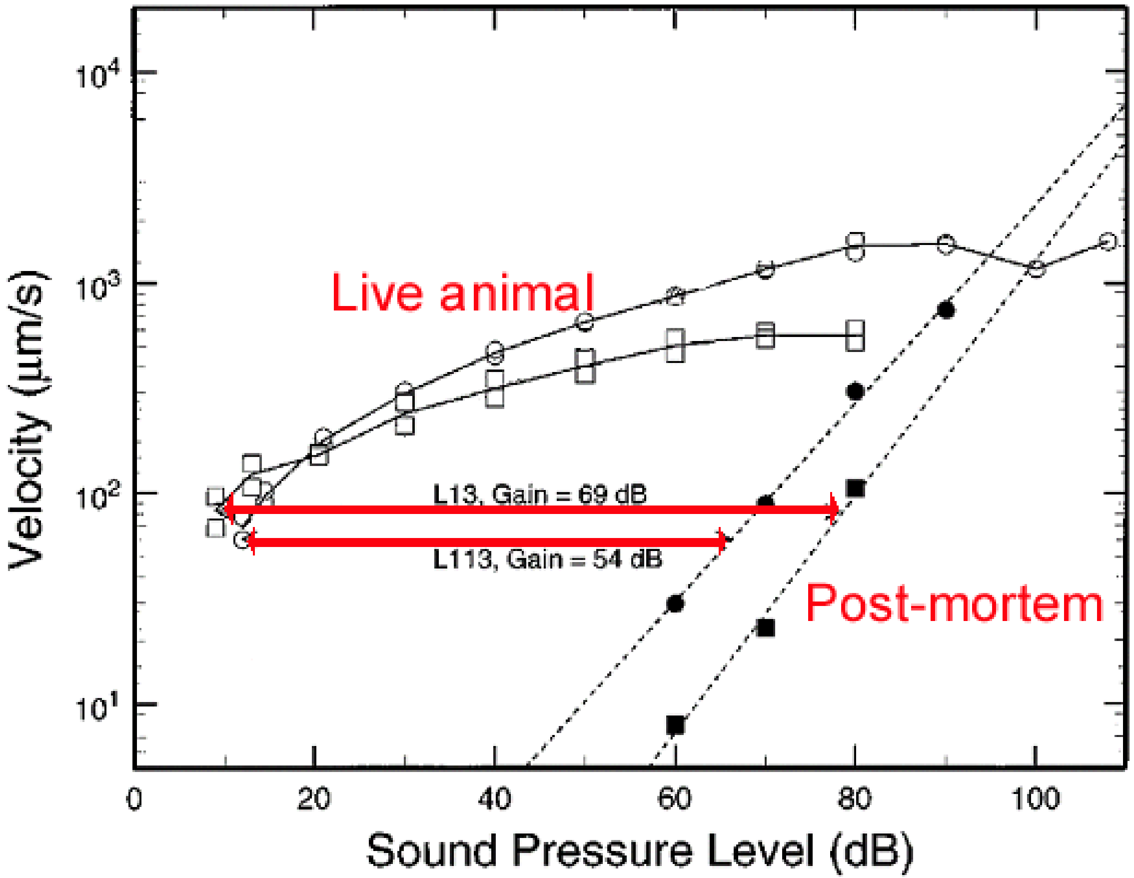
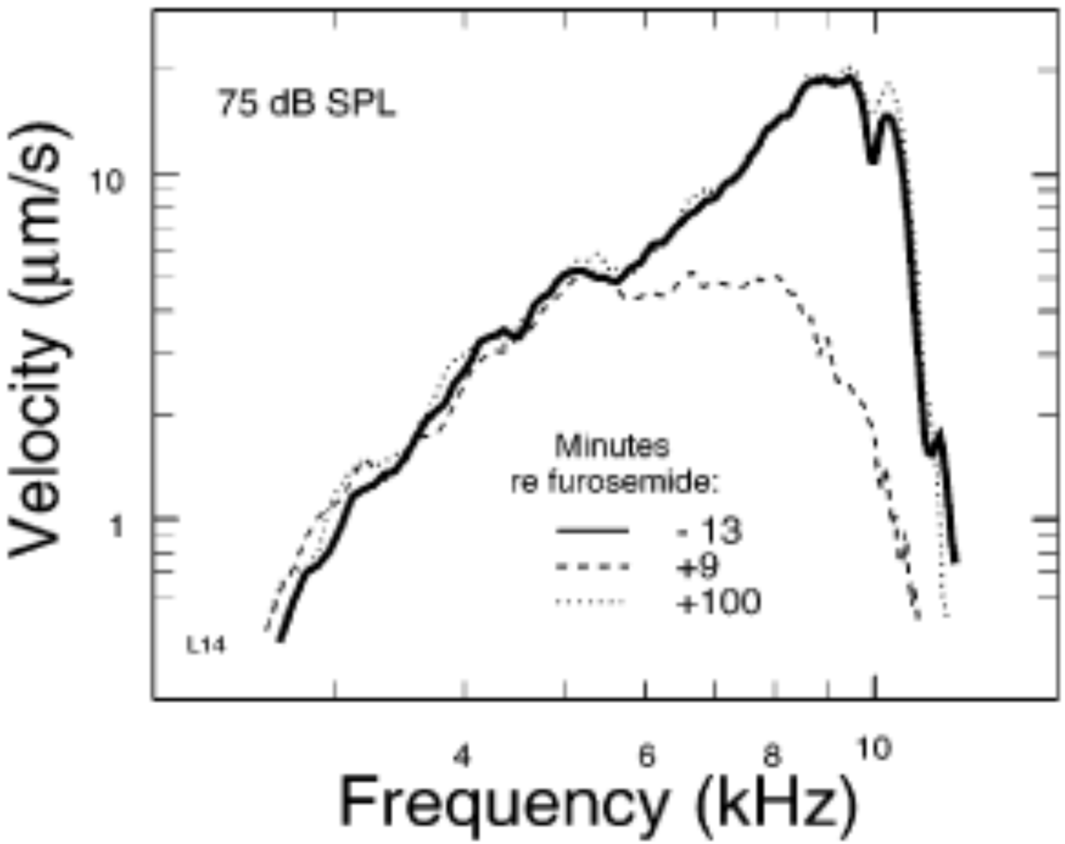


FIG. 16. Stability and vulnerability of responses to CF and near-CF tones. The open symbols depict the peak velocities of responses to CF tones (L13: squares; L113: circles) recorded in the sensitive cochleae of two live chinchillas. The filled symbols represent the CF responses recorded immediately after (within minutes of) death. Responses to CF tones in both cochleae were measured both early in the experiment and 160–240 min later.

Frequency response of a single place on the BM in an impaired ear (furosemide)



Ruggero and Rich (1991)

Inner Hair Cell (IHC) damage ...

- Leads to a more sparse representation of *all* auditory information passed on to higher auditory centres.
- There are possibly even regions of the cochlea without any IHCs — so-called *dead regions*.
- Hence, there may be a degradation of a wide variety of auditory abilities *(e.g*. temporal resolution).

Relation of Hair Cell loss to audiogram

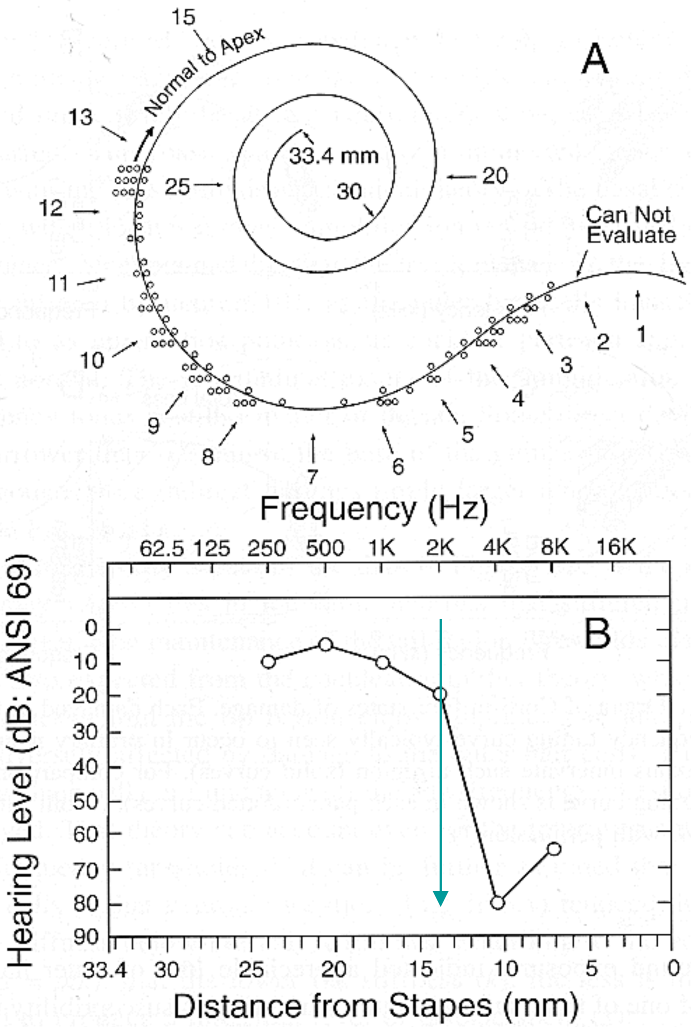
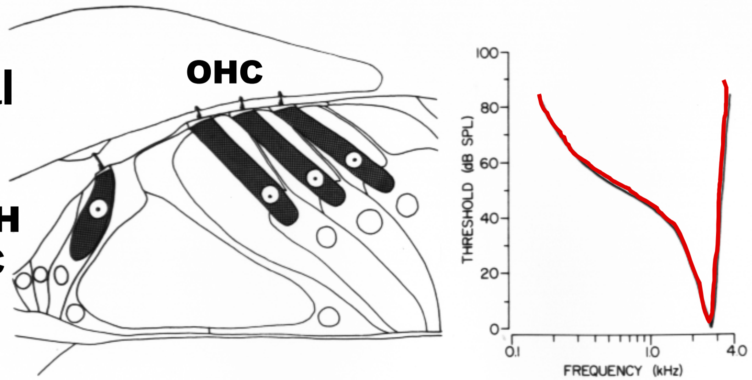


Figure 16.5. Comparison of cochlear pathology with the audiogram of a human patient. *A.* Patient's cytocochleogram, showing in pictorial form the hair cells (circles) remaining in each of the four rows of hair cells, regardless of their condition, plotted as a function of distance from the stapes. Note the extensive hair cell loss in the most basal 12 mm. *B.* Patient's audiogram, showing a profound hearing loss above 2 kHz (top scale of abscissa). The apical border of the extensive hair cell loss corresponds well with the 3 kHz place on the characteristic-frequency/location map for primary auditory neurons in humans (bottom scale of abscissa). (From Schuknect, 1993, with permission.*)

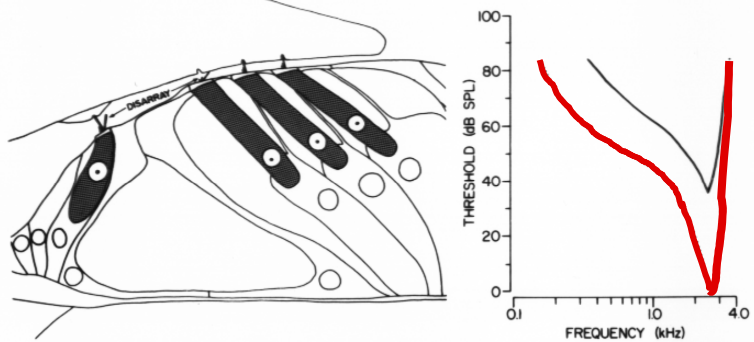
Auditory Nerve Fiber Responses From Damaged Cochleae

slide courtesy
of Chris Brown,
Mass Eye & Ear

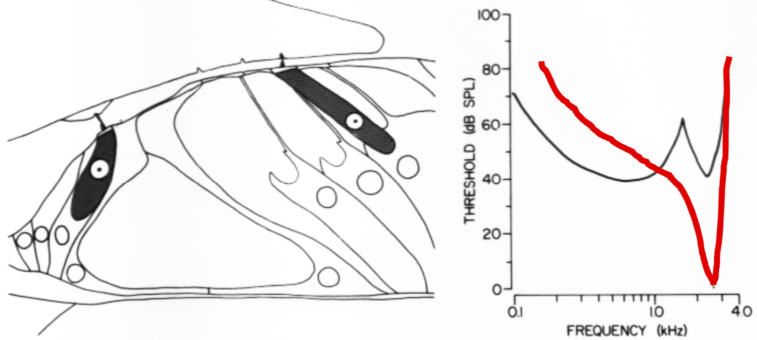
Normal



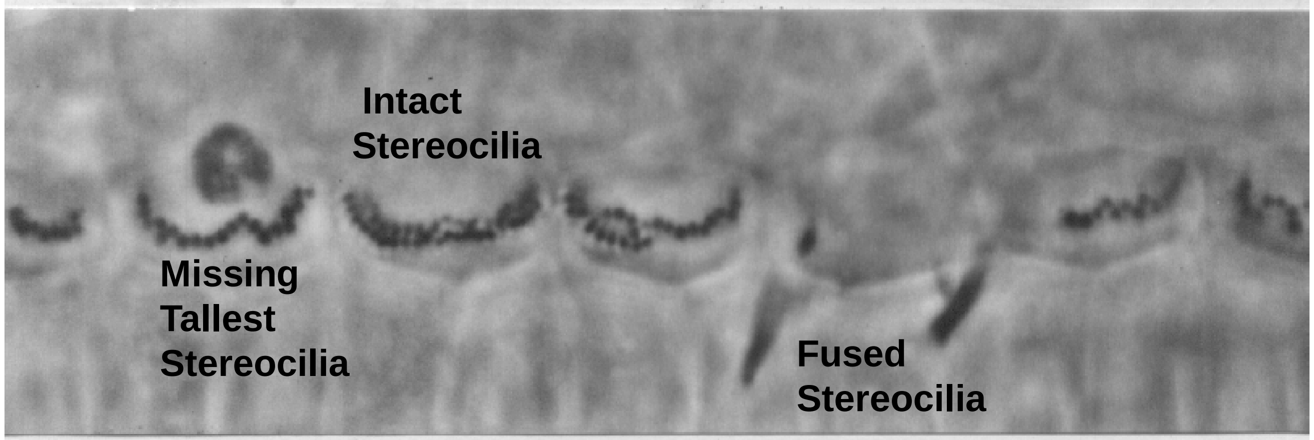
IHC Stereocilia Damage



OHC Damage

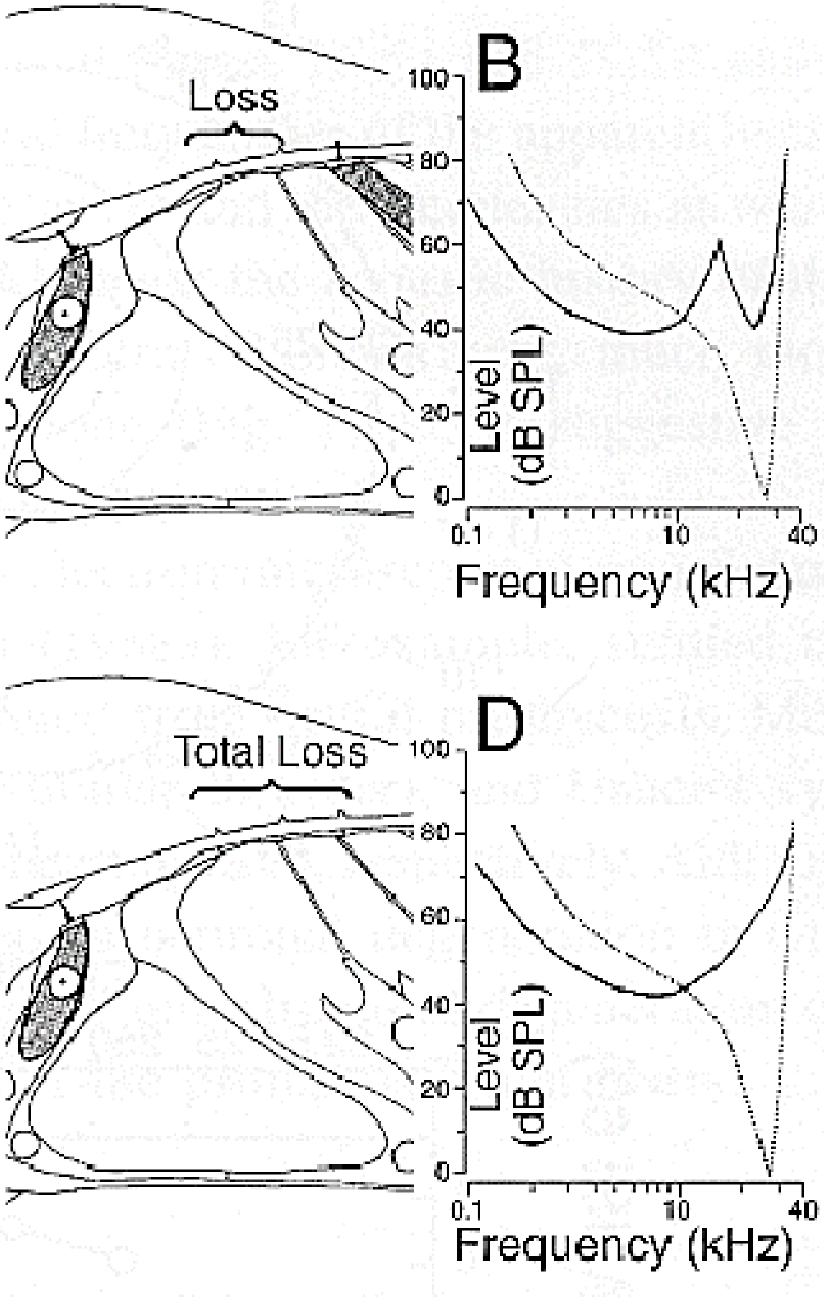


Stereocilia
on IHCs



Liberman and
Kiang (1978)
Liberman and Beil
(1979)
Liberman
and Dodds (1984)

Effects of OHC damage and total loss on tuning in the auditory nerve

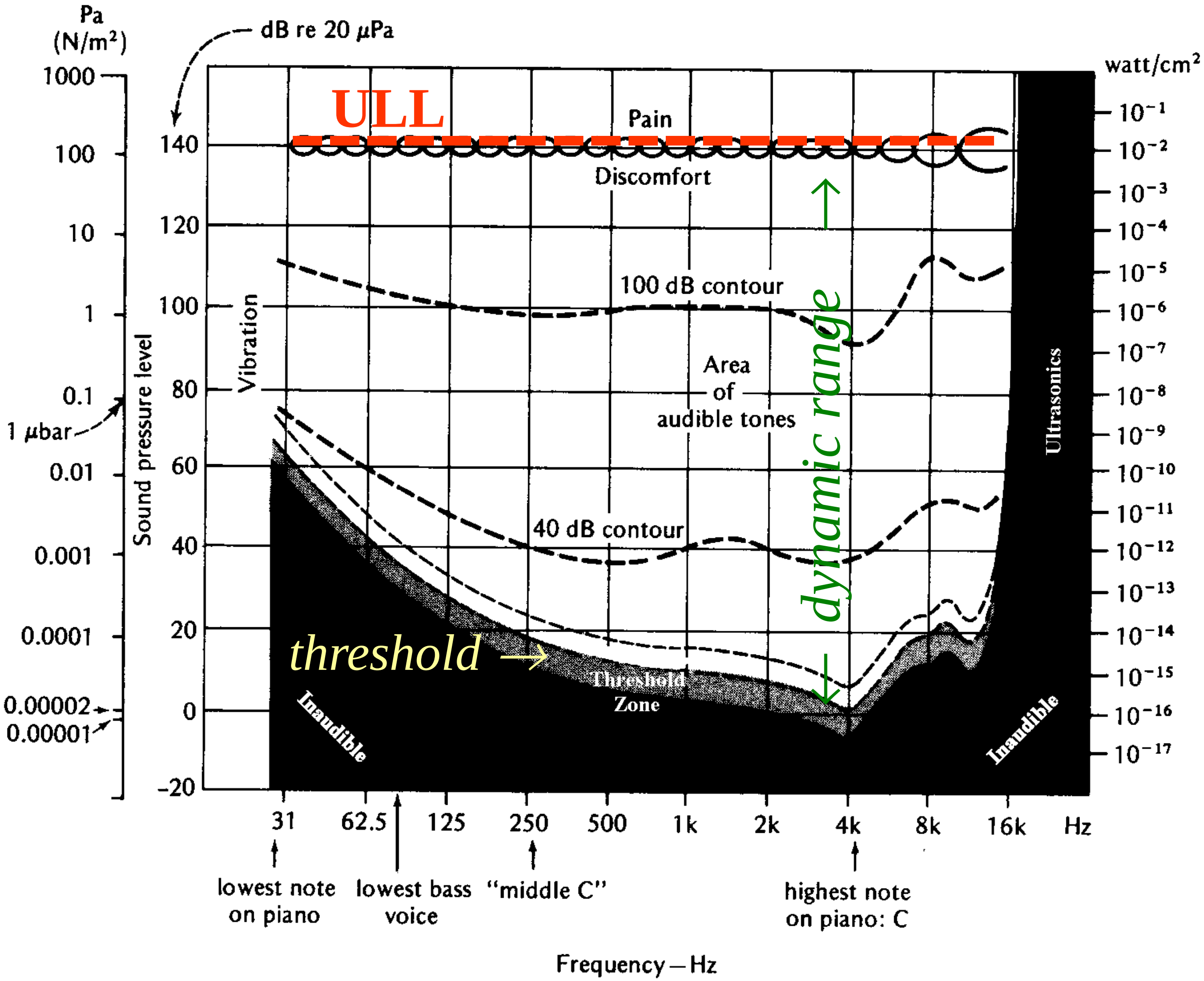


Psychoacoustic consequences of sensori-neural (cochlear) hearing loss

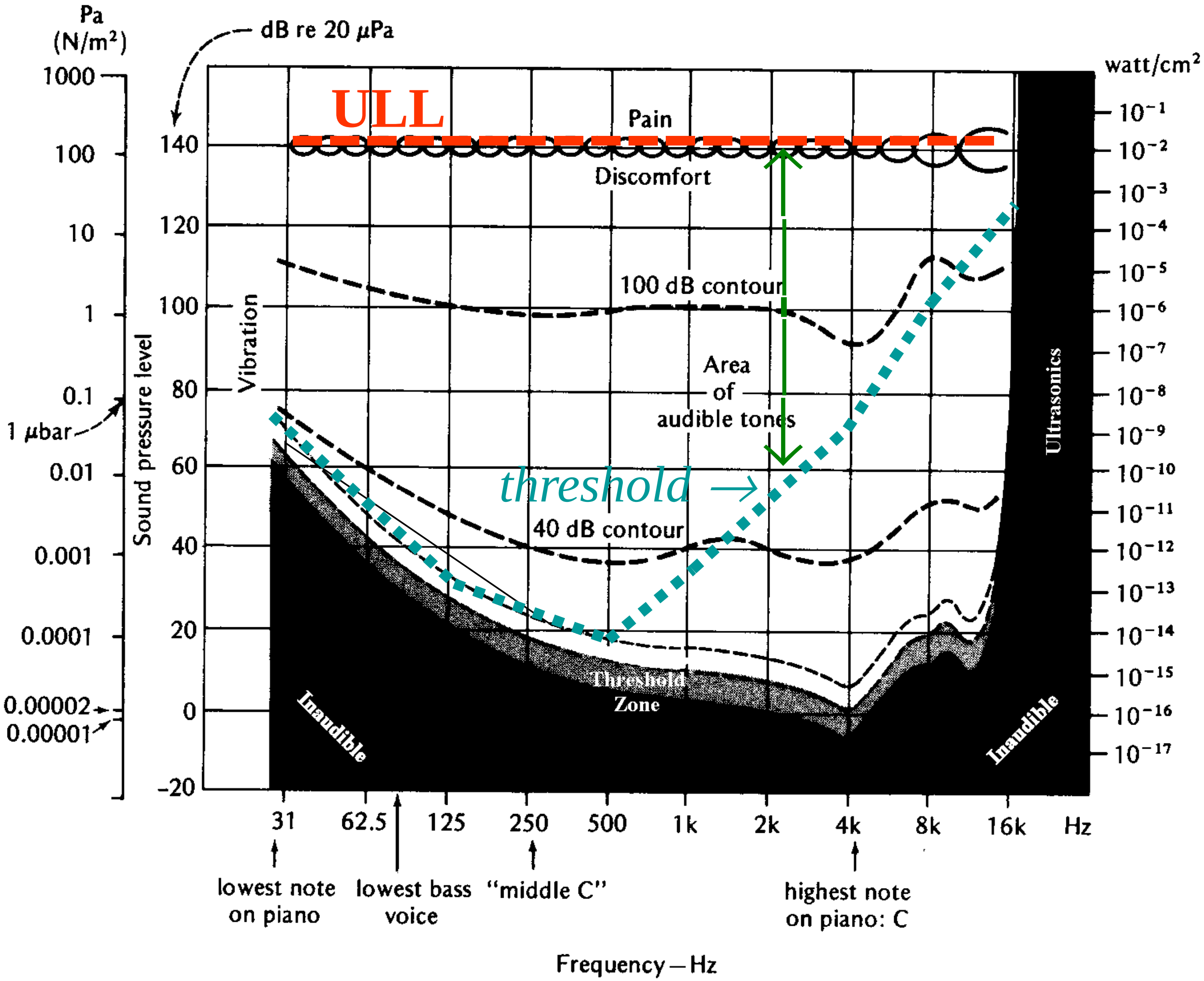
- Raised thresholds
- Reduction of dynamic range and abnormal loudness growth
- Impaired frequency selectivity

What is the impact on speech perception?

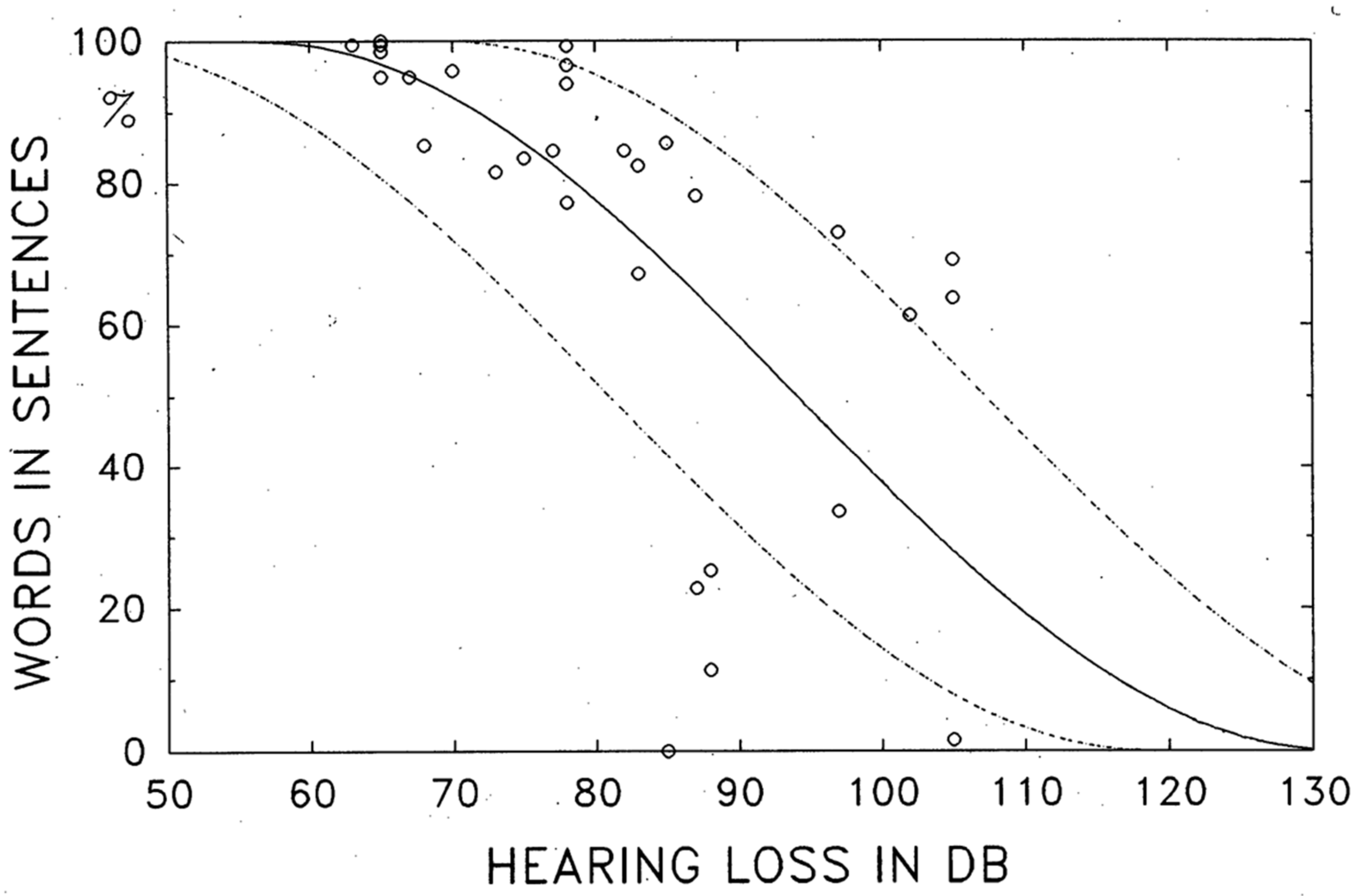
A normal *auditory area*



An *auditory area* in sensori-neural loss



Hearing Loss & Speech Perception

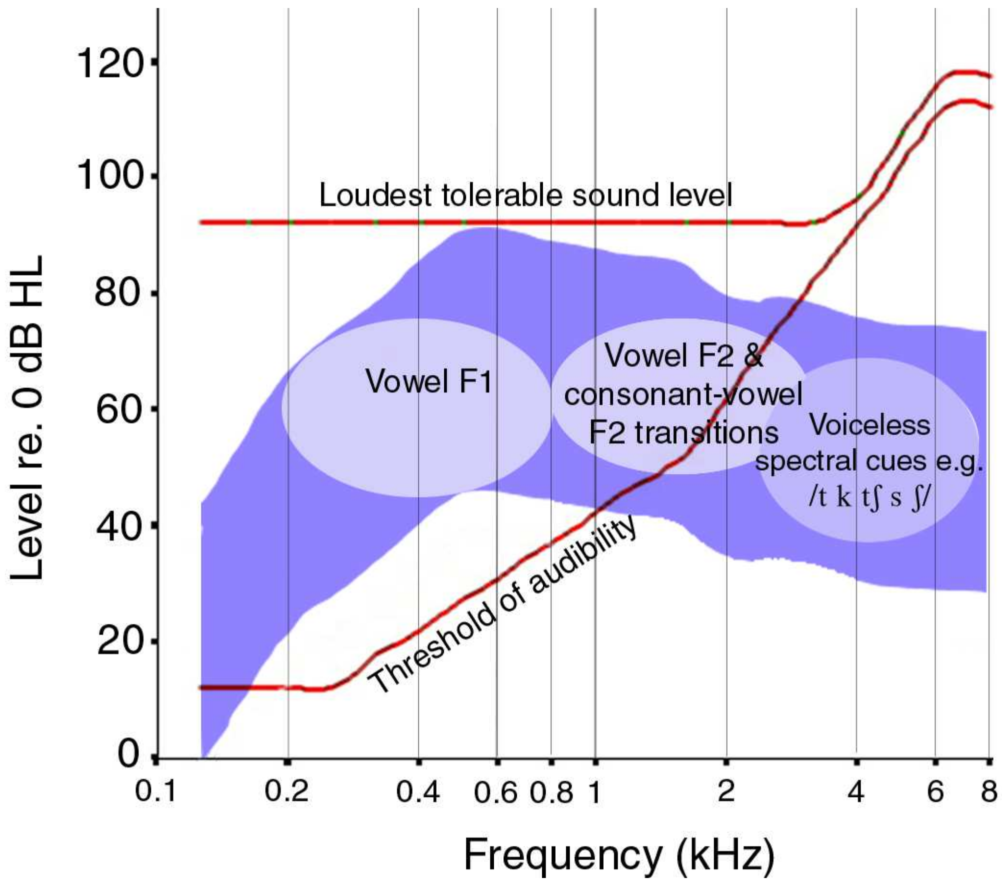


Words recognised from simple sentences in **quiet** by **aided** hearing impaired adults as a function of average hearing loss at 0.5, 1 and 2 kHz. (After Boothroyd, 1990)

The Role of Audibility

- Much of the impact of hearing loss is thought of in terms of ***audibility***
- How much of the information in speech is audible?
  - Over frequency
  - Over intensity
- Consider the audible area of frequency and intensity in relation to the range of frequencies and intensities in speech

Speech energy and audibility



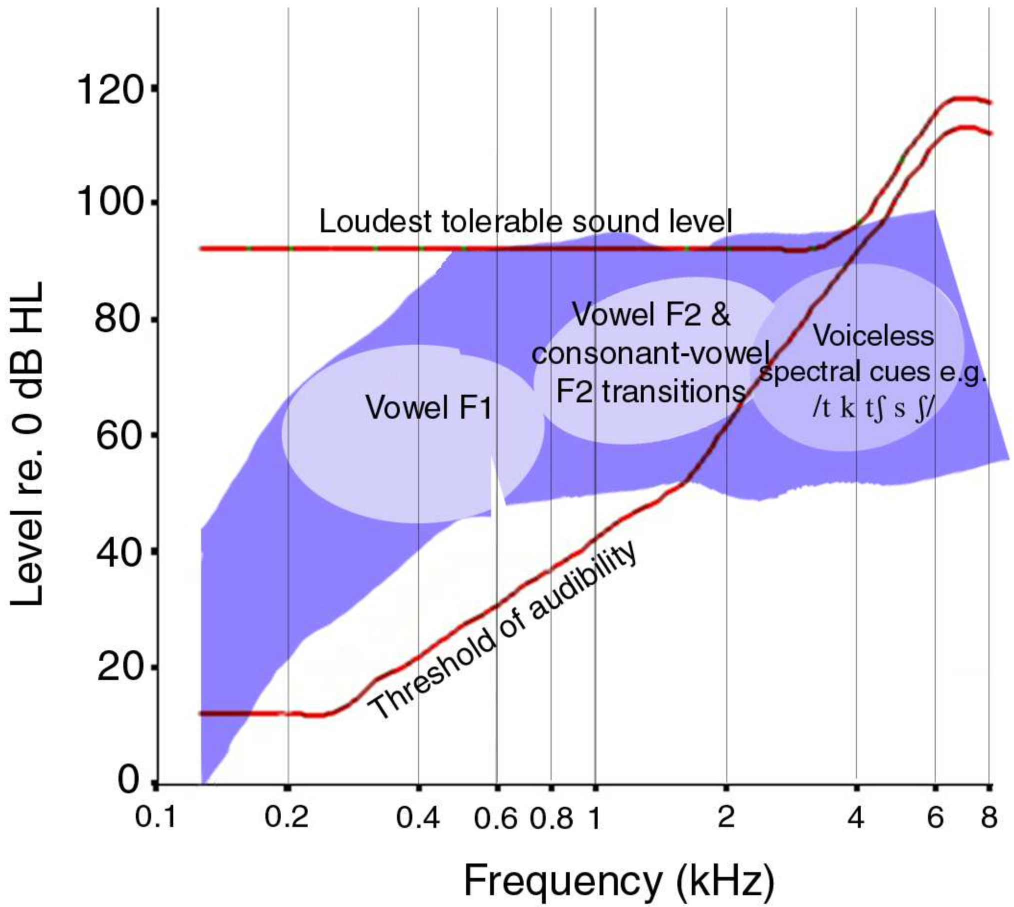
blue: the energy range of speech according to frequency relative to the normal threshold of hearing.

red: the range of audible levels over frequency for a typical moderate sloping hearing loss.

Intelligibility can be predicted from the portion of the speech range that is audible.

Hearing aids can be set to increase audibility by overall amplification and by shaping of frequency response

Speech energy and audibility

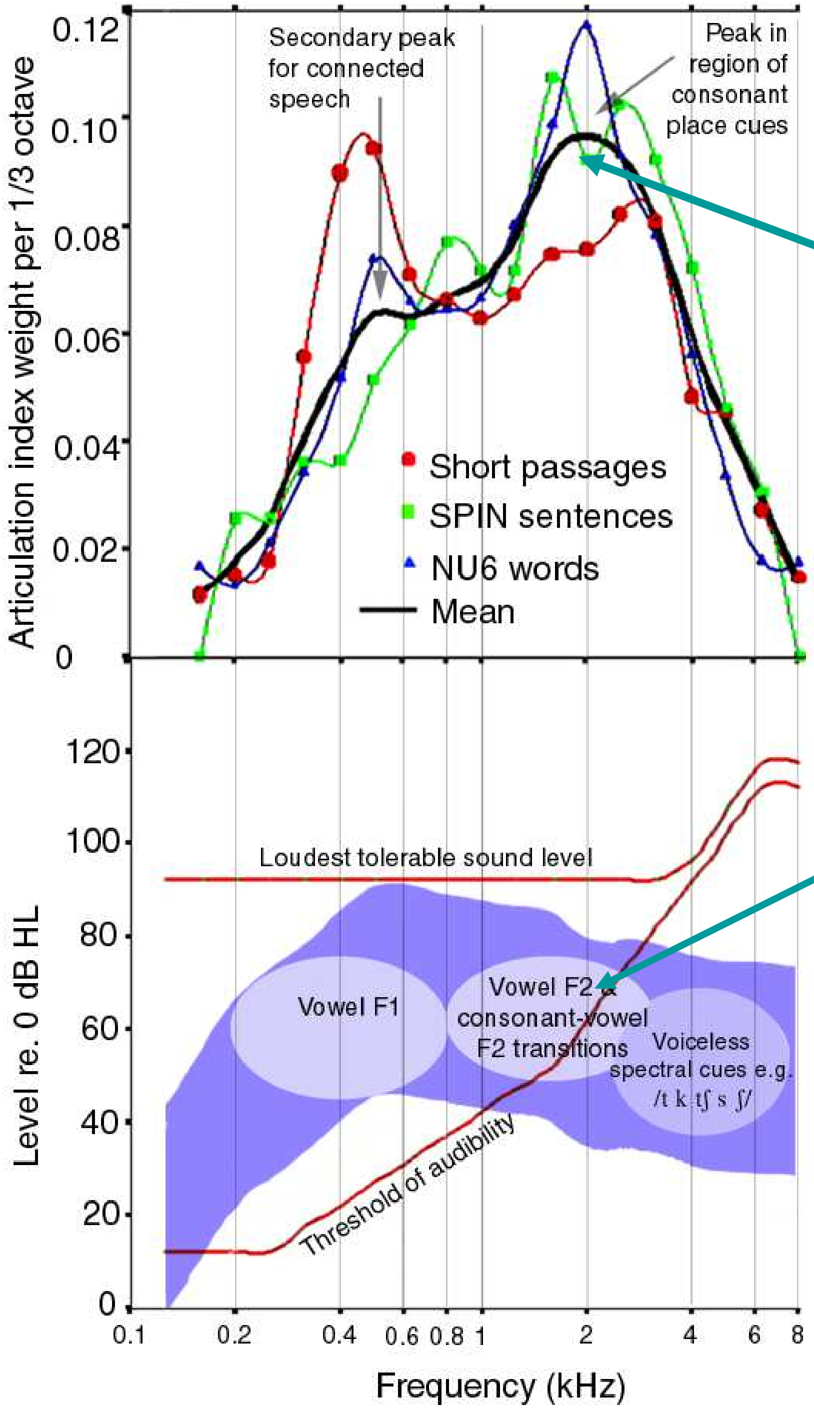


Note frequency-varying amplification

Articulation Index (AI)

- An attempt to quantify the role of audibility in speech perception
- Related to standard rules for setting HA frequency response
- Intelligibility is assumed to relate to a simple sum of the contributions from different frequency bands
- Some frequency bands are more important than others

Frequency importance weightings: AI



I (2000 Hz)

$$A = \sum_{i=1}^{n} I_i \quad W_i,$$

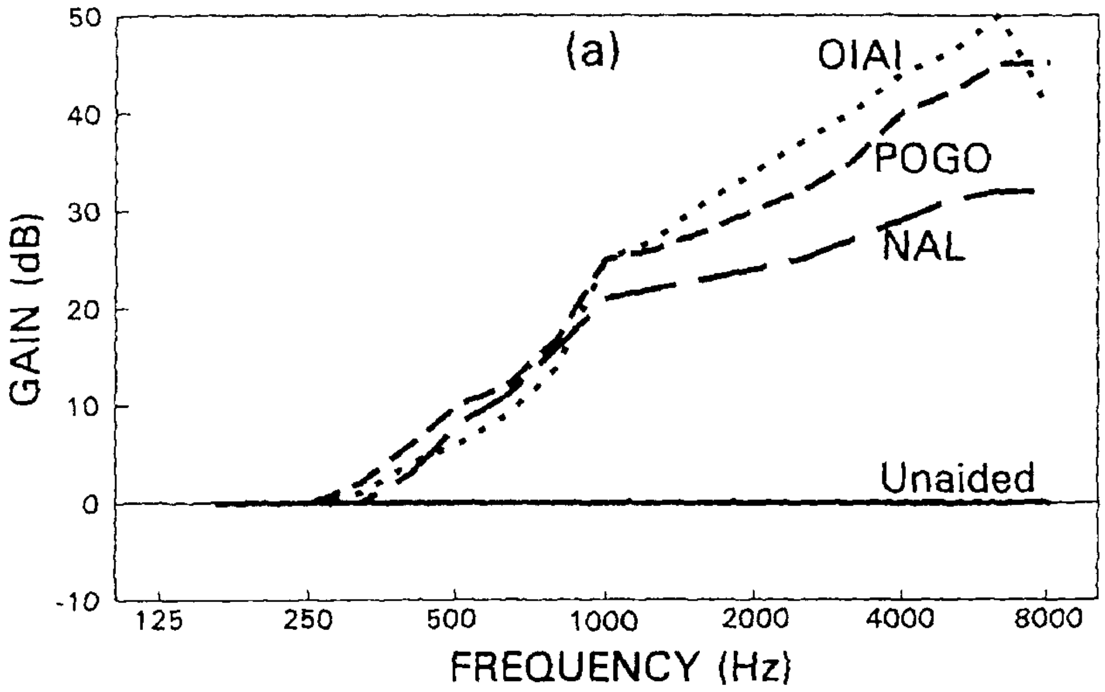
W (2000 Hz) – here W is approx 0.6

A is the Articulation Index (predicted intelligibility).

A is determined by adding up ***W x I*** over frequency bands, where ***I*** is the band importance weight and ***W*** is the proportion of a 30 dB dynamic range of speech in that band that is audible.

AI theory allows the calculation of a hearing aid response for a given audiogram that should maximise intelligibility.

This is similar to that from standard aid fitting rules, although these generally recommend less gain than AI where losses are more severe.



AI predictions

AI predicts intelligibility rather well for mild and moderate hearing losses. But not for severe and profound losses – here the effects of audibility are not enough to explain limits to speech recognition

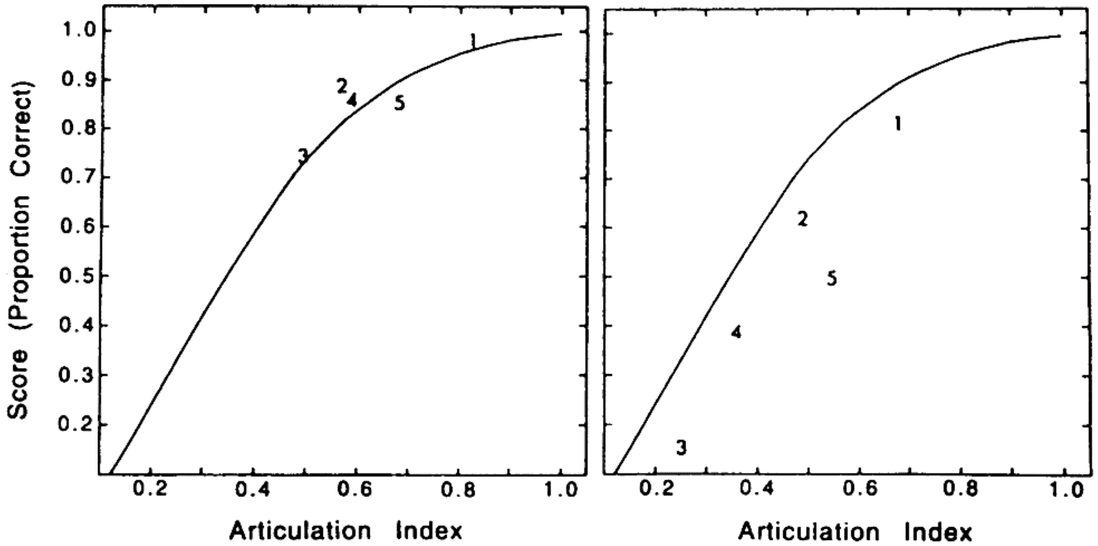
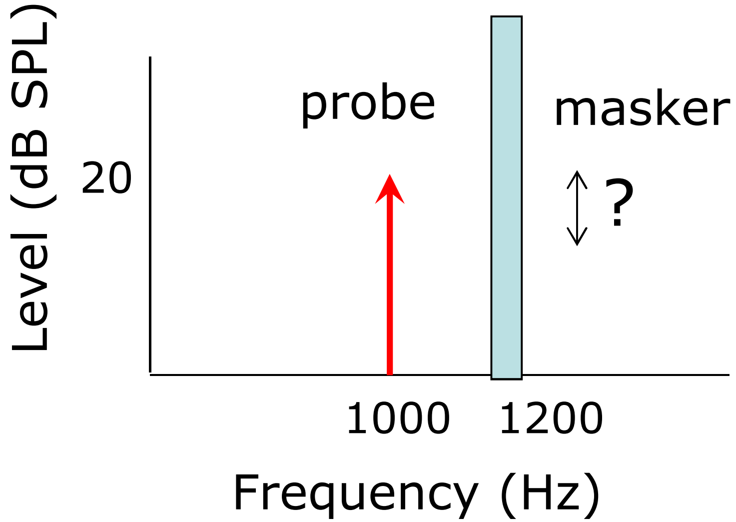


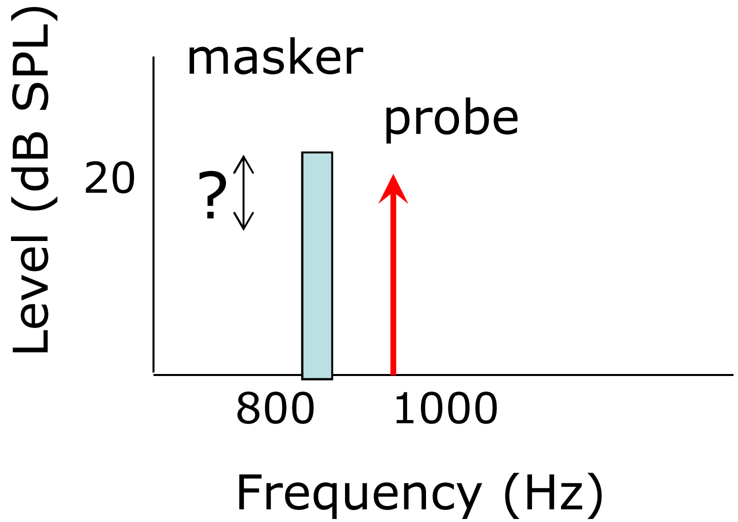
Figure 8.1: Results of Pavlovic (1984) comparing speech recognition scores of hearing-impaired subjects with predictions based on the AI. Each number represents the mean score across subjects for a specific condition of filtering/background noise. For subjects with mild losses, the predictions are accurate (left panel); for subjects with more severe losses, the obtained scores fall below the predicted values (right panel)

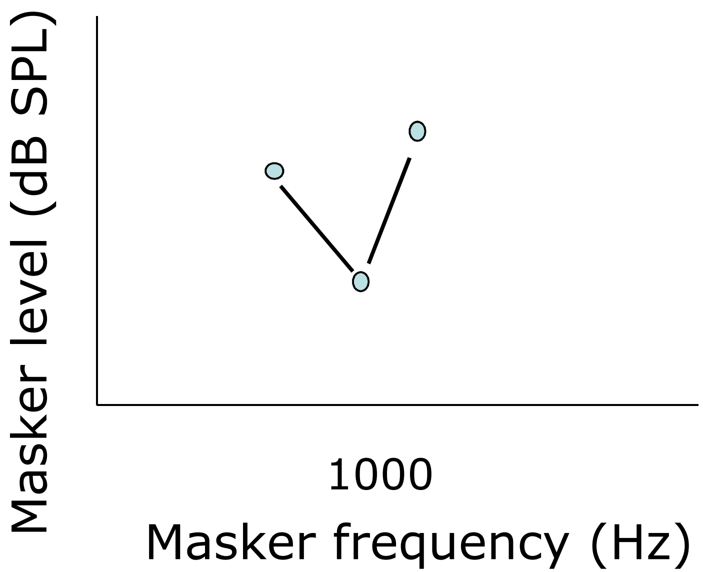
‘Dead’ regions: An extreme case of increased threshold

- Regions in the inner ear with absent or non-functioning inner hair cells (IHCs)
- No BM vibrations in such regions are directly sensed
- But spread of BM vibration means that tones can be detected ‘off-place’
  - by auditory nerve fibres typically sensitive to a different frequency region
- Most clearly seen when measuring PTCs
  - directly interpretable

Psychophysical tuning curves (PTCs)

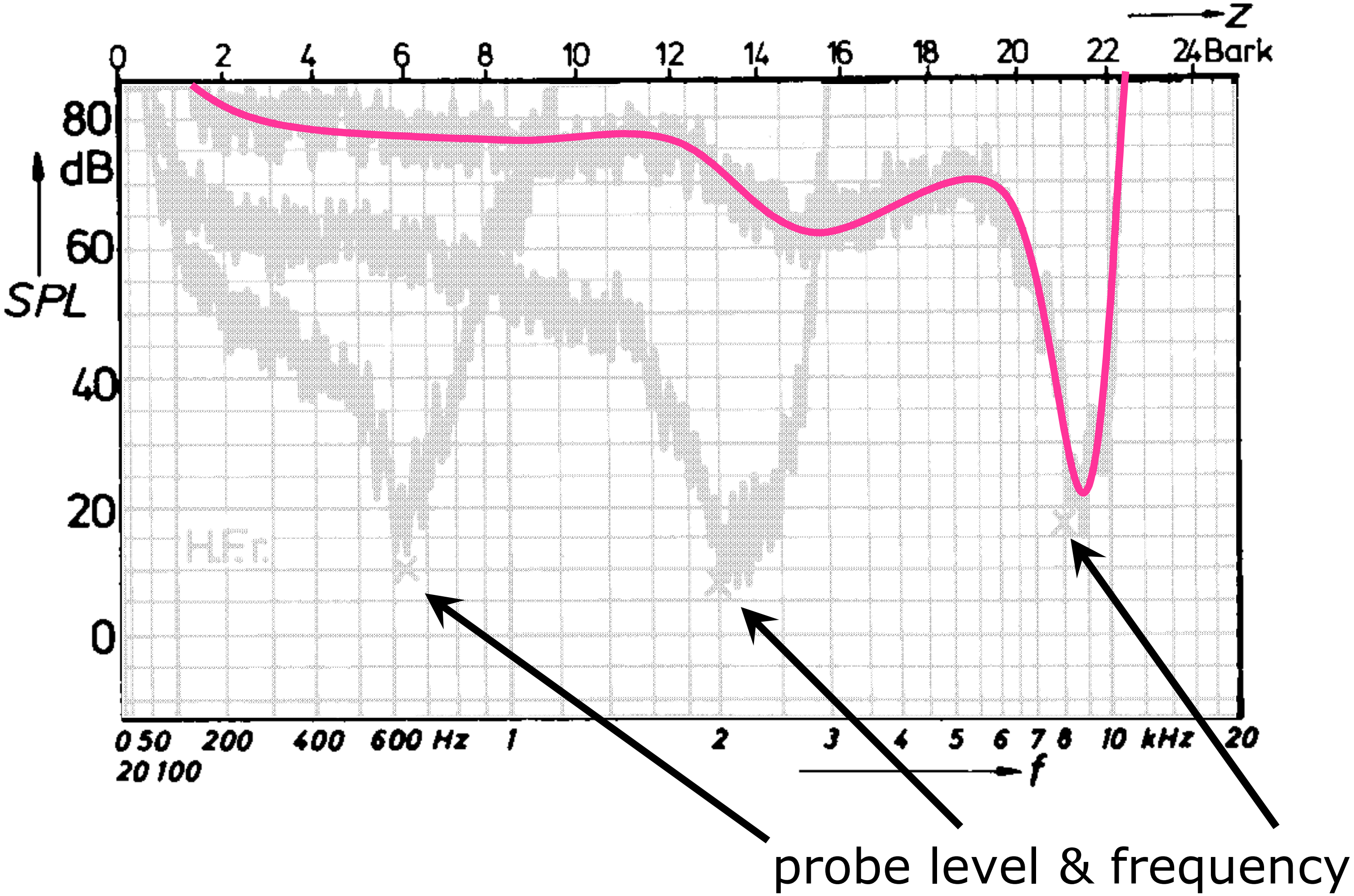




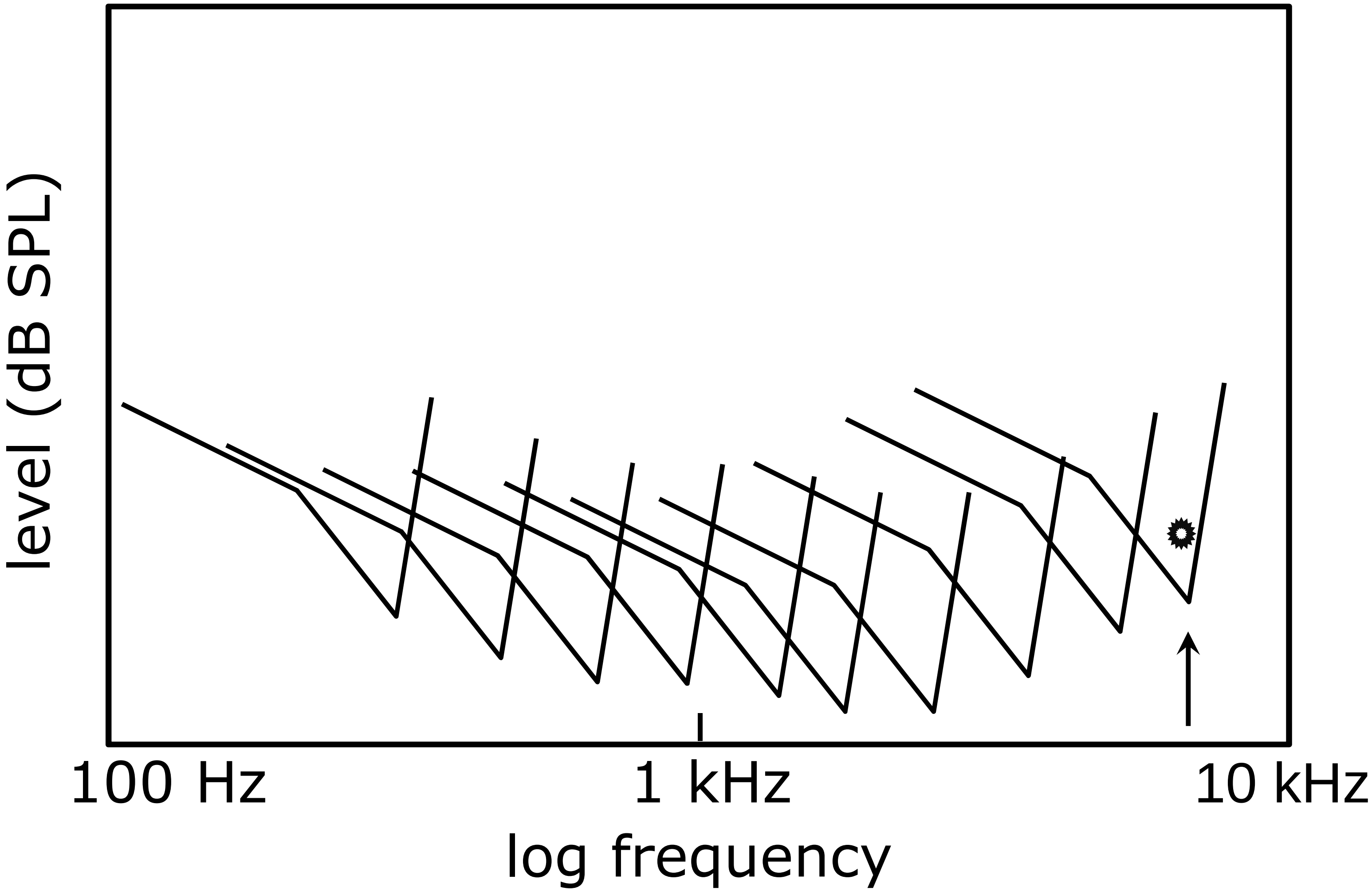


Psychophysical tuning curves (PTCs)

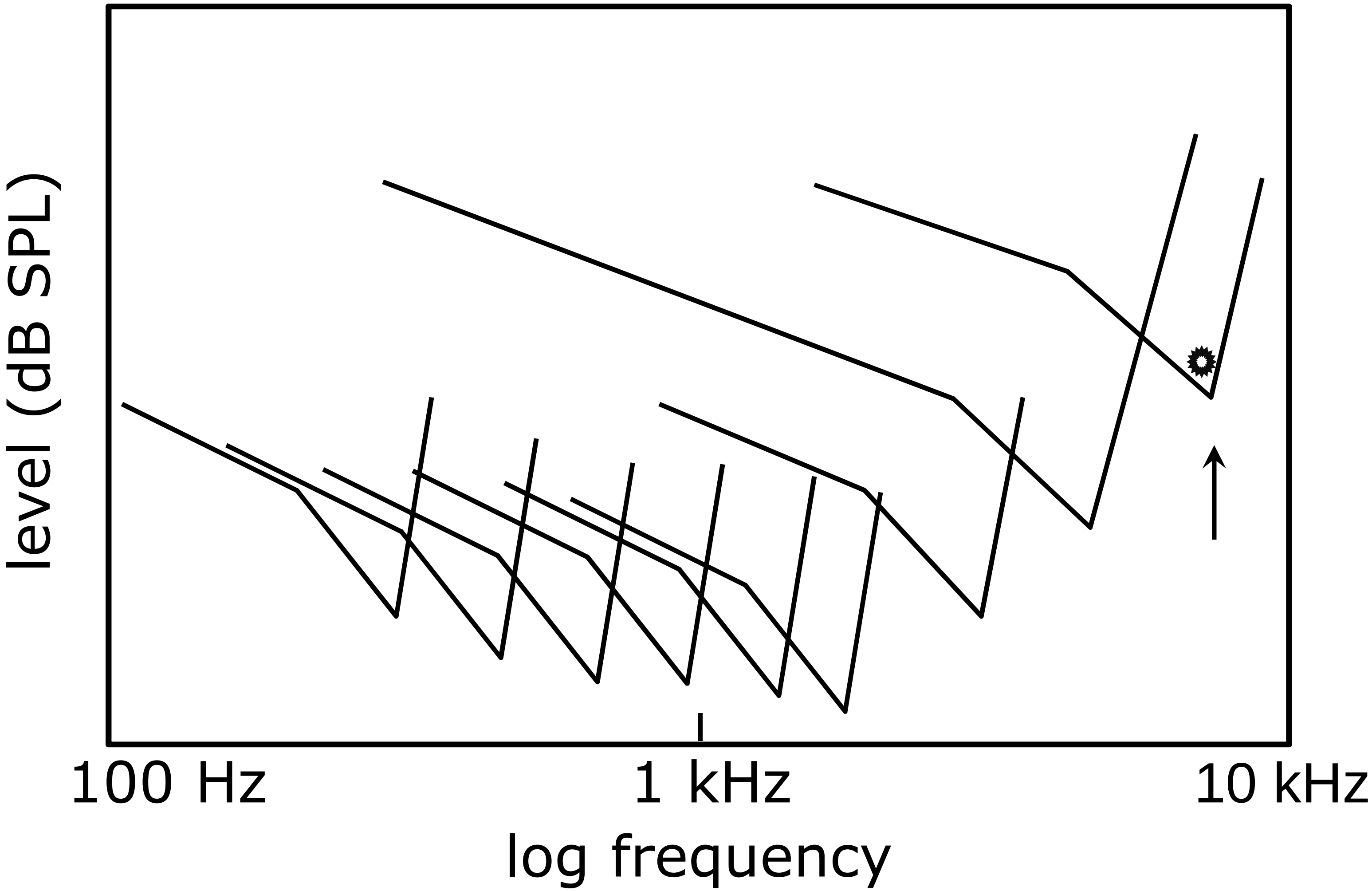
Determine the minimum level of a narrow-band masker at a wide variety of frequencies that will just mask a fixed ***low-level*** *sinusoidal probe.*



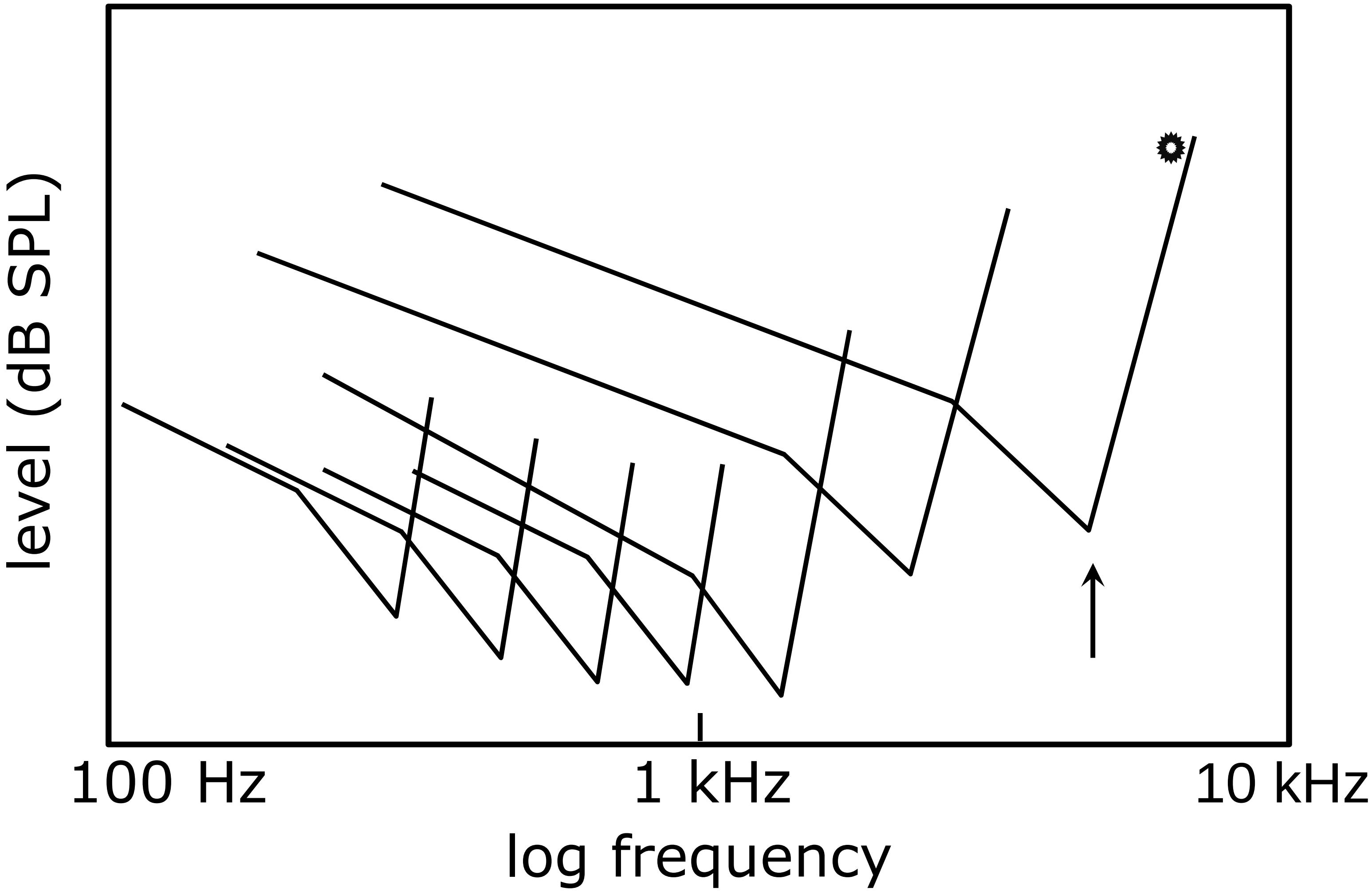
Physiological TCs for a range of auditory nerve fibres: Normal hearing



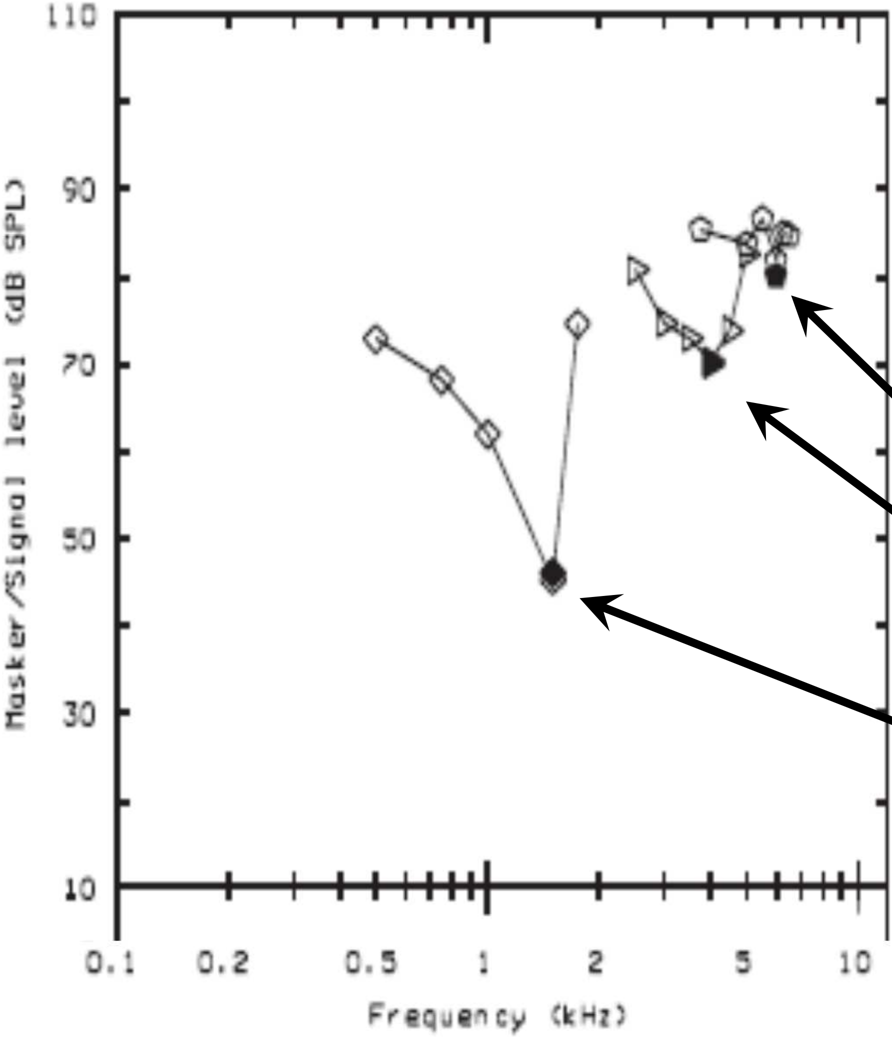
Hearing loss *without* a dead region

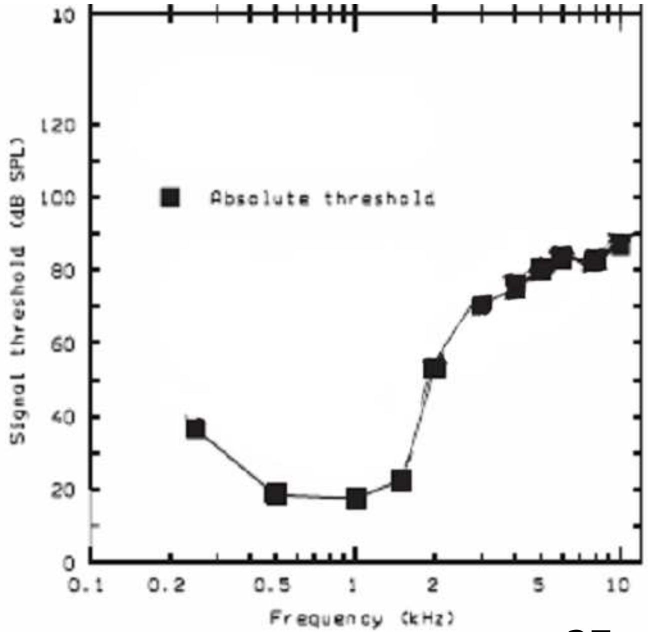


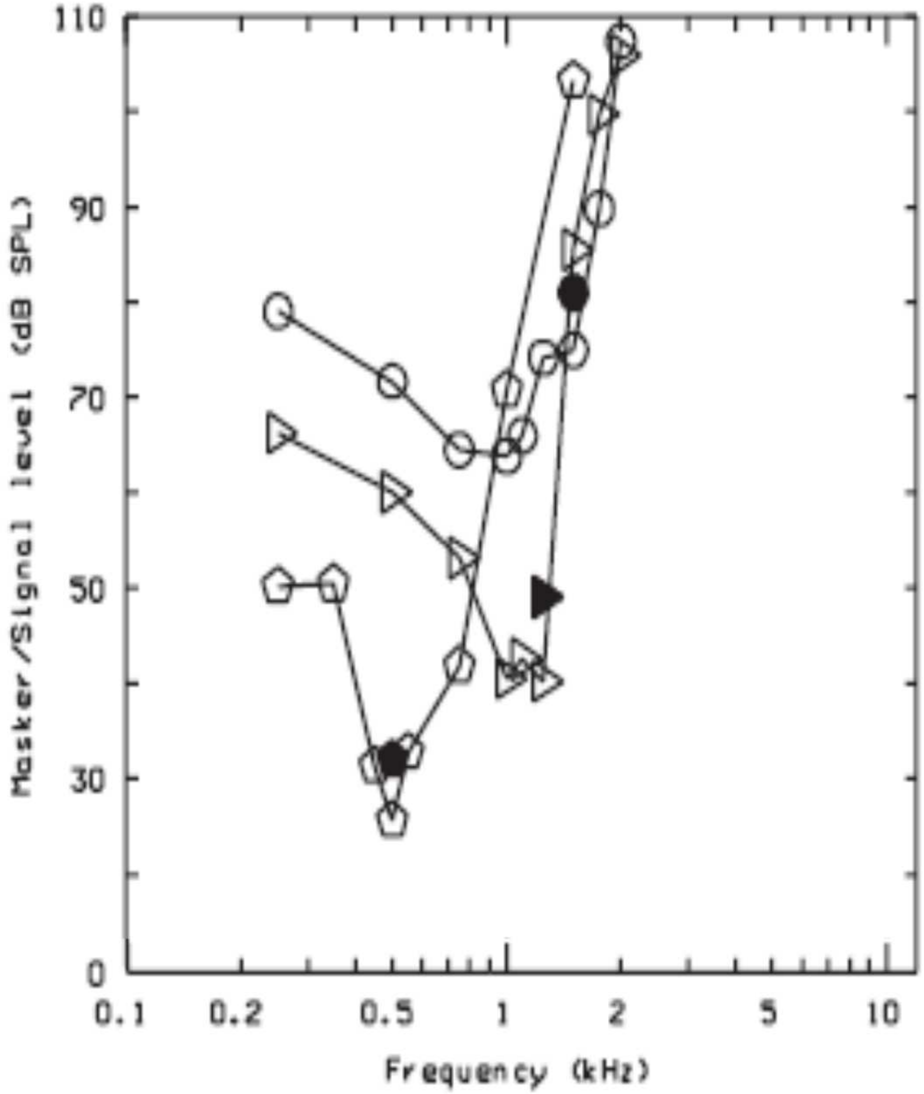
Hearing loss *with* a dead region



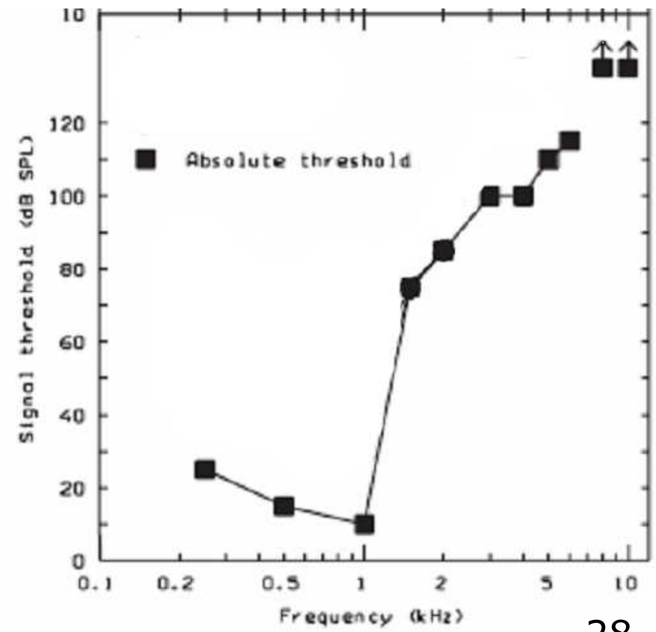
SNHL without dead region: PTCs





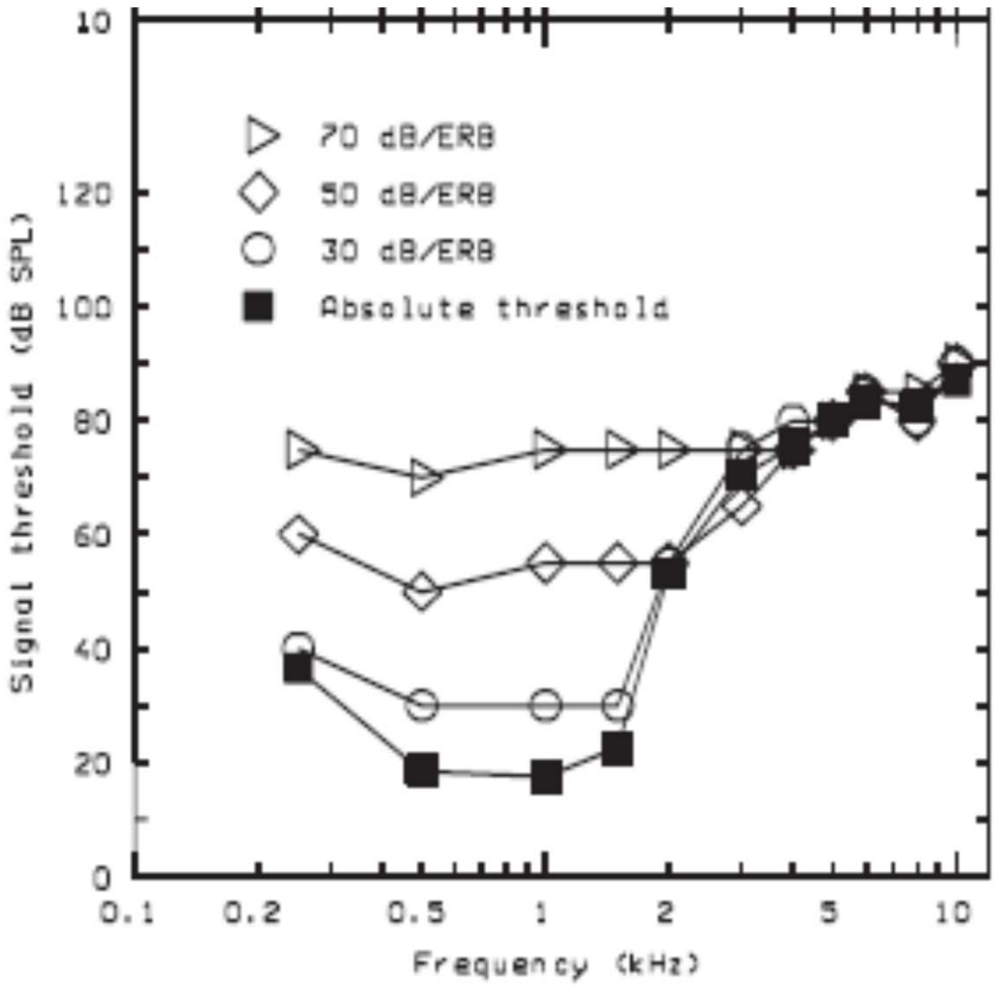


SNHL with dead region: PTCs

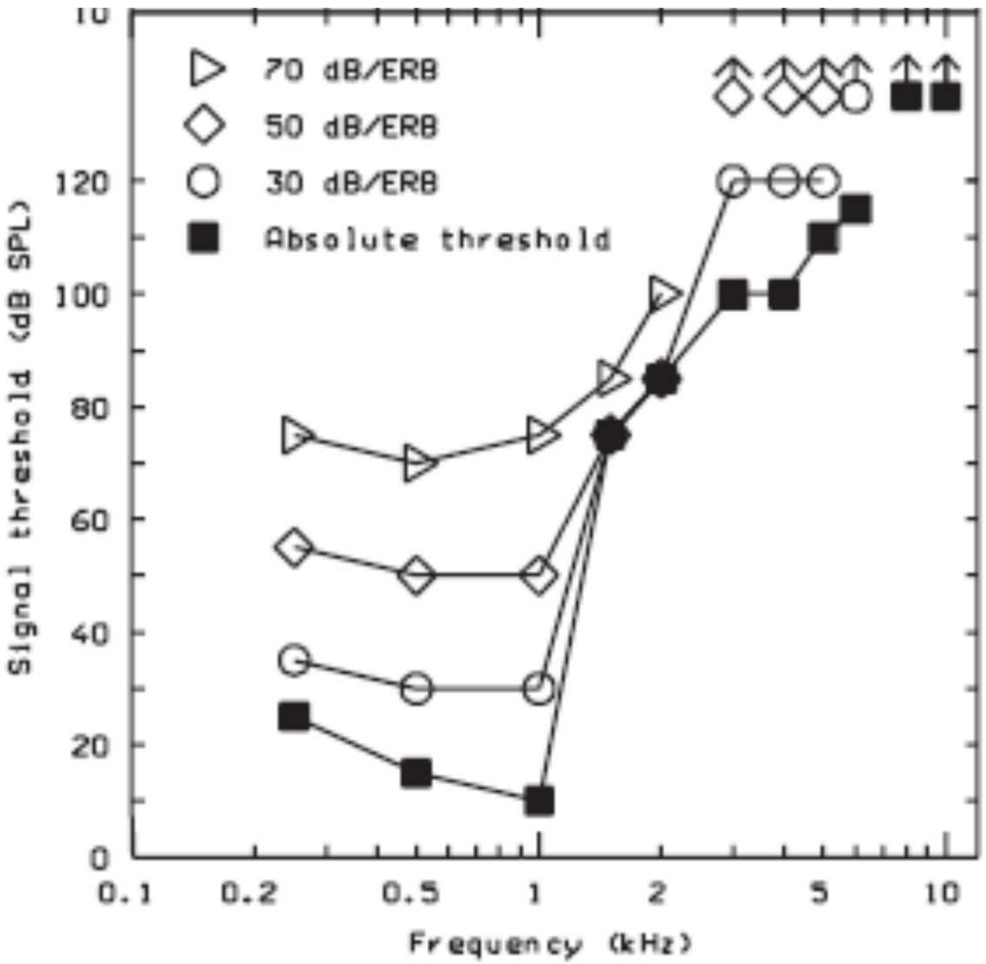


Diagnosing dead regions

- PTCs perhaps clinically impractical
- TEN test (threshold equalizing noise)
  - a broad band noise designed to produce approximately equal masked thresholds over a wide frequency range
- Rationale
  - a tone within a dead region is detected with neurons whose CF is remote from the tone frequency …
  - so amplitude of BM in the remote region smaller than in the dead region …
  - so broad-band noise more effective, as it need only mask the reduced response at the remote place



SNHL without dead region: TEN test

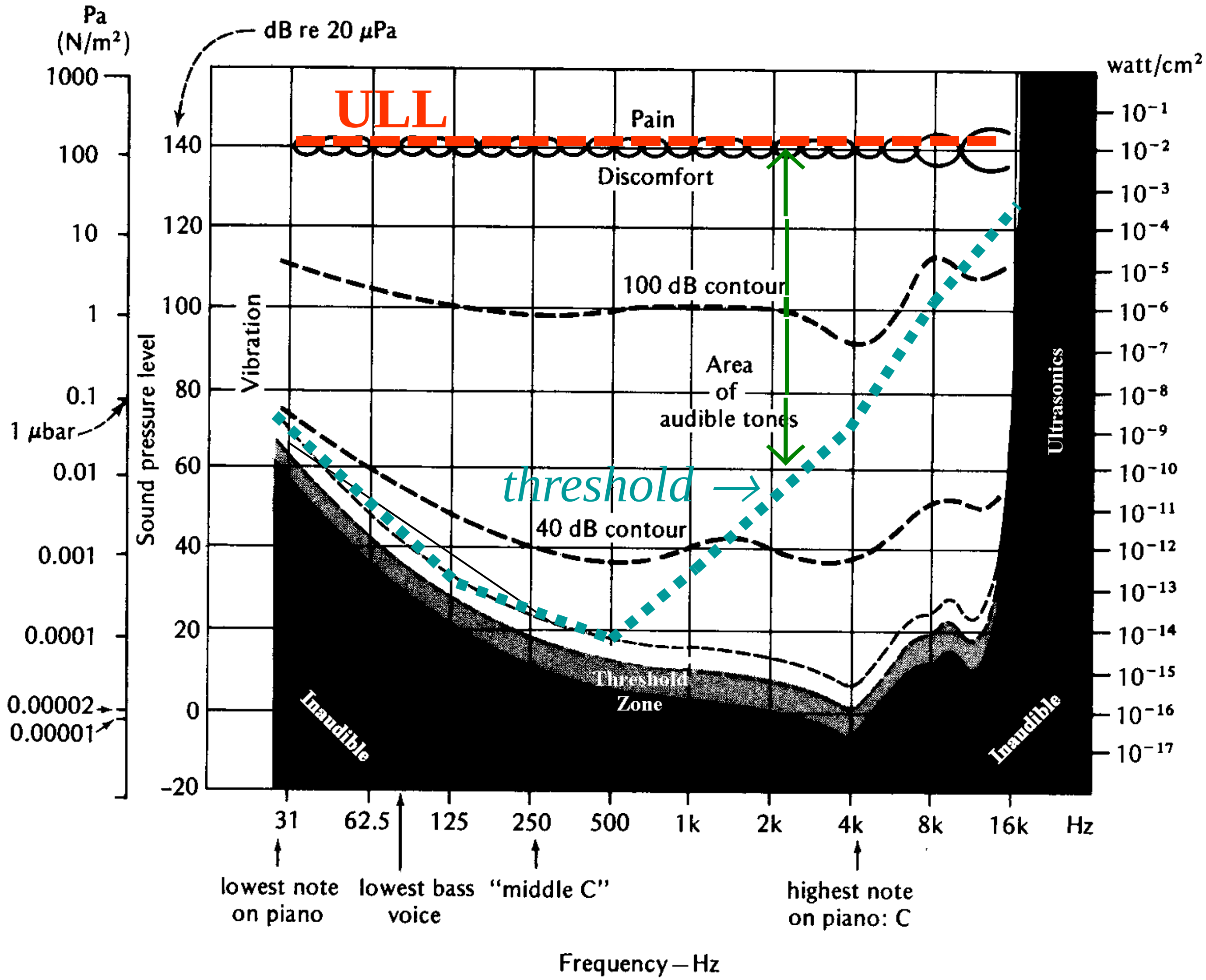


SNHL with dead region: TEN test

Audibility accounts don't explain everything

- Good predictions of speech intelligibility from audibility hold only for mild to moderate hearing losses
- Complete restoration of audibility with more severe losses cannot restore intelligibility
- And these predictions only hold for speech in quiet

Reduced dynamic range in sensori-neural hearing loss



Recruitment requires compression as well as amplification to maximize audibility

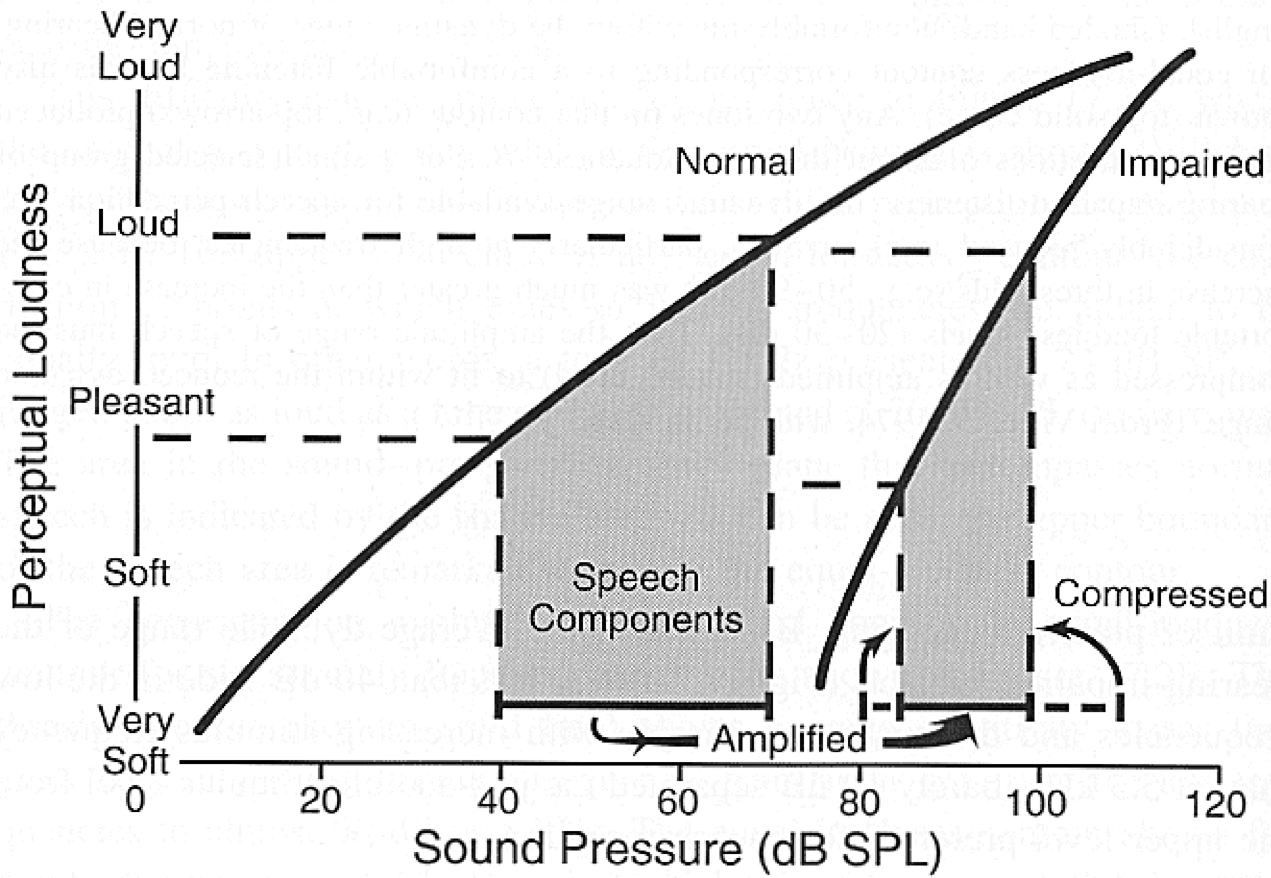
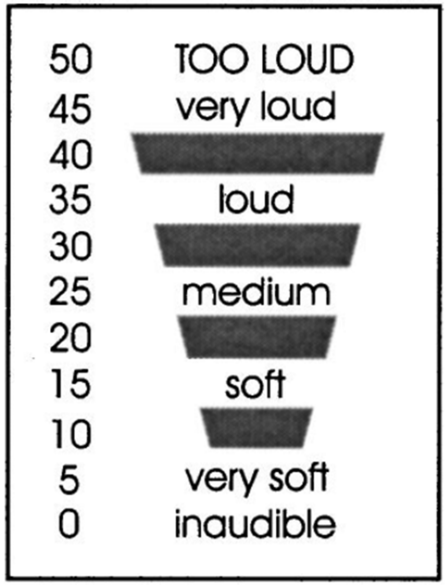


Figure 17.3. Idealized relations between sound pressure and perceptual loudness for subjects with normal hearing (left curve) and those with severely impaired hearing (right curve) for a representative band of frequencies (e.g., around 2 kHz). To produce the same levels of subjective loudness as those experienced by normally hearing listeners, speech for the hearing impaired must be both amplified *and* compressed. (Adapted from Pluvinage, 1994.)

Categorical scaling of loudness ACALOS (adaptive categorical loudness scaling)



ACALOS category scale. Subjects do not see the numbers.
Brand and Hohmann (2002) JASA 112, 1597-1604

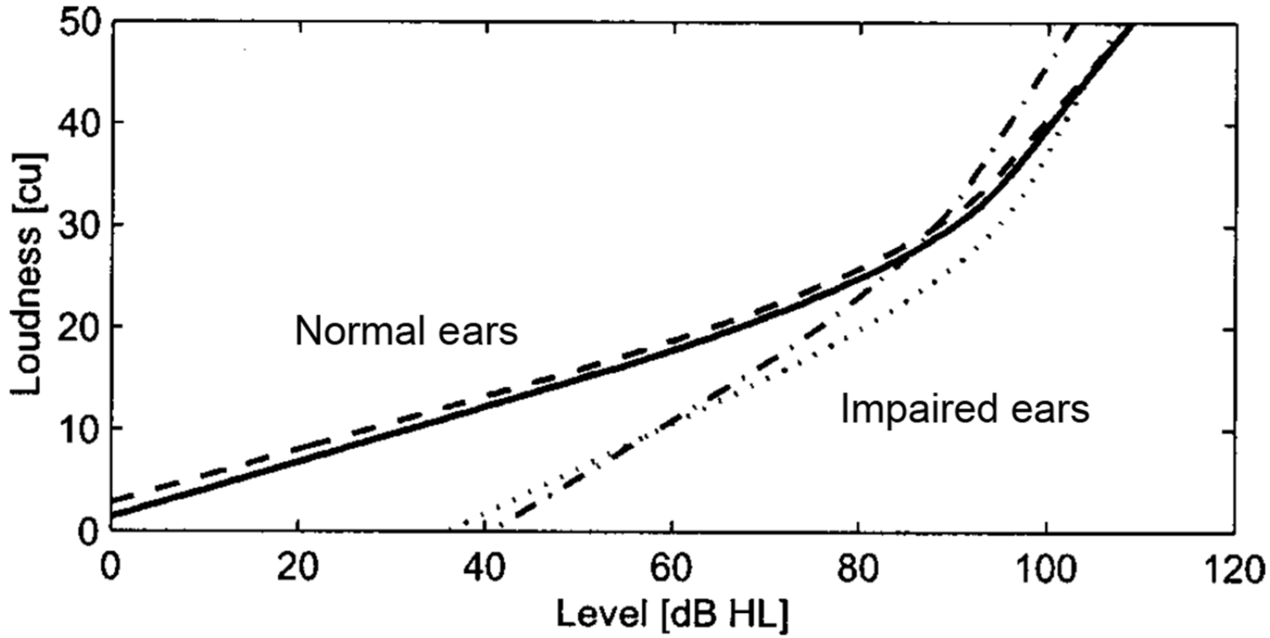
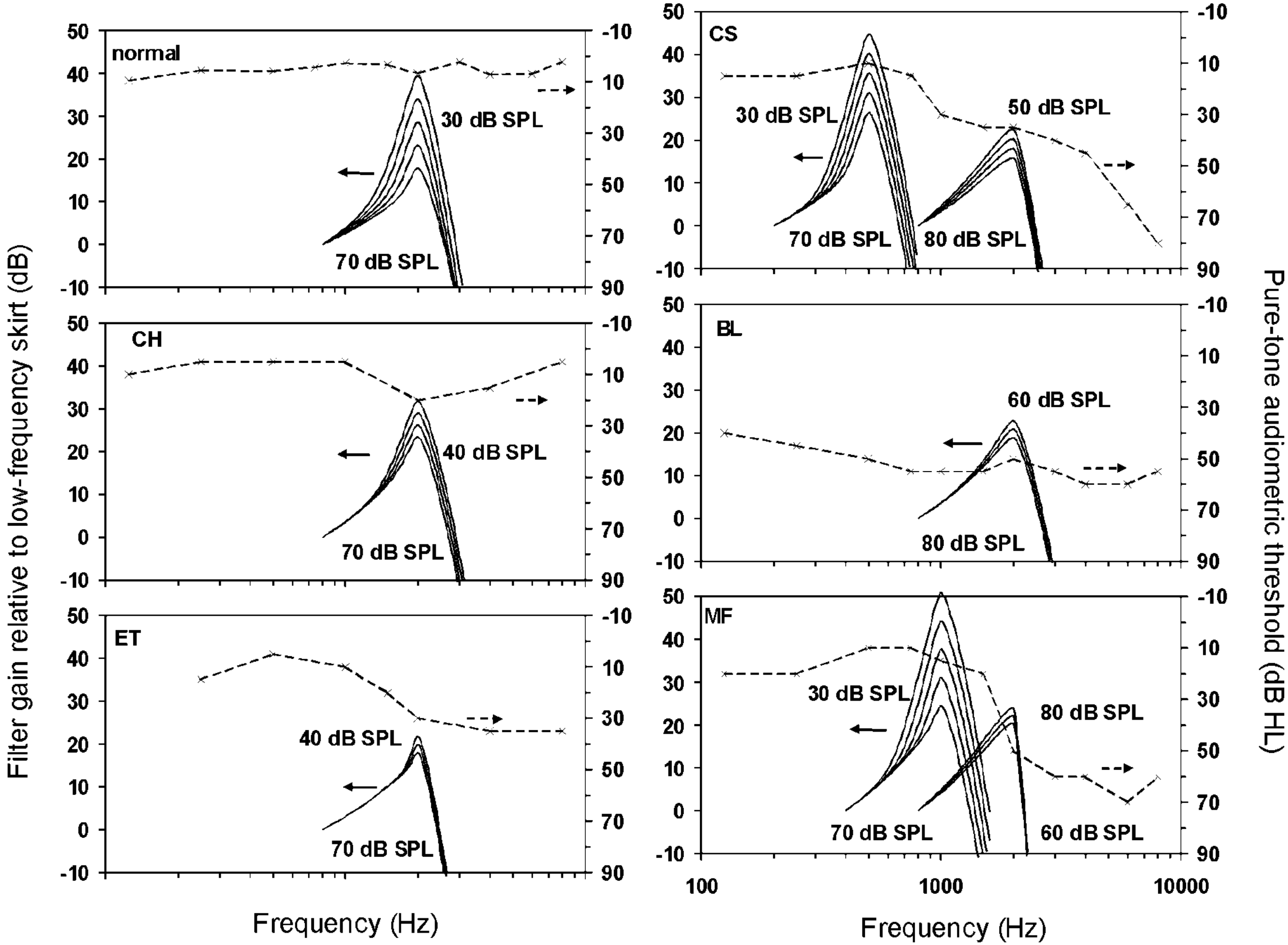
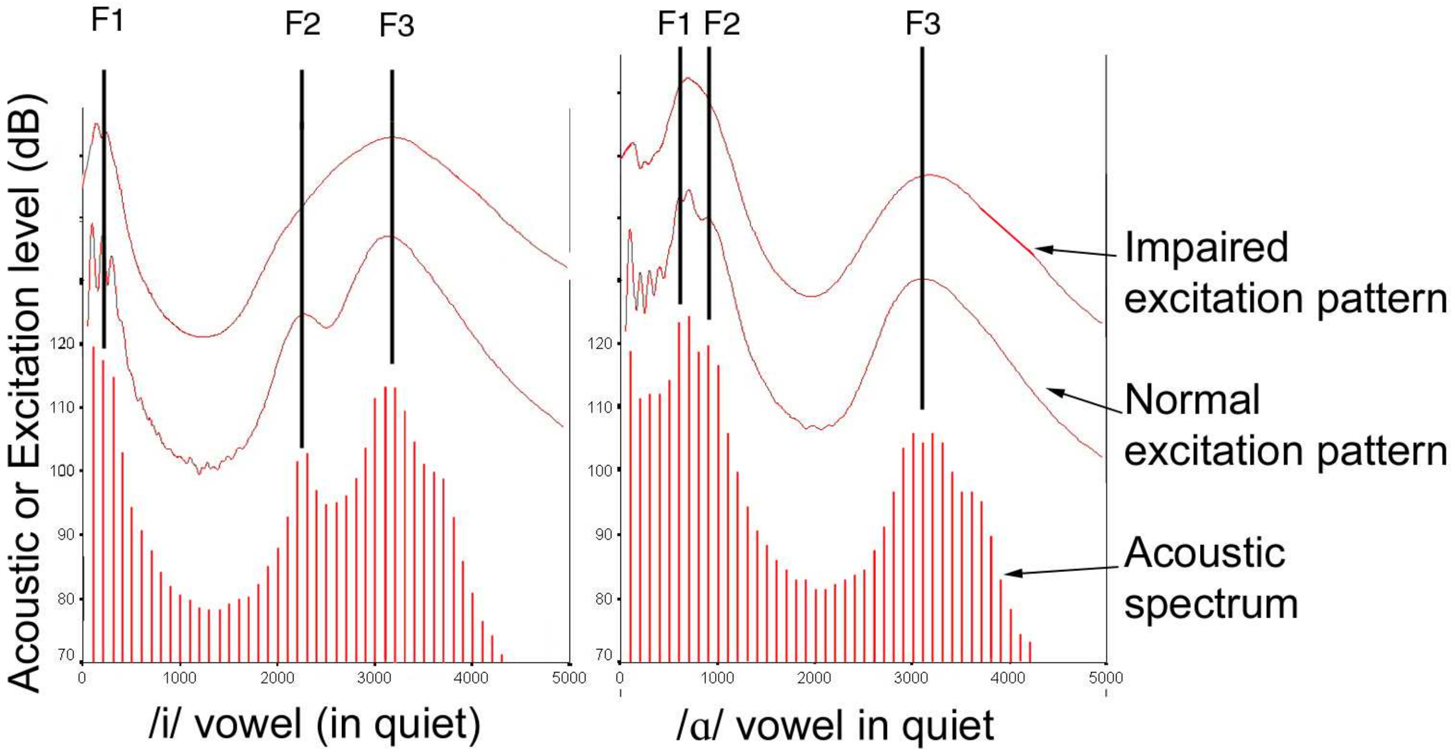


FIG. 5. Loudness functions with the median parameters displayed in Table I. Normal-hearing subjects with adaptive procedure (solid), normal-hearing subjects with constant stimuli procedure (dashed), subjects with hearing impairment with adaptive procedure (dotted), subjects with hearing impairment with constant stimuli procedure (dash-dotted).

Changes in frequency selectivity reflect loss of nonlinearity
Rosen & Baker (2002)

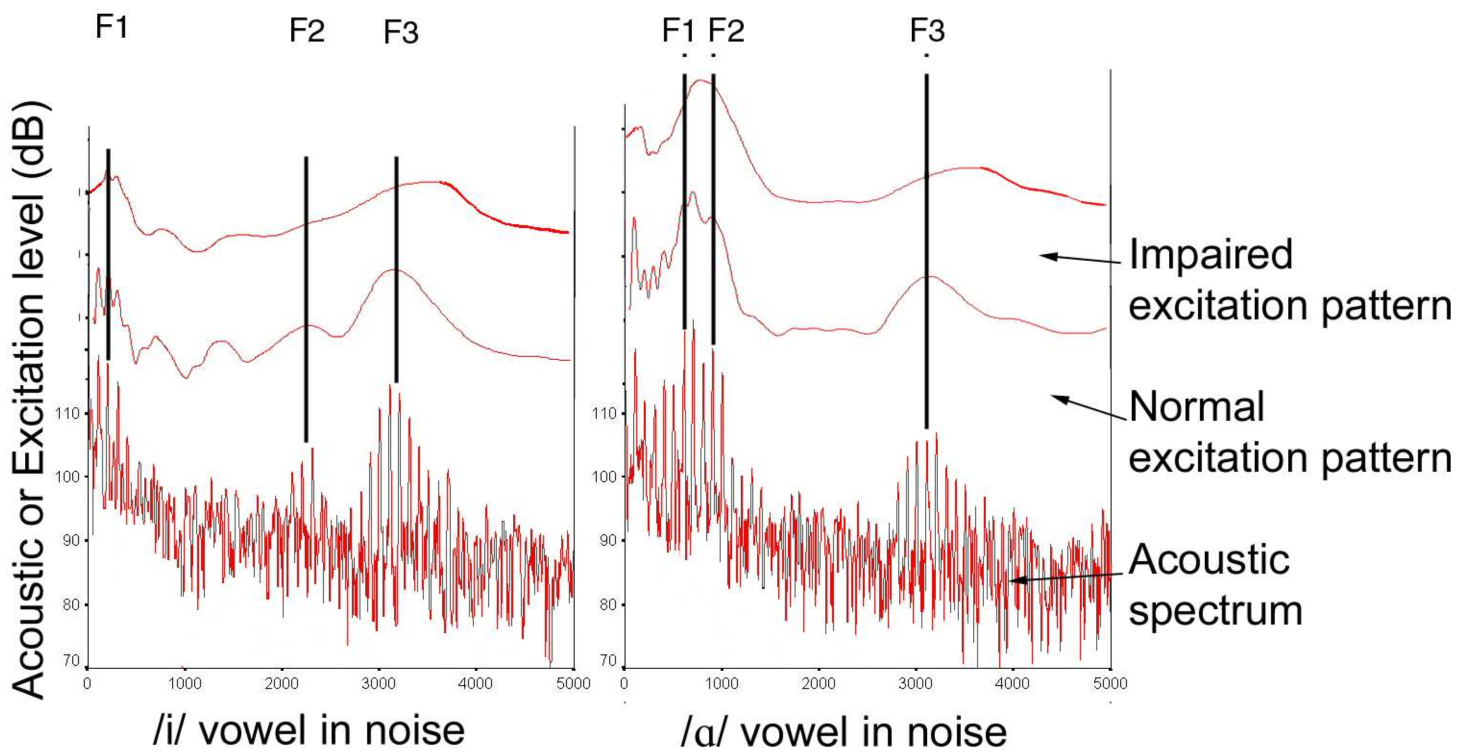


Normal compared to impaired excitation patterns - quiet



Impaired excitation pattern - retains much of formant structure in quiet

Normal compared to impaired excitation patterns - noise



SNR = +6 dB

Normal excitation pattern retains much of formant structure in noise

Impaired excitation pattern has reduced formant structure in noise

What can current hearing aids do for …

- Hearing loss
  - *amplification*
- Reduced dynamic range & loudness recruitment
  - *compression*
- Degraded frequency selectivity
  - *nothing*
- Dead regions
  - *nothing*
- Extent of impairment to TFS not yet clear
  - *no effects of hearing aids, if there is any*