What do we know about physiological reflections of sensori-neural hearing loss?  
focus on hair cell damage

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

![Auditory Nerve Structure and Function](image)

**Liberman (1982)**

![Input/Output functions on the basilar membrane](image)

**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; L11.3: circles) recorded in the sensitive cochlea 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

Auditory Nerve Fiber Responses From Damaged Cochleae

Figure 6B. Comparison of cochlear pathology with the audiogram of a human patient. J. Pollen’s cytoarchitecture, showing the orientation of the hair cells; red line indicates each of the four rows of hair cells, regardless of their condition, plotted as a function of distance from the modiolus. Note the extensive hair cell loss in the most basal 12 mm. J. Pollen’s audiogram, showing a profound hearing loss above 3 kHz; filled circle indicates 3 kHz placed on the characteristic-frequency-identification map for primary auditory neurons in humans (bottom scale of abscissae). (From Schulten et al., 1990, with permission.)

Liberman and Kiang (1978)
Liberman and Bel (1979)
Liberman and Dodds (1984)
Psychoacoustic consequences of sensorineural (cochlear) hearing loss

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

What is the impact on 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

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

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.
‘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)**

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

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

SNHL without dead region: TEN test

SNHL with dead region: TEN test
Reduced dynamic range in sensori-neural hearing loss

Recruitment requires compression as well as amplification to maximize audibility

Categorical scaling of loudness
ACALOS (adaptive categorical loudness scaling)

Changes in frequency selectivity reflect loss of nonlinearity
Impaired excitation pattern - retains much of formant structure in quiet

Normal excitation pattern retains much of formant structure in noise

Impaired excitation pattern has reduced formant structure in noise

SNR = +6 dB

Normal compared to impaired excitation patterns - 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