Psychoacoustics of hearing impairment

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

- A loss of cochlear compression (a linearised input/output function)

- Loss of frequency tuning (analogous to widened filters in an auditory filter bank)

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

![Auditory Nerve Structure and Function](slide courtesy of Chris Brown, Mass Eye & Ear Liberman (1982))
Frequency response of a single place on the BM in an impaired ear (furosemide)

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

Liberman and Kiang (1978)
Liberman and Bel (1979)
Liberman and Dodds (1984)
Effects of OHC damage and total loss on tuning in the auditory nerve

An auditory area in sensorineural loss

Recruitment requires compression as well as amplification to maximize audibility

Categorical scaling of loudness
ACALOS (adaptive categorical loudness scaling)

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 Plavins, 1994.)

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


‘Dead’ regions

- 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

SNHL without dead region: PTCs

Hearing loss *with* a dead region

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

What can current hearing aids do for ...

- Hearing loss
- Reduced dynamic range & loudness recruitment
- Degraded frequency selectivity
- Dead regions