Dead regions in the cochlea: What are they and why do they matter?
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Objectives

To develop:

1. a basic understanding of the anatomy and physiology of dead regions

2. a basic understanding of the tests available for detecting dead regions

3. a basic understanding of the implications of dead regions for fitting hearing aids
Dead regions

Much of the work into dead regions has been conducted by Professor Brian C.J. Moore of the Department of Experimental Psychology at the University of Cambridge, UK

http://hearing.psychol.cam.ac.uk

Key reference:
Anatomical/physiological basis

**Organ of Corti**

- **Scala media (endolymph)**
- **Scala vestibuli (perilymph)**
- **Basilar Membrane**
- **Scala tympani (perilymph)**
- **Nerve fibres**
Anatomical/physiological basis

Hair Cell Movement

1. Sound induced pressure changes deform the inner ear tissues
2. This displaces the hair bundles of the hair cells
3. This cause the hair cells to pivot at their base
Anatomical/physiological basis

Pivot motion causes tiny ion channels to open

This results in a change in electrical potential across the hair cell

The change in electrical potential causes a neural impulse letting the brain know a sound has been heard at a certain frequency
Anatomical/physiological basis

In summary.....

- acoustic energy enters the cochlea via the motion of the stirrup
- the stirrup and oval window vibration induces a wave which travels towards the apex on the basilar membrane
- as each frequency component approaches the cut-off point along the membrane it slows down;
- at the same time, the outer hair cells sense the basilar membrane motion and inject energy with the correct timing to enhance the vibrations (like timing pushes of a child on a swing)
Anatomical/physiological basis

- **Outer hair cells (OHCs)** - actively enhance the response to weak sounds (increases amplitude of vibration) and sharpen the tuning of the basilar membrane (frequency selectivity)
  
  **OHC = AMPLIFIERS**

- **Inner hair cells (IHCs)** transform the mechanical vibrations of the basilar membrane into neural activity in the auditory nerve. IHCs are the transducers of the auditory system.
  
  **IHC = TRANSDUCERS**
Anatomical/physiological basis

Sensori-neural hearing loss is often associated with damage to the hair cells within the cochlea. This damage results in elevated thresholds in two main ways:

1. *Damage to OHCs impairs ability to hear soft sounds.*

2. *Damage to IHCs reduces the efficiency of transduction.*
Anatomical/physiological basis

Normal

IHCs

OHCs
Anatomical/physiological basis

OHC pathology

IHCs

OHCs
Anatomical/physiological basis

What is a dead region?

IHCs at certain places along the basilar membrane may be completely non-functioning.

Also, the auditory neurones may be non-functioning.

Anatomical/physiological basis

IHC pathology (dead region)

IHCs

Dead regions

OHCs
Anatomical/physiological basis

When a dead region is present, the audiogram may give a misleading impression of the amount of hearing loss (Halpin, 2002).

Pure tones at frequencies within a dead region may not be detected at their normal place ("on-frequency listening") **BUT**
May be detected by inner hair cells at the edge of the dead region: "off-frequency listening".

Anatomical/physiological basis

Two instances that give rise to off frequency listening:

1. **Upward spread of excitation**
   - Low frequency sounds may be detected via neurones that are tuned to higher frequencies

2. **Downward spread of excitation**
   - High frequency sounds may be detected via neurones that are tuned to lower frequencies
Anatomical/physiological basis

Example of upward spread of excitation:

(Moore, 2001)
Anatomical/physiological basis

Upward spread of excitation
Low frequency dead region to 1.3 kHz.

Presented 250Hz tone  Response recorded at 60dB

(Moore, 2001)

250 Hz tone detected at 1.3 kHz off-frequency
10dB threshold
Anatomical/physiological basis

Example of downward spread of excitation:

(Moore, 2001)
Anatomical/physiological basis

Example of downward spread of excitation:
High frequency dead region above 1kHz

Presented following tones:

- 1.5kHz response at 85dB
- 1.4kHz response at 80dB
- 1.3kHz response at 70dB
- 1.2kHz response at 60dB
- 1.1kHz response at 55dB

All tones detected off-frequency

(Moore, 2001)
Tests for detecting dead regions

How useful is PTA at detecting dead regions?

A pure-tone audiogram gives us thresholds across the frequency range. It does not tell us if detection is "on-frequency" or "off-frequency".

*Dead regions cannot be reliably detected using Pure Tone Audiometry*
Tests for detecting dead regions

Detecting dead regions

1. Psychophysical tuning curve (PTC)

2. Threshold Equalising Noise (TEN) test
Psychophysical Tuning Curve (PTC)

The Psychophysical Tuning Curve (PTC) involves plotting a curve of the minimum masking noise required to mask a pure-tone of a fixed frequency.
PTC Test – Procedure

1. If a dead region is suspected at a particular frequency a pure-tone at this frequency is generated at 10 dB sensation level (10 dB above PTA threshold).

2. In the same ear a narrow-band masker is introduced with an identical centre frequency.

3. The level of the narrow-band masker is increased until the pure-tone is masked. The level of the masker is recorded.
Psychophysical tuning curve

PTC Test – Procedure

4. With the same pure-tone, the centre frequency of the narrow-band masker is altered and the procedure repeated.

5. The procedure is repeated until a number of narrow-band maskers (above and below the pure-tone frequency) have been measured.

6. A curve is generated consisting of the minimum masking levels for various narrow-band noises to mask the pure-tone.
Psychophysical tuning curve

Psychophysical tuning curves for 1000 and 2000 Hz

(Moore, 2001)
Psychophysical tuning curve

Interpretation

- In on-frequency hearing, the masker is most effective (less masking noise required) when its frequency is close to that of the pure-tone.

- In the presence of a dead region (off-frequency hearing), the masker is most effective in areas that are shifted well away from the pure-tone.
Psychophysical tuning curve

Psychophysical tuning curves for 1000 and 2000 Hz

No dead region – “on frequency listening”

(Moore, 2001)
Psychophysical tuning curve

Low-frequency dead region
Upward spread of excitation and “off frequency listening” (Moore, 2001)

High-frequency dead region
Downward spread of excitation and “off frequency listening” (Moore, 2001)
Psychophysical tuning curve

Summary of the Psychophysical tuning curve

Strengths:
Good research tool (once considered GOLD STANDARD for diagnosing dead regions)(Summers, et al., 2003)

Psychophysical tuning curve

Summary of the Psychophysical tuning curve

**Weaknesses:**
- Time-consuming and it is not suitable for use in clinical practice
- The choice of the appropriate signal frequency and level can be difficult
Threshold Equalising Noise

TEN Test

The Threshold Equalising Noise test (TEN) involves doing pure-tone audiometry in the presence of a special background noise called “threshold-equalising noise” (Moore et al, 2000).

Threshold Equalising Noise

The “threshold-equalising noise” is a broadband noise that is spectrally shaped so that the masked threshold is approximately the same for all frequencies in the range of 250 Hz to 10 kHz, for people with normal hearing.

![Graph showing noise spectrum level vs. frequency and signal threshold vs. frequency for normal hearing listeners with different signal levels.]
Threshold Equalising Noise

TEN Test – set-up

1. Feed the left output from the CD player to the left (or A) line-level input on the audiometer, and the right output from the CD player to the right (or B) input.

2. Select the left (A) input from channel 1 on the audiometer, and the right (or B) input from channel 2 on the audiometer.

3. Play track 1, set the audiometer so that both line inputs are played continuously (press the interrupt buttons), and adjust both VU meters to read 0 dB. Turn off the two inputs (press the interrupt buttons).

4. Mix the two channels, and direct the mixed channels to the desired ear (left or right).
Threshold Equalising Noise

TEN Test – procedure

1. Set the desired TEN noise level using the channel 1 control (10 dB higher than the audiometric threshold).

2. Measure the masked threshold of each ear at each frequency, using tracks 2-8 of the CD, while playing the noise continuously (press the interrupt button for channel 1). The test-tone level is controlled via channel 2. The level in dBHL corresponds to the dial reading on the audiometer. Use a 2 dB final step size.
Threshold Equalising Noise

Interpretation

If a pure-tone in a dead region is heard “off-frequency”, the amount of vibration at this remote region will be less than in the dead region and so the TEN noise will be very effective in masking it.

A dead region at a particular frequency is indicated by a masked threshold that is at least 10 dB above the PTA threshold and 10 dB above the TEN(HL) noise level.
Threshold Equalising Noise

TEN Test

Threshold\(_{\text{noise}}\) >
or = PTA + 10 dB

YES

YES

Th\(_{\text{noise}}\) > or
= TEN Noise + 10 dB

YES = dead region

NO = no dead region
Threshold Equalising Noise

Ten Test - High frequency dead region

1500 Hz pure-tone presented and the threshold determined to be 60dB.

The pure-tone is being heard off-frequency at 1 kHz.
Threshold Equalising Noise

Ten Test - High frequency dead region

The TEN noise is introduced at 10dB sensation level (70 dB).

The new 1500 Hz pure-tone threshold is determined to be 95dB.

Detection in TEN
Threshold Equalising Noise

TEN Test

Threshold \(_{\text{noise}}\) (95 dB) >
Threshold \(_{\text{quiet}}\) + 10 dB (60 + 10 = 70 dB) >
TEN Noise level + 10 dB (70 + 10 = 80 dB)

= dead region at 1.5kHz
Threshold Equalising Noise

Validity

To assess the validity of the TEN test, Moore et al. (2000) measured PTCs using the same hearing-impaired listeners as tested with the TEN. 20 ears of 14 subjects with sensori-neural hearing loss were tested.

Generally, there was a very good correlation between the results obtained using the TEN and the PTCs.

Threshold Equalising Noise

Summary of the TEN test

**Strengths:**
Good for clinical practice since it is quick to administer

**CDs containing the test are available from:**
http://hearing.psychol.cam.ac.uk/dead/dead.html

CDs cost: £15 sterling, $25 US or 20 Euros
Implications for fitting hearing aids

The presence or absence of dead region can have important implications for fitting hearing aids and for predicting the likely benefit of hearing aids:

1. If there are one or more extensive dead regions, the benefit of a hearing aid is likely to be limited, and aided speech intelligibility is likely to be poor. (Vickers, Moore and Baer, 2001)

2. When a person has a dead regions, there may be little or no benefit in applying amplification for frequencies well inside the dead regions. Indeed, such amplification may impair speech intelligibility. (Moore, 2004)
Implications for fitting hearing aids

Some indicators of the existence of high-frequency dead regions are:

- Whenever the audiogram has a very steep slope, the threshold worsening rapidly with increasing frequency

- With acquired losses, losses greater than 90 dB at high frequencies or 75-80 dB in the low frequencies are often associated with dead regions (Moore, 2001)

- The patient reports a noise rather than tone perception during pure-tone audiometry

- Lack of benefit from previously fitted hearing aids
Implications for fitting hearing aids

For people with high frequency dead regions, there is little or no benefit to speech discrimination from amplifying frequencies well inside a dead region, but there may be some benefit in amplifying frequencies up to 1.7-2 times the estimated edge frequency of the dead regions (Vickers, Moore and Baer, 2001)

The situation for patients with dead regions at low frequencies is less clear cut. Further research into this area is needed (Moore, 2004)

Dead regions in the cochlea: What are they and why do they matter?

I believe you, but be careful when fitting hearing aids.