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Diagnosing Hearing Loss - Beyond the Audiogram

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Hearing loss is usually quantified by measuring the lowest intensity of a tone that can be detected, for tone frequencies from 125 up to 8000 Hz. A graph of the detection threshold plotted against frequency is called the audiogram. However, the audiogram reveals little about the underlying problems that lead to the hearing loss.

Within the part of the inner ear called the cochlea, sounds lead to vibrations of a flexible ribbon called the basilar membrane. A tone of a given frequency produces a pattern of vibration that travels from one end (the base) to the other end (the apex) and peaks at a specific place (Figure 1). Low frequencies produce a peak towards the apex and high frequencies produce a peak towards the base. Lying above the basilar membrane is a structure called the organ of Corti (Figure 2). This contains two types of specialist cells, the inner hair cells (IHCs) and outer hair cells (OHCs). The IHCs detect the vibrations of the basilar membrane and convert them into electrical signals (action potentials) in the auditory nerve; they are the transducers of the cochlea (like the rods and cones in the eye). The OHCs act like miniature motors to amplify the vibrations on the basilar membrane and to sharpen the tuning.

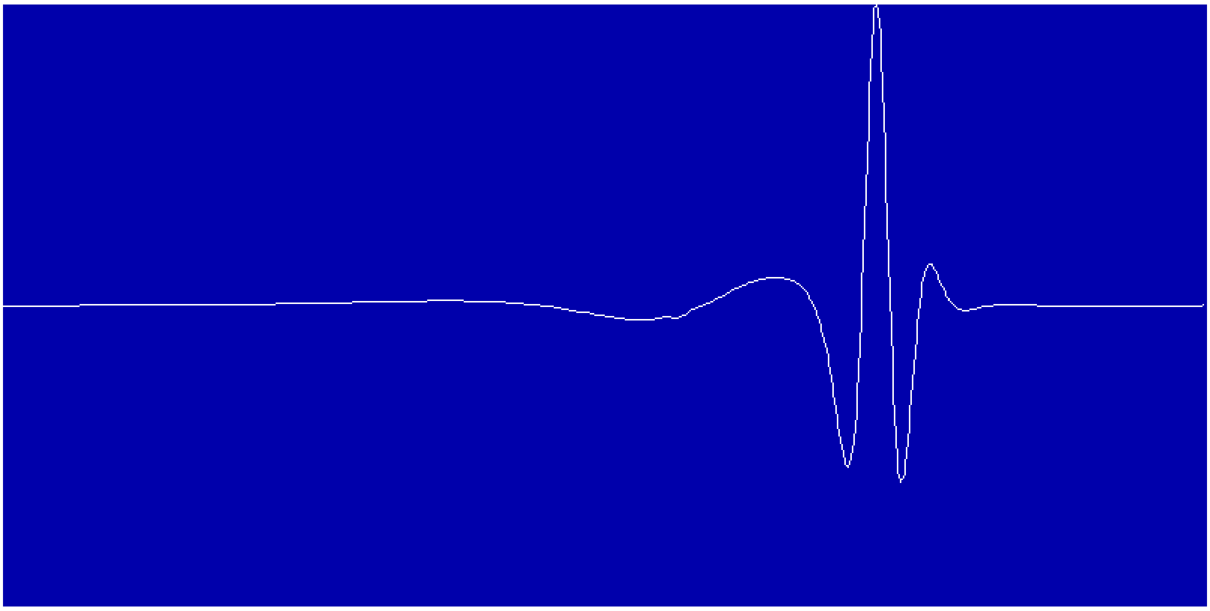


Figure 1. The travelling wave on the basilar membrane in response to a tone. The wave moves from the base towards the apex. The position of peak vibration depends on the frequency of the tone. Demonstration courtesy of Steve Neely (Boys Town Institute, Omaha, Nebraska).

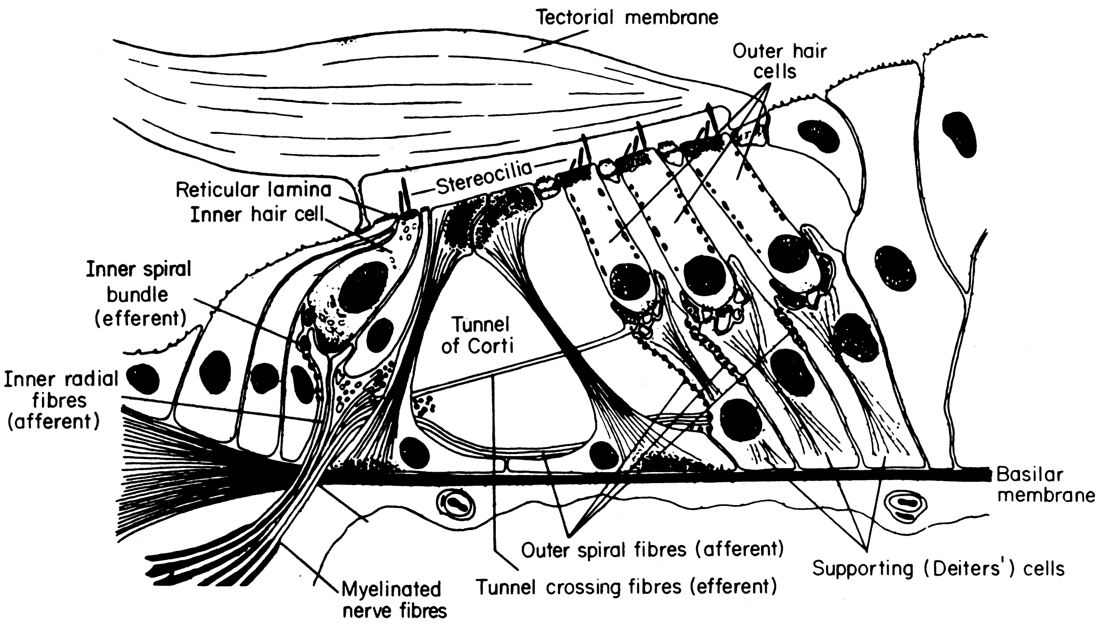


Figure 2. Cross section of the organ of Corti, including the basilar membrane (at bottom), which runs perpendicular to the plane of the figure. A single IHC and three OHCs are visible. From Moore, B. C. J., 2012. An Introduction to the Psychology of Hearing, 6th Ed., Brill, Leiden, The Netherlands.

Hearing loss is often associated with reduced function of the IHCs and OHCs. Sometimes, the IHCs and OHCs themselves are damaged. In other cases, problems with the metabolism of the cochlea stop the IHCs and OHCs from working normally. If the IHCs are functioning very poorly, or not at all, over a certain region along the basilar membrane, this can lead to degeneration of the neurons connected to that region (Figure 3). Such a region is called a dead region. Basilar membrane vibration in a dead region does not give rise to a signal in the auditory nerve. However, a tone that produces its peak response in a dead region may still be detected if it is made sufficiently intense, as the vibration pattern can spread to a region that is not dead. Hence, a dead region cannot be diagnosed from the audiogram.

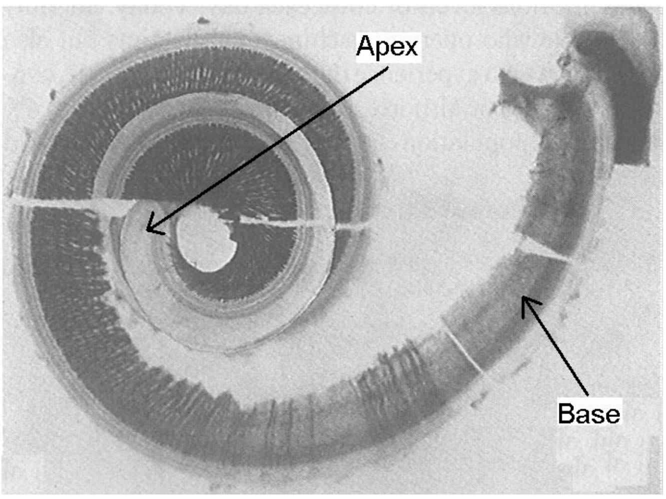


Figure 3. A cross-section of the cochlea of a 25 year old man with a history of using shotguns and rifles. There are some cracks resulting from the preparation technique. The dark lines represent the axons of neurons that form part of the auditory nerve. Note the absence of neurons at the base, indicating a dead region. Redrawn from Johnsson, L. G., 1974. Sequence of degeneration of Corti's organ and its first-order neurons. Ann. Otol. Rhinol. Laryngol. 83, 294-303.

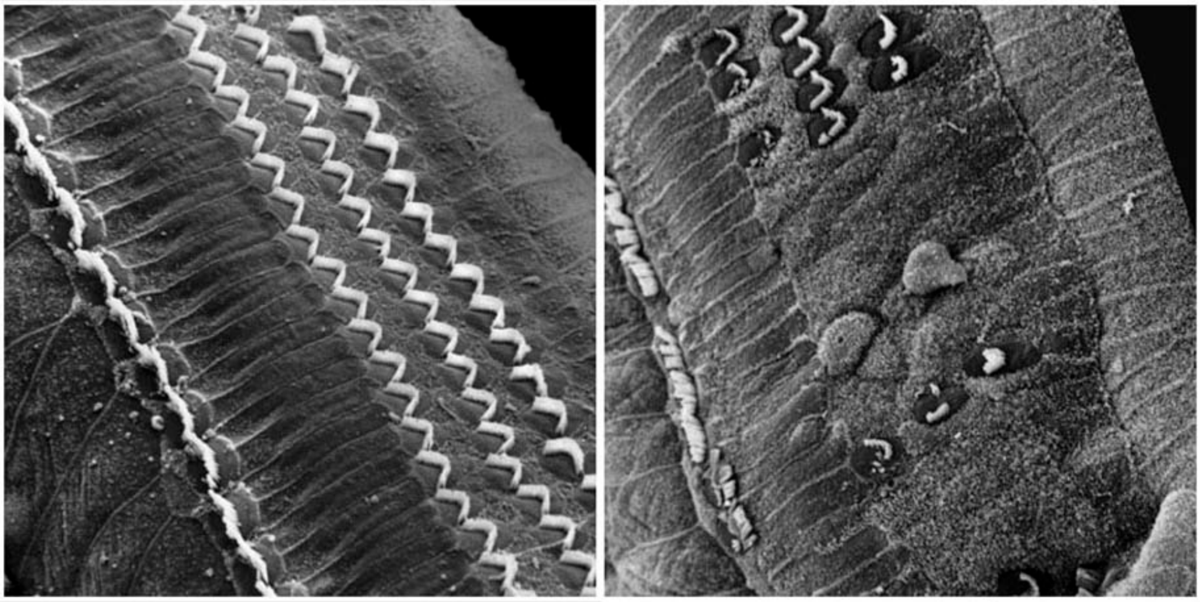


Figure 4. The left panel shows a view looking down at the top of the organ of Corti, showing the tops of the three rows of outer hair cells (OHC) and single row of inner hair cells (IHC), from the ear of a normal mouse. The right panel shows a similar view for a mouse with a damaged ear. OHCs are missing over the bottom ¾ of the figure, and IHCs are missing at the very bottom, indicating the start of a dead region. Image courtesy of [Baylor College of Medicine](), Houston, Texas.

Brian Moore and his colleagues at Cambridge have developed a test for diagnosing dead regions. The test involves measuring the threshold for detecting tones of various frequencies in a special background noise, called threshold equalising noise (TEN), so the test is called the TEN test. When a dead region is not present, the detection threshold is almost independent of frequency over a wide frequency range. However, if the test tone produces peak vibration in a dead region, the detection threshold is markedly higher than "normal", as the tone has to be made sufficiently intense to allow it to be detected via an adjacent region that is not dead. Hence, an abnormally high detection threshold indicates the presence of a dead region.

The results of the TEN test can be useful when adjusting hearing aids to suit the individual. There seems to be little benefit, and sometimes there are negative effects, of amplifying frequencies that produce peak vibration well inside a dead region. Hence, the results of the TEN test can be used to determine the range of frequencies over which amplification should be applied. This leads to more effective use of hearing aids.

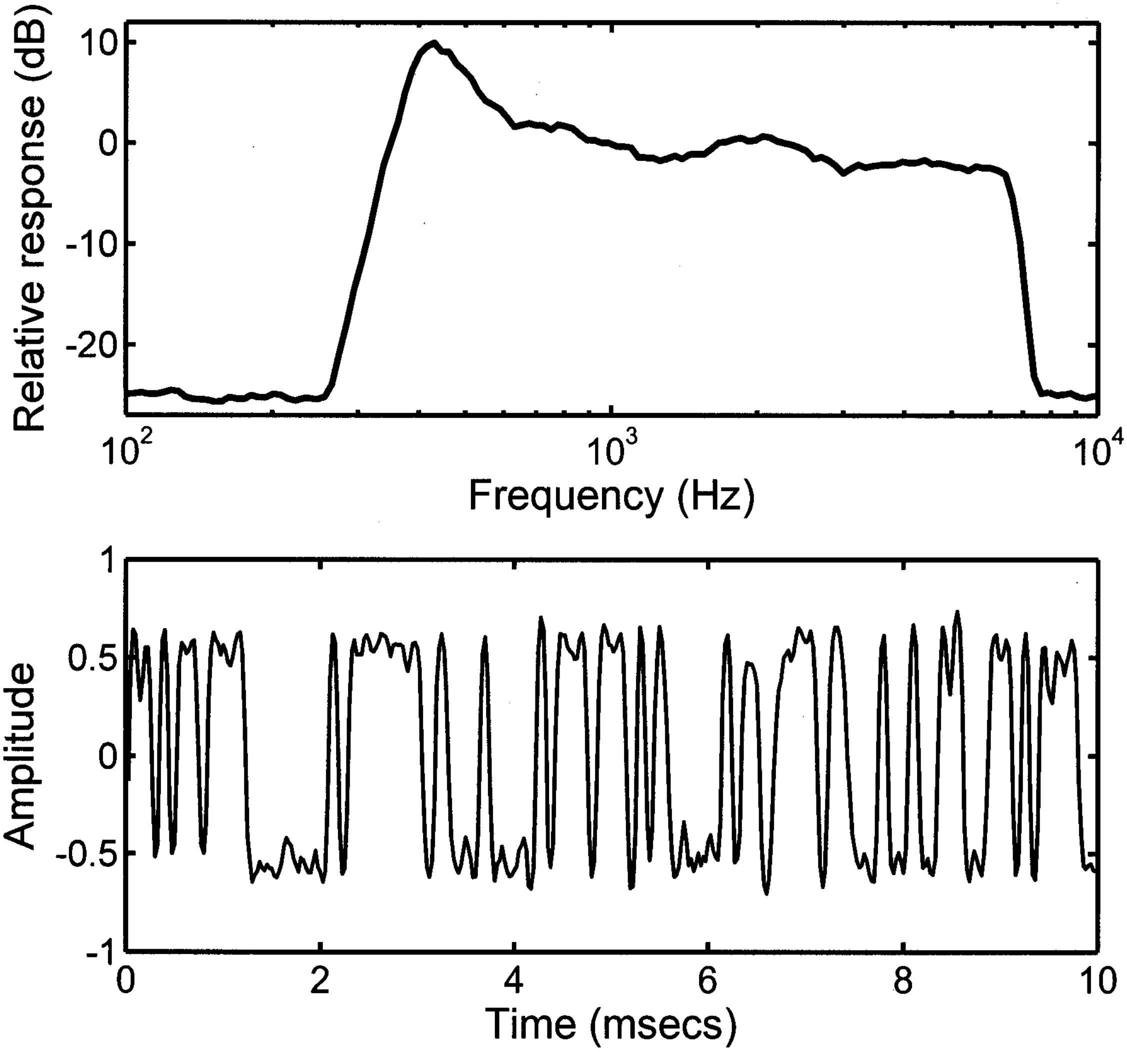
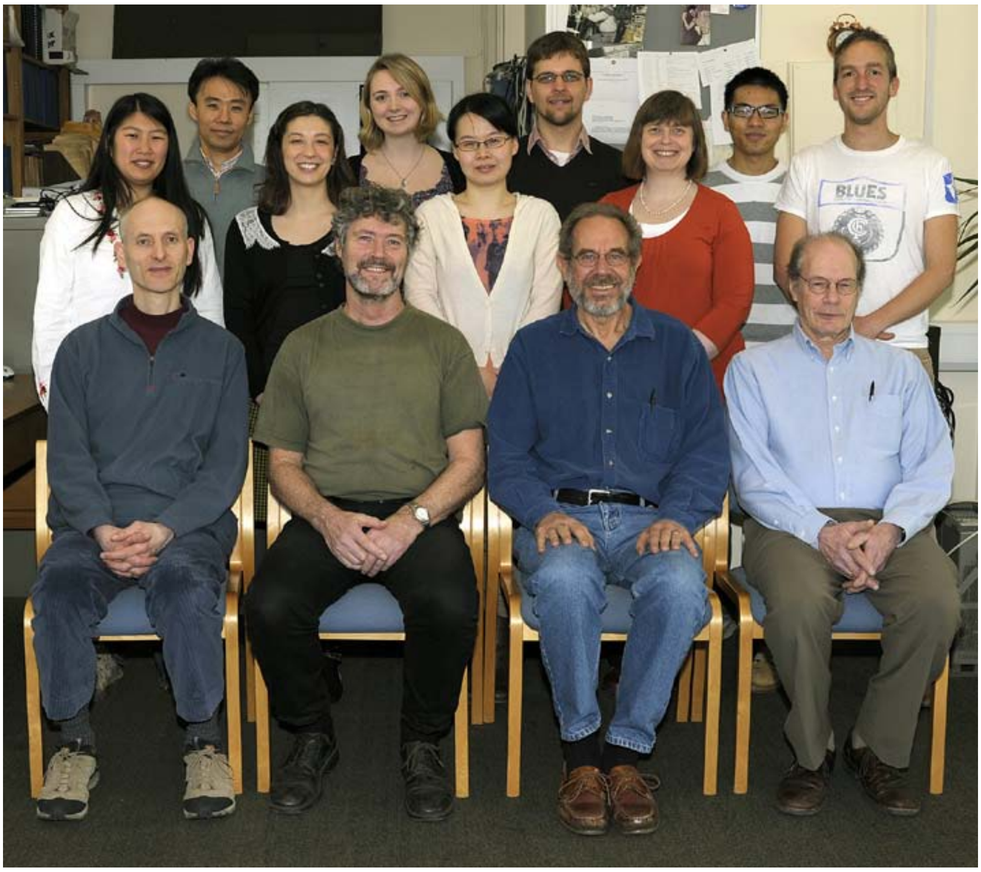


Figure 5. Showing the spectrum (top) and a segment of the waveform (bottom) of the TEN.



Members of the Auditory Perception Research Group in the Department of Psychology, University of Cambridge. Front row (from left to right) Michael Stone, Brian Glasberg, Brian Moore and Tom Baer who all played a role in the development of the TEN test.