How to find cochlear dead regions

One of the first studies that pointed to the possibility that certain frequency regions in the cochlea could be so damaged that avoiding them would be better than amplifying them was from Hallowell Davis and his colleagues in 1950. Davis created a unilateral temporary hearing loss by exposing his subjects to noise. Two unmarked knobs were provided to the subjects- one controlling the sound level and the other controlling the frequency. The subjects were asked to match the loudness and the frequency of tones heard in the normal hearing ear with that of the temporarily damaged ear. For low frequency tones there was a good one-to-one match between the ears but in the damaged cochlear region the subjects heard an increase in frequency as merely an increase in loudness but NOT frequency. That is, the subjects heard sounds in the temporarily damaged ear as flat relative to the good ear. Clinically, one could ask the hard-of-hearing client whether any "distorted" sound was sharp or flat. If the sound was heard as flat, this is evidence of a cochlear dead region to be avoided upon subsequent amplification. Davis and his colleagues referred to this as "diplacusis" but in today's jargon, it would equally be referred to as a cochlear dead region.

Despite knowing about this phenomenon for over 70 years, the identification of cochlear dead regions has been the subject of much research only over the last 15 – 20 years, and its importance cannot be overemphasized for the clinic. Given a cochlear dead region, "less is typically more". Minimizing gain (or shifting away) from frequency regions with significant cochlear damage can result in a more successful hearing aid fitting.

Two clinical studies taken together delineate the audiometric conditions where one would most likely observe cochlear dead regions: Moore and Tan (2003) and Ricketts, Dittberner, and Johnson (2008). While the Moore and Tan study dealt with speech and music, the Ricketts et al. study only dealt with speech. Nevertheless, since cochlear dead regions have more to do with cochlear pathology and not about the input stimulus per se, both studies can be extended to speech and to music.

These studies provide us with two rules of thumb:

- If the hearing loss is at least at a moderate level (or greater than 60 dB HL) then there can be cochlear dead regions.
- If the slope of the audiogram is very steep, then there can be cochlear dead regions.

Therefore, cochlear dead regions need only to be assessed for more significant hearing losses, especially if there is a steeply sloping audiometric configuration. In contrast, for those people with a mild, gently sloping hearing loss, the odds are low that there will be any cochlear dead regions.

Three clinical approaches

Other than asking the hard-of-hearing client whether they heard music as sharp or flat (where "flat" would indicate a cochlear dead region), there are three clinical approaches to locating and assessment of cochlear dead regions: the TEN test (Moore, 2004), using a piano or keyboard (Chasin, 2019), or creating a "distortion-o-gram" (Wm. Martin, 2021 personal communication). Each will provide slightly different information and each will take varying amounts of time.

The TEN (HL) test

A commonly used diagnostic test is the Threshold Equalizing Noise (TEN) test that is a clinically efficient pre-recorded psychophysical test based on masking and cochlear tuning curves (Baer, Moore, and Kluk, 2002; Moore, 2004). The original TEN test took about 20 minutes to obtain results (2 dB steps and 4 octave test frequencies from 500 Hz to 4000 Hz). Using a shaped masker noise that mimicked the HL to SPL curve, Moore, Glasberg, and Stone (2004) created the TEN (HL) version and have been able to reduce the clinical time to roughly 8-10 minutes. The TEN (HL) version has been implemented on some clinical audiometers.

Since cochlear dead regions typically are seen when there is significant inner hair cell damage, clinical suggestions are to only perform this test if the audiometric threshold is greater than 50 dB HL. Moore, Glasberg, and Stone (2004) do suggest some caveats when using this test since artifacts in the results may occur with people with central auditory involvement or in cases of auditory neuropathy.

Piano or keyboard

While the TEN (HL) approach to the assessment of cochlear dead regions is based on the research into masking done mostly in the 1950s, the piano approach is based directly on the work of Davis and his colleagues where hard-of-hearing subjects with an induced unilateral hearing loss heard sounds in the damaged ear as being flat relative to their normal hearing ear. Unlike the TEN (HL) test, this piano-based test takes about 15 – 20 seconds and allows for a clear discussion with the potential hearing aid consumer about some fine-tuning modifications that may be necessary apart from hearing aid fitting formulae. Any garage-sale electronic keyboard would suffice, since this test is merely about a person judging whether two adjacent notes are the "same" or "different" and not about the quality of the music. This is something that the client can perform at home, or at a friend's place who has a piano and they can bring the results with them. They are asked where on the piano the difficulty begins and usually a statement about how many white keys from the top (or above middle C), is the region of their pitch problem. Ask the hard-of-hearing person (without hearing aids) to sit down at the keyboard and begin somewhere on the middle-right side (250+ Hz) by playing every adjacent note going upwards (white key, white key, black key, white key…). They are to judge whether any two adjacent notes (semitones) are the same or different in pitch. Even for people with significant sensorineural hearing loss, the first octave or so will be quite easy, but as one reaches the last upper octave (2000 – 4000 Hz) on the piano or keyboard, this becomes a more difficult task. Once they find a region where they are beginning to have difficulty distinguishing the pitch, or simply cannot distinguish if there was a change in pitch, then this may be considered a cochlear dead region. The result is converted from notes on the piano keyboard to frequency in Hz. The "C" that is one octave below the top note is 2000 Hz, the "G" above that is close to 3000

Hz, and the top note "C" is close to 4000 Hz. This 20-second exercise can then be used to adjust frequency lowering for speech, or gain reduction for music, depending on the results.

How does this compare with the TEN (HL) test? In a pilot study of 10 hard-of-hearing people given a criterian of being within ½-octave, 8 out of the 10 gave results that were within ½-octave of the more time-consuming TEN (HL) test. Given this more clinically efficient version of the TEN (HL) test, questions about cochlear dead regions might be addressed quickly and sometimes with surprising results (Chasin, 2019).

Distortion-o-gram

One limitation of the piano/keyboard method is that only information about the frequency of the cochlear dead region is provided, but not the sound level. It is possible (and probable) that for lower sound levels, a damaged cochlear region may function quite adequately and this may be the case for speech, but more likely, not the higher sound levels associated with music.

Although never published, William (Billy) Martin (personal communication, 2021) describes another approach that can provide information on both frequency and sound level. Using sound field testing, or under earphones, the stimulus sound level is increased in 5 dB increments from 0 dB HL until the client reports an onset of "distortion" or an undefinable change, but a change nevertheless. This can be performed with as many, or as few frequency regions as you would like and have time for clinically. A distortion-o-gram can be created which is a frequency/sound level map of the distortion in both frequency and in sound level. This can be performed with or without client comments about the degree of distortion and can be useful to identify cochlear dead regions (at higher stimulus levels) or even triggers for tinnitus or hyperacusis at lower levels.

A comparative study of these three methods of assessing cochlear dead regions would provide for an interesting project: The TEN (HL) test can take 8 – 10 minutes (for two ears and four test frequencies) whereas the piano keyboard (which only requires a "same/different" judgment of pitch) only takes 20 seconds and can actually be used prior to a client coming to the clinic. In addition, the distortion-o-gram which provides information on both frequency and sound level may allow the clinical audiologist to paint a better picture. A comparative study of these three methods of assessing cochlear dead regions would be an interesting project and this work can be translatable to the busy clinical environment.

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