Why Long Electrode Arrays: More Natural Tonotopic Coding

The human cochlea has remarkable arrangement. Along two and a half turns, natural frequency response is intricately ordered in a descending logarithmic scale. This tonotopic frequency response along the whole cochlea allows frequency mapping along a clear, logical path—the Greenwood function.\(^1\)

With the Greenwood function, you can determine the natural tonotopic frequency of any point along the basilar membrane. You’ll only need to know the cochlear duct length, measured from center of the round window to the helicotrema, which corresponds to the length of the Organ of Corti.

Short Electrode Arrays = Less Coverage

In humans, the average cochlear duct length (CDL) has been measured as approximately 31.5 mm, though it can range up to 35 mm.\(^2,3\) Interestingly, the basal turn alone can account for the first ~20 mm of the total cochlear duct length.\(^2,3,4\)

Say you take a common pre-curved or straight electrode array, designed for a 20 mm insertion depth. These arrays are often marketed as “full-length”, but with only 14–19.1 mm of active stimulation length, only a single turn can be stimulated for most cochleae.\(^3,5,6\) These arrays may be inserted deeper, but it would limit coverage of high frequencies in the first turn.\(^5\)

So, where would a 20 mm insertion reach along the tonotopic map of the basilar membrane?

- In an average cochlea (31.5 mm CDL), a 20 mm insertion would reach the 820 Hz tonotopic location.\(^1,2,3\)
- In a slightly longer cochlea, (32.5 mm CDL), 20 mm would correspond to the 917 Hz
Even in a smaller-than-average cochlea (29.5 mm CDL), 20 mm would only reach the 640 Hz location.\(^1,2,3\)

Single-turn arrays may claim to have “the most active electrodes”, but these electrodes often may not stimulate much of the cochlea beyond the high frequencies in the first turn.

Out of Reach

So with these single-turn arrays, even the most apical electrode may likely only reach roughly the 600–800 Hz position on the natural tonotopic map.\(^1,2,3,7\) If an electrode array can’t reach the apical region in the second turn, low-to-mid pitches cannot be naturally mapped according to the Greenwood function.\(^1,5,7\)

Now, do fundamental frequencies lower than 600–800 Hz really matter? Let’s take a look at a few examples of what falls below 700 Hz.

It’s not just the drums or bass that’d be missing. For reference, Middle C (C4) on a piano is 261.63 Hz, and the highest-pitch open string on a violin is 659 Hz (E5). A standard guitar tuning doesn’t reach much higher than 659 Hz (E5 up on the 12\(^{\text{th}}\) fret). On the other hand, above 700 Hz you’d still find most of the notes from a piccolo.

This high-pitch tuning doesn't just come up short at the concert hall. In everyday conversation, the fundamental frequencies and lower harmonics of voice are much lower than 700 Hz.\(^8,9\)

- Male voice: \(F_0 \sim 120\) Hz, \(F_1 \sim 240\) Hz, \(F_2 \sim 360\) Hz, \(F_3 \sim 480\) Hz, \(F_4 \sim 600\) Hz
- Female voice: \(F_0 \sim 200\) Hz, \(F_1 \sim 400\) Hz, \(F_2 \sim 600\) Hz
The natural tonotopic coding of the cochlea is like the tuning of the keys on a piano. Without a long electrode array to better cover the cochlea, most of the notes are simply out of reach, so lower pitches have to be transposed onto a higher octave.

**Place-Pitch Mismatch**

Lower frequencies can be mapped on single-turn arrays, but there will likely be a significant place-pitch mismatch.\(^{1,5,7,10}\) This unnaturally skewed pitch mapping may shift low frequencies up by roughly two octaves, so sound quality can be distinctly affected.

With short arrays and single-turn insertions, outcomes can often be less than ideal.

- Experienced users have described the sound as “robotic”, “tinny”, “echoey”, or “mechanical”\(^ {11}\)
Reduced speech understanding in quiet and in noise $^{12,13,14,15}$

Neural adaptation can take years for even a single octave correction $^{7}$

Limited improvement in speech perception over time $^{13}$

**Complete Cochlear Coverage**

On the other hand, long electrode arrays (28 mm or 31.5 mm) enable electrode coverage across the first and second turn of the cochlea. This allows tonotopic stimulation of mid-to-low frequencies that’s place-pitch matched to the Greenwood function down to approximately 100 Hz. $^{5,10,16}$


*Flexible full-length MED-EL electrode arrays can provide exceptional cochlear coverage while gently adapting to the natural shape of the cochlea.*

**Better Coverage, Better Outcomes**

Cochlear implants aren’t able to restore natural hearing—but we believe they should offer a closer match when possible. When it comes to more natural sound quality, this accurate place-pitch match is the right place to start. $^{16}$

What benefits can long electrode arrays provide?

- “Vocals much more clear and resonant” and “Deeper, more resonant, more natural sound” $^{11}$
- Significantly better speech understanding in quiet and noise $^{13,15}$
- More natural frequency mapping $^{16,17}$
- Significant improvement in speech understanding in a short time $^{13,18}$

In part two of this post, we’ll look at the second half of the equation—rate-pitch matched coding in the apical region. Why is important to combine both place-pitch and rate-pitch match?

*Hint: “An unparalleled restoration of tonotopic pitch perception”—Rader et al. (2016)* $^{16}$

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*Not all products, features, or indications shown are available in all areas. Please contact your local MED-EL representative for more information.

References:


