A POSSIBLE LEVEL CORRECTION TO THE COCHLEAR FREQUENCY-TO-PLACE MAP: IMPLICATIONS FOR COCHLEAR IMPLANTS

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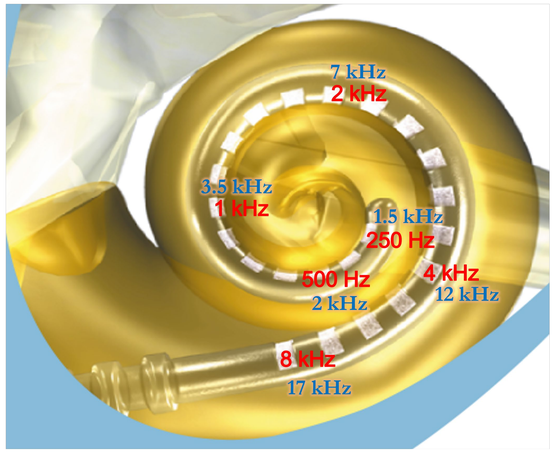
INTRODUCTION

Frequency mismatch in postlingually deaf patients



Blue numbers: characteristic frequency of the stimulated neurons (obtained using Greenwood's equation).

Red numbers: default analysis filters of the cochlear implant's speech processor.

- Cochlear implant (CI) speech understanding highly variable
- Placement of CI electrodes commonly listed as a contributing factor
- CIs not completely inserted into cochlea, but electrodes are assigned frequencies important for speech understanding
- May result in a tonotopic mismatch between frequency information delivered to electrodes and the frequencies associated with the neural elements they activate
- Current anatomical estimates suggest CI electrodes deliver frequencies an octave or more higher than frequencies associated with spiral ganglion frequency-to-place map
- CI users' adaptation to tonotopic mismatch may be incomplete and may impair their speech understanding
- At the core of estimating tonotopic mismatch in CIs is Greenwood's function (Greenwood, 1990)

Greenwood's Function

$$x = \frac{1}{a}\log_{10}\left(k + \frac{F}{A}\right)$$

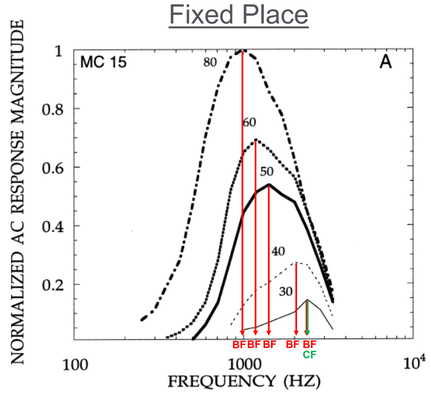
- Near-logarithmic function relating cochlear place (x) to frequency (F)
- Many studies rely on specific parameter values A=165.4, a=0.06, and k=0.88 or 1
- Generally good for predicting the characteristic frequency (CF) associated with a cochlear place (i.e., frequencies where cochlear locations are most sensitive)
- **However, several physiological data sets show that frequencies associated with maximum cochlear amplitude (i.e., best frequency, or BF) are level dependent**
- **BF can shift to lower frequencies as sound level is increased**
- **i.e., higher-level sounds activate more basal cochlear regions than lower-level sounds.**

PURPOSE

The purpose of the present study is to revisit Greenwood's frequency-to-place map in the context of level-dependent basalward shifts in best-frequency (BF) relative to characteristic frequency (CF)

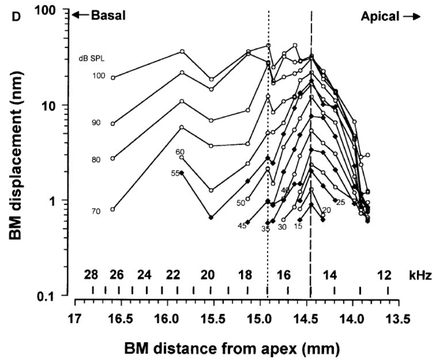
BEST FREQUENCY AND BASALWARD SHIFTS WITH LEVEL

Fixed Place



- IHC response to frequency sweeps of increasing sound level in Mongolian Gerbil (Chatterjee & Zwislocki, 1998)
- At low sound level, best frequency (BF) response equals characteristic frequency (CF)
- At higher sound levels, BF shifts to lower frequencies

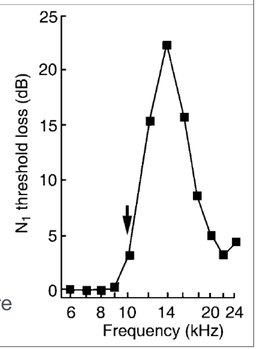
Fixed Frequency



- Basilar membrane (BM) response to 15 kHz tones of increasing level in guinea pig (Russel & Nilsen, 1997)
- At low sound levels, BM response isolated to narrow cochlear place (CF = 15 kHz)
- At higher sound levels, BM response broadens and shifts towards the base

"Half-Octave Shift"

- "Half-octave-shift" provides more evidence for a level-dependent basalward shift in cochlear frequency-to-place mapping
- Graph on right shows threshold elevation in guinea pig due to 10 min exposure of 10 kHz tone at 103 dB SPL (Rajan and Johnstone, 1988)
- Modest threshold elevation at 10 kHz presentation frequency (arrow)
- Maximum threshold elevation at 14 kHz (nearly half-octave higher)
- So a very intense 10 kHz tone impacts threshold at a more basal location associated with the 14 kHz place
- Suggests that cochlear response to a very intense tone peaks at a more basal location than when that tone is presented at lower level

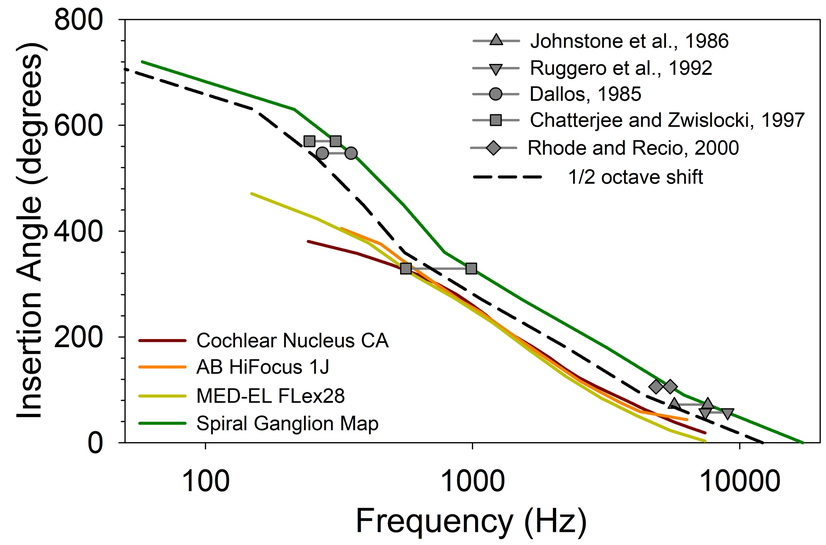


METHODS

- Basalward shift estimated from 5 studies:
  - Johnstone et al. (1986)
  - Rugerro et al. (1992)
  - Dallos (1985)
  - Chaterjee and Zwislocki (1997)
  - Rhode and Recio (2000)
- Shift measured from CF to BF at centroid of physiological response at ~70 dB SPL
- CF and BF transformed to animal specific cochlear positions (% cochlear lengths) following Greenwood (1990)
- % cochlear lengths projected to human frequency values, which were then transformed to spiral ganglion positions using Stakhovskaya et al. (2007)
- CFs on spiral ganglion map corrected to BFs
- Results compared to average CI frequency-to-place map (Landsberger et al., 2015)

RESULTS

Cochlear Place-Frequency Map



- Physiological-based CFs (gray data to the right) projected onto spiral ganglion map (green)
- BFs shifted to lower frequencies based on physiological responses at 70 dB SPL (gray data to the left)
- Spiral ganglion map reflects frequency position values for basilar membrane (Greenwood, 1990) corrected to human spiral ganglion anatomical positions (Stakhovskaya et al., 2007)
- **level corrected BF values follow 1/2-octave shift (dashed curve) which lies closer to average place frequency allocations for 3 CI devices.**

CONCLUSIONS

- Preliminary evaluation of physiological data suggests that estimates of tonotopic mismatch in CI users may not be as extreme as previously thought, particularly for basal and middle electrodes (less so for apical electrodes).
- Shifting spiral ganglion frequencies down by ½-octave provides a simple approximation to the shift in place-frequency map associated with higher presentation levels (e.g. 70 dB)
- Level-corrected frequencies may be more tonotopically accurate for CI users than those from Greenwood (1990)

CI	Frequency Range (Hz)		
	default center-freq	Anatomic Map	
		spiral ganglion	½ Octave
Cochlear	250-7500	725-13880	510-9810
AB	300-6500	660-10500	470-7420
MED-EL (Flex28)	150-7500	500-16250	350-11490

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