Vertical Perception of Simple Stimuli in Normal-Hearing and Cochlear-Implant Listeners
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Background
In normal-hearing (NH) listeners, elevation perception depends upon frequency-dependent peaks and notches imposed by filtering from the pinna. However, limited spectral resolution and current spread in cochlear-implants (CIs) make it difficult to encode spectral cues. Previous research has shown that elevation can be perceived from single tones. Sounds presented over headphones or with CIs lack filtering from the pinna and are perceived “within” the head. We examined the perceived intracranial elevation of tones in NH listeners and single-electrode stimulation in CI listeners. We hypothesized that post-lingually deafened CI users would show systematic changes in elevation with electrode number, while pre-lingually deafened CI users would not. The ultimate goal was to determine the importance of typical elevation perception development from acoustic stimulation.

Methods
NH listeners were presented monaural and diotic tones varying from 0.125 to 16 kHz (19 frequencies) using ear-insert headphones. Stimuli were calibrated to a comfortable and equal loudness (reference of 50 dB SPL-A at 1000 Hz). Unilateral and bilateral stimulation was presented to two bilateral CI listeners; unilateral stimulation was presented to three unilateral CI listeners. Stimuli were biphasic, monopolar pulse trains at one of 13 electrodes or electrode pairs, all presented at comfortable levels. The rate of pulse trains was 300 or 1000 pulses per second (pps); conditions with rate roving were also tested (50% randomization) to confound assigning elevation simply to pitch. On each trial, listeners indicated where they heard the auditory image by clicking on a face (horizontal and vertical position).

Results
Preliminary NH data showed that listeners perceive a change in elevation as frequency increases. Specifically, sounds are perceived higher as the frequency increases between 0.25-12 kHz and does not change at higher frequencies. Most post-lingually deafened CI users showed that the basal electrodes were often perceived as higher in elevation and responses were unaffected by rate roving. No prelingually-deafened CI users showed a change in elevation that was unaffected by rate roving, implying that these listeners were simply assigning elevation to pitch.

Conclusion
These data highlight the association between place of stimulation and elevation perception in NH and CI listeners. Post-lingually deafened individuals may be making use of their spatial maps developed prior to hearing loss and may help us understand how the auditory system develops the perception of elevation. These data also demonstrate the potential to present elevation cues to CIs.