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Neurophysiological responses and their relation to binaural psychophysics in bilateral cochlear implant users

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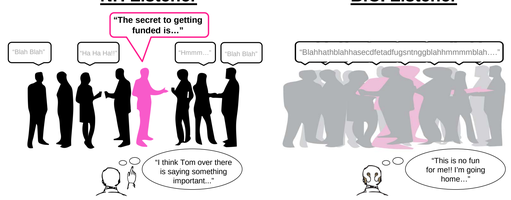
BACKGROUND

Bilateral Cochlear Implants (BiCIs)

- BiCIs improve the ability to locate sound sources compared to a single implant[1].
- However, sound localization accuracy is relatively poor compared to normal hearing (NH) listeners[1,2].
- Poor sound localization likely contributes to difficulties BiCI users have listening in noisy environments

NH Listener **BiCI Listener**

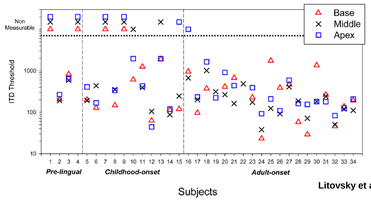


One of the many factors affecting sound localization in BiCI users is a lack of reliance on:

Interaural Time Differences

- For broadband signals, such as speech, ITDs are the dominant cue for normal hearing listeners[3]
- Transmission of acoustic ITDs by clinical processors is not done in a way that can be perceived reliably by BiCI users

However, many BiCI users are sensitive to ITDs delivered directly on interaural pairs of electrodes…



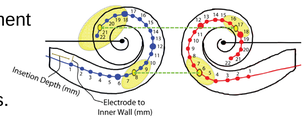
…But ITD sensitivity varies across subjects and cochlear place of stimulation within the same subject[4]

Motivation Behind Current Study

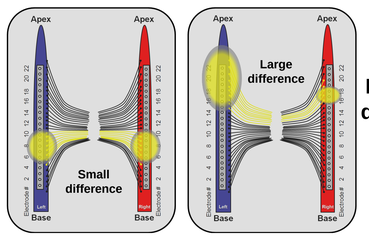
- The ITD threshold variability in BiCI users is larger than typically measured in NH listeners across cochlear place.
- Prior work studying pulse rate limitations on ITD sensitivity suggests that peripheral factors may limit binaural processing[5].
- **We wanted to assess how physiological measures of peripheral activation between the ears relate to ITD sensitivity.**

Why might this variability in ITD sensitivity exist?

- While there are numerous possible sources for such variability, we focused on how **electrical current spread** may affect ITD sensitivity.
- Current levels and electrode placement are independent across ears.
- Therefore, the electrical spread of current is different between the ears.



- As a result, the neural *spread of excitation* (SOE) across auditory nerve fibers is different and might impact ITD sensitivity.



Does a larger interaural difference in neural SOE correspond to poorer ITD sensitivity?

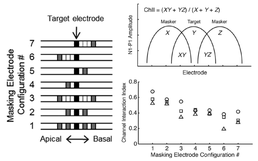
- **We currently do not know whether *asymmetry* in the neural SOE across the two ears affects ITD processing.**

The current study aimed to:

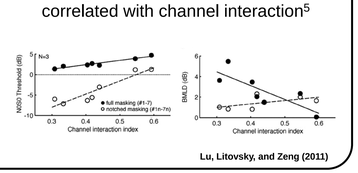
Investigate whether objective measures of neural SOE could provide physiological insight to the variability observed in ITD sensitivity for different interaural electrode pairs

Measures of neural SOE have been correlated to another binaural listening task

Spread of neural excitation increases channel interaction



Speech reception thresholds and binaural masking level differences (BMLDs) are correlated with channel interaction[5]



Lu, Litovsky, and Zeng (2011)

PARTICIPANTS

Listeners

- 4 post-lingually deafened BiCI Cochlear Nucleus users

Table 1. Listener profiles and etiology

ID	Age	Sex	Bilateral Experience (years)	Etiology
IBF	62	F	5	Hereditary
IBY	51	F	8	Unknown
ICJ	65	F	3	Illness
ICP	52	M	3	Nerve damage

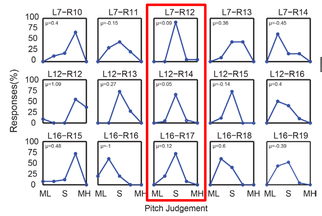
EXPERIMENTS

1.) INTERAURAL ELECTRODE PAIR SELECTION

Direct Pitch Comparison

- Electrodes were first *loudness balanced*.
- 2-interval, 5-alternative forced choice task. Listeners indicated whether the second sound was:
  1) much higher
  2) higher
  3) the same
  4) lower
  5) much lower
  in pitch compared to the first sound.

These categories were given values of: 2, 1, 0, -1,-2



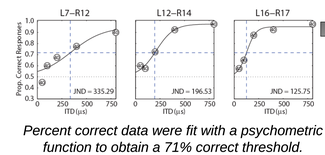
A metric, μ was calculated by summing the enumerated values assigned to responses. The pair with a μ closest to zero was chosen as the "matched" pair (*outline in red*)

μ metric =
-2 x (# of ML) + -1 x (# of L) + 0 x (# of S) + 1 x (# of H) + 2 x (# of MH)

2.) JUST-NOTICEABLE-DIFFERENCE (JND) ITD THRESHOLDS

ITD Discrimination

- Interaural pairs were adjusted to produce a *centered auditory image*.
- 2Interval-2Alternative Forced Choice Left/Right discrimination task.
- 300 ms left-leading and right-leading pulse trains were presented in random order.
- Subjects reported whether the auditory image in the second interval was perceived to the left or right of the first.

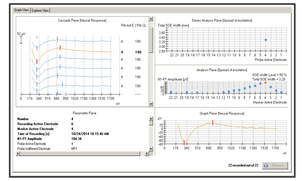


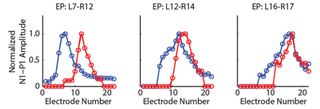
Percent correct data were fit with a psychometric function to obtain a 71% correct threshold.

3.) NEURAL SPREAD OF EXCITATION (SOE)

Neural SOE functions

- Neural Response Telemetry (NRT) available in the Cochlear® Custom Sound EP 4.1 software was used to measure electrically evoked compound action potentials (eCAPS).
- eCAPS for systematically varying probe-masker combinations along the cochlear array were used to estimate SOE as a function of electrode.
- Probe-masker current levels used to measure SOE functions were the same as those used in psychophysical testing.





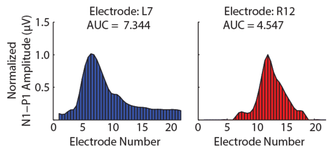
Interaural electrode pairs

- Measurements were made for all electrodes used in psychophysical testing.
- The SOE functions were normalized and smoothed for comparisons across the ears.

Binaural Difference Index

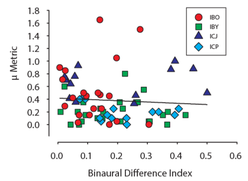
- Areas under the curve were calculated for both left and right SOE functions.
- Differences in SOE functions for interaural pairs of electrodes were calculated:

$$\text{Binaural Difference Index} = \frac{\text{[Left Area – Right Area]}}{\text{[Left Area + Right Area]}}$$



RESULTS

1) Current Spread and Interaural Pitch Comparisons

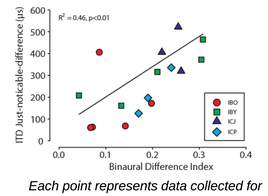


The μ metric shown is the absolute value. *Each point represents data collected for one pitch matched pair.*

Pitch percepts being judged as similar for interaural pairs of electrodes are not related to differences in the neural SOE across the ears

- The Binaural Difference Index was calculated for all interaural pairs used for pitch comparisons. Pitch similarity measures (μ metric) for interaural electrode pairs were then plotted as function of their corresponding Binaural Difference Index.
- Across this group of participants, regression analysis revealed no relationship between pitch judgements and differences in neural SOE across the ears.

2) Current Spread and ITD Sensitivity



Each point represents data collected for one pitch matched pair

Binaural differences in the neural SOE across the ears are correlated with ITD sensitivity

- For interaural pairs of electrodes matched in pitch percept and stimulated at levels producing a centered auditory image**, larger differences in the neural activation across the array were correlated to larger ITD JNDs**.
- There were some instances were poor ITD sensitivity (relative to the other pairs tested in a subject) were observed for small differences in neural SOE across the ears.

CONCLUSIONS

- Pitch judgements do not appear to be influenced by differences in the neural spread of excitation for loudness balanced interaural pairs of electrodes.
- This suggests direct pitch comparisons of interaural pairs of electrodes are impacted more by cochlear place of stimulation than by differences in the neural spread of excitation across the ears.
- Larger interaural asymmetry in neural SOE typically resulted in poorer ITD sensitivity.
- At least some of the variability observed in ITD sensitivity across the electrode array is a result of differences in peripheral neural stimulation across the ears.
- However, this assumes the interaural electrode pairs selected by pitch comparisons are stimulating similar cochlear places, or at least populations of auditory nerve fibers that ultimately converge in binaural nuclei, which may not be the case.
- ITD sensitivity may be optimal for interaural electrode pairs that are both pitch matched, and at binaurally matched current levels that stimulate similar amounts of current spread along the cochlear array.

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