Listening with two different ears

Justin Aronoff, PhD
University of Illinois at Urbana-Champaign
Cochlear implants over time

• Unilateral cochlear implant performance improved vastly in the early days

• But performance has not improved much in the last 15 years (for unilateral users)
Two ears are better than one

• Improvements have come from changes such as the use of bilateral cochlear implants

• Having two ears provides a number of benefits
  • Understanding speech in noise
  • Localizing
Two cochlear implants are not as good as two acoustic ears

- Bilateral cochlear implant users get smaller and fewer benefits than those using two acoustic ears (e.g., Loizou et al., 2009; Kerber & Seeber, 2012)

- A major reason for that is likely that bilateral cochlear implant users’ two ears are very different

\[ \text{RMS error (degrees)} \]

Aronoff et al., 2012
Two very different ears
Two very different ears

• The left and the right CI can differ in many ways, even if they are the same device

• CI users will often have a better and worse ear

• The two CIs will often sound different
Spectral resolution

• In noisy environments, you need to separate what you want to hear from the background

• The ability to do this relies in part on separating sounds that have similar but distinct pitches

• Your ability to do this is referred to as spectral resolution
Spectral resolution

• Do both ears have similar spectral resolution?

• To test this we had nine bilateral CI users complete a spectral resolution test using each ear alone
Spectral resolution

- The test we used was the Spectral-temporally Modulated Ripple Test* (SMRT; Aronoff & Landsberger, 2013)

*This test is available free of charge at http://smrt.tigerspeech.com
Spectral resolution

- SMRT can be used to predict speech perception in noise (each RPO increase = ~12% improvement in speech perception in noise)

Lawler, Yu, & Aronoff (2017)
• There can be considerable differences in performance depending on which ear a participant is using

• We can look at this with other tasks as well

*One participant was at floor
Music

• Do both ears have similar abilities to accurately identify musical contours?

• To test this we had the same nine bilateral CI users complete a musical contour identification test
Melodic contour identification

• Participants presented with five note sequences

• The starting note and the interval between the notes vary across trials

• Participants needed to select the contour they heard
Melodic contour identification

- There can be considerable differences in performance depending on which ear a participant is using.

- Not only is performance difference but the two ears sound different.
Mickey Mouse ear and a rumbly ear

• Participants often describe the sound they hear in the two ears as being very different
  • One ear often described as sounding like Mickey Mouse
  • The other often described as sounding rumbly

• Does this mean that the two ears are hearing different pitches?
Comparing pitches across ears

• Data was collected from 16 bilateral CI users

• Pitch heard in left and right ear was compared

• One electrode was stimulated in one ear

• Participants moved the stimulation in the opposite ear until they heard the same pitch in both ears
Comparing pitches across ears

- For some participants, the left and right ear provided comparable pitches.
- For others, there was a considerable and systematic difference in the pitches heard in the two ears.
Comparing pitches across ears

• There were significant differences between the pitches heard in the two ears for most participants

• There was considerable variability across listeners

Aronoff et al., 2016
Mickey Mouse voice and a rumbly voice?

• Your voice can provide an indication of what you hear

• If what you hear is altered so that your voice sounds low, you will compensate by increasing the pitch of your voice

• Do participants also have a Mickey Mouse voice and a rumbly voice?
Comparing vocal pitch

• 16 bilateral CI users were asked to say “ahhh”

• Participants were tested when using either the left or right CI
Vocal pitch

• Participants’ voice can often be different when using their left or right CI
Vocal pitch

- The pitch of a CI user’s voice can be quite different depending on which ear they are using.

- This provides further evidence that the pitches they hear in the two ears can differ considerably.

- Is this an isolated effect caused by the artificial task or will it extend to tasks participants do in their every day life?
Singing

• Do participants also sing different notes with the two ears?

• 10 bilateral CI users were tested

• Asked to sing “Happy Birthday”

• Tested with their left and right CI
• As with sustained vocalizations, singing suggests that the two ears hear different pitches
When ears are mismatched
Binaural fusion

- One effect of mismatches may be that sounds received by the two ears do not combine (or fuse)
- When sound is presented to two normal hearing ears it fuses into one coherent percept
Binaural fusion

• This is not always the case for CI users (Fitzgerald et al., 2015)
The effect of mismatch across ears

• What are the effects of mismatch between ears on binaural fusion?

• 8 NH listeners tested with cochlear implant simulation

• Simple task:
  • Do you hear one sound or two?

• Change whether and how much the signals in the left and right ear are mismatched
Creating mismatches between ears

• For some conditions, the signals in the two ears were matched

• For others, a mismatch was simulated
The effect of mismatch across ears

• There is a systematic relationship between the magnitude of the mismatch across ears and the likelihood of binaural fusion

Aronoff et al., 2015
Mismatches lead to mismatched signals

- It may not be the mismatch alone that is causing problems
- Each electrode encodes a different part of the signal
Mismatches lead to mismatched signals

• When there is a mismatch, matched locations will receive different parts of the signal for each ear
• Will this decrease fusion?
Mismatches lead to mismatched signals

• 3 bilateral CI users tested

• Participants moved a dial to indicate if they heard the sound coming from a small single point, a diffuse area, or two separate locations

• All stimuli were delivered to the same electrodes but the signal was either matched or mismatched
Mismatches lead to mismatched signals

- Mismatched signals reduce binaural fusion
Singing with two ears

• Does hearing different sounds in each ear make it difficult to sing a melody?

• Ten bilateral CI users sung “Happy Birthday” with their left, right, or both CIs
Singing with two ears

- Participants’ sung melodies were compared to the target melody.

Accurate melody: $r = 0.94$

Inaccurate melody: $r = 0.25$
Singing

• Accuracy is generally better with the better ear alone than with both ears together

Aronoff et al., In press
Mismatches affect non-spectral task

– Many of the benefits of having two ears come from two binaural cues

Interaural time differences (ITDs)

Interaural level differences (ILDs)
The effects of mismatch on ITD and ILD sensitivity

• 5 bilateral CI subjects

• Compared the effects of mismatch on
  • ITD sensitivity
  • ILD sensitivity

• Comparisons were done for up to five reference locations, spaced across the array
Measuring sensitivity

- Participants are presented with four sounds
- The first and last are reference sounds
- One of the two middle sounds are the target
- Participants choose the target (the one with a non-zero ITD or ILD)
Measuring ITD sensitivity

- A reference electrode was chosen.

- The minimum detectable ITD was measured when the reference was paired with different electrodes in the other ear.

Example ITD thresholds

Axes:
- X: Electrodes
- Y: Threshold (μs)

- Aligned
- Better
Measuring ILD sensitivity

• A similar procedure was used for measuring ILD sensitivity

• The only difference is that all stimuli had a 0 µs ITD and the ILD (in terms of current units) was manipulated
Mismatches and ITD and ILD sensitivity

• Mismatches adversely affect both ITDs and ILDs (see also Hu & Dietz, 2015; Kan et al. 2013; Poon 2009)
• ITDs tend to drop off quickly with increasing misalignment
• ILDs tend to decrease more slowly
Mismatches

• Mismatches are
  • Prevalent
  • Detrimental

• Can CI users adapt to these mismatches?
Learning to listen with two ears
Clinical processors

• The brain has an amazing ability to adapt

• Within six months of using a cochlear implant sounds go from being very mechanical to being natural sounding

• Will time fix the perceived mismatch between the two ears?
Adaptation

- Six bilateral CI users were asked to match pitches across ears just after activation, after six months, and after one year.

- Patients do partially adapt to mismatches.
Is adaptation sufficient

- Mismatches persist even after years of bilateral use
- Time will help, but it does not solve the problem
The (likely) future for bilateral CIs
Bilateral maps

• If time is not enough to fix the problem of mismatches, the solution might be to change the way we program bilateral CI users’ devices

• Will changing the programming such that electrodes that produce the same pitch in the two ears also encode the same frequency region improve performance?
Creating pitch-matched maps

• Seven bilateral CI users were tested with electrodes paired
  • based on electrode number only
  • based on pitch matches

• Compared performance based on SMRT
• All participants had better spectral resolution with the pitch-matched maps.

• Suggests that pitch-matched maps are an improvement over current methods.

Creating pitch-matched maps

[Bar graph showing comparison between pitch-matched and numerically matched maps with numerically matched being better at lower ripples per octave and pitch matched being better at higher ripples per octave.]
Conclusions

• Bilateral CI users have two very different ears

• When the two ears are not matched it can detrimentally affect perception

• CI users are able to adapt to some of the mismatches, but only partly

• New ways of programming bilateral CI users’ devices are needed
Thank You!

**Binaural Hearing Lab**
Elizabeth Abbs
Abbigail Kirchner
Daniel Lee
Elise Lippmann
EmilyAnn O’Brien
Kevin Shi
Hannah Staisloff
James Woods

**UIUC**
Ratnam Rama

**UIC**
Jeff Yu

**Advanced Bionics**
Leo Litvak
Smita Agrawal

**Carle**
Michael Novak
Jennifer Black

**University of Alberta**
Torrey Loucks

**NYU**
David Landsberger
Monica Padilla
Ann Todd

**Funding**
NIH/NIDCD
Advanced Bionics
National Organization for Hearing Research
Action on Hearing Loss
American Hearing Research Foundation
Center for Health, Aging, and Disabilities (UIUC)

**Our dedicated participants**

binauralhearinglab.shs.illinois.edu