Music, Hearing Loss, and Cochlear Implants
The Next Frontier

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Disclosures

- Advanced Bionics Corporation
  - Consultant (2006-present)
  - Research support

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- Frequency Therapeutics, Inc.
  - Consultant (2016)
Treatment for hearing loss has evolved

1800s
2000s
Why music?
First musical instrument?

Bird bone flute

Recovered from southern Germany

(Giessenklösterle)

~35,000 years old

Patel, et al., 2009

Current

'Snowball' gets his groove on

Patel, et al., 2009

Current
Despite success in language perception, most cochlear implant users cannot hear music well.
What does music sound like for a CI user?

In normal hearing, place and rate pitch mechanisms are seamlessly integrated and support one another.

In electric hearing, place and rate pitch mechanisms are both disrupted.

Pitch perception is the single biggest obstacle for CI-mediated perception of music

Relative pitch > absolute pitch

Difference between middle C and one semitone above or below ~15 Hz
Typical CI frequency map covers range of 60+ semitones

Rachmaninoff Prelude Op. 3, No. 2 in C# minor: original

Rachmaninoff Prelude Op. 3, No. 2 in C# minor: original
Rachmaninoff Prelude Op. 3, No. 2 in C# minor: +/- 1 s.t.
CI Users Utilize Tempo Rather Than Mode to Interpret Musical Emotion

CI Users Demonstrate Fusion of Polyphonic Pitch

<table>
<thead>
<tr>
<th>CI Confusion Matrix</th>
<th>NH Confusion Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presented</td>
</tr>
<tr>
<td><strong>Class. %</strong></td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td>199</td>
</tr>
<tr>
<td>Interval</td>
<td>84</td>
</tr>
<tr>
<td>Chord</td>
<td>90</td>
</tr>
</tbody>
</table>

Donnelly et al., 2009
How do we measure musical sound quality in CI users?

Musical Sound Quality is Poor in CI Users

- CI users subjectively report poorer musical sound quality following implantation (Gfeller et al 2002; Lassalletta et al 2008)
- Sound quality traditionally assessed via questionnaires or rating scales (Lassalletta et al 2008; Gfeller et al 2008; Looi et al 2008, 2011)
- Assessment of sound quality can be used as a tool, not an indicator of preference or enjoyment
Cochlear Implant-MUltiple Stimulus with Hidden Reference and Anchor (CI-MUSHRA)

- 25 full quality musical stimuli are increasingly degraded:
  - Example: Removal of bass frequencies
  - Hidden reference (best sound quality)
  - 200 Hz HPF
  - 400 Hz HPF
  - 600 Hz HPF
  - 800 Hz HPF
  - 1000 Hz HPF
  - Anchor (1000-1200Hz band-pass filter)

No Alterations

Highly Altered
MUSHRA: ITU-R Recommendation BS.1534
For evaluation of lossy audio compression algorithms

CI-MUSHRA
25 excerpts, from 5 genres (pop/rock, country, jazz, classical, hip-hop)

Roy et al., 2012

Sound Quality Rating

Stimulus Version

Roy et al., 2012
How do we improve music for CI users?

- Change the CI
- Change the brain
- Change the music

Can we tune cochlear implants?
FPCT distinguishes all 216 individual electrode contacts

Frequency-place mismatch increases in apical and basal electrodes
A radiograph of a cat with a cochlear implant shows the 6 electrode contacts (e:electrode 1 at white arrowhead) within the cochlea.
PET is quiet, non-magnetic
Is CI listening similar to normal listening?

- Normal listeners
- CI listeners

Limb et al., 2010

10 postlingual CI users / 10 controls
Roy et al., 2014
Conclusions

- Music is the pinnacle of hearing
- Critical impairments in pitch, timbre and sound quality are observed in CI users
- These impairments reveal limitations of CI processing that speech testing does not
- Cochlear implants are severely out of tune
- We must work to improve CI designs, processing strategy, musical training, and even the music itself

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