fMRI: Uses in Tinnitus and Cochlear Implants

Aniruddha Deshpande
University of Cincinnati/CCHMC
Introduction

- Different neuroimaging techniques can be utilized to study brain function
- E.g. PET, SPECT, fMRI, MEG
- Each has its own advantages and disadvantages w.r.t auditory research
fMRI – Nuts and Bolts

- Functional magnetic resonance imaging (fMRI) offers an interesting gateway to brain activity.
- fMRI makes use of the paramagnetic and diamagnetic properties of blood and tissue to arrive at the Blood Oxygen Level Dependent (BOLD) contrast.
The BOLD contrast can be used as an indirect measure of neuronal activity.
Advantages of fMRI

- It does not utilize radioactive tracers like other neuroimaging techniques do (e.g. positron emission tomography- PET).
- The high spatial and temporal resolution that fMRI provides can be used to study the central auditory nervous system (CANS) in response to various auditory tasks.
fMRI is non-invasive and according to the US Food and Drug Administration (FDA) guidelines (Zaremba, 2003), poses no known risks if operated within specified limits.
Patient Preparation

- https://research.cchmc.org/c-mind/visitors/preparing

- fMRI scans are performed in the Imaging Research Center, CCHMC on the 3.0 Tesla Philips scanner.

- A registered radiological technologist explains the procedure to the participant (or the parents in case of children) in simple terms.
- He/she also reviews the standard checklist of patient questions used for clinical MRI protocols.

- One of the investigators explains the informed consent process, answers any questions that the patient/parent may have, and request that they sign the informed consent.
Problems in Auditory Research

- Magnet incompatible
  http://www.youtube.com/watch?v=nrjtkSo73Es
- Scanner Noise
- Motion Artifacts
- Sedation
HUSH All...

- To acquire the BOLD contrasts, a silent fMRI acquisition method - Hemodynamics Unrelated to Sounds of Hardware (HUSH - Schmithorst and Holland, 2004) - may be performed.

- The scanner acquires images between the acoustic conditions and thus helps obtain high fidelity scans free from the MRI scanner noise.
<table>
<thead>
<tr>
<th>Gradients/Acq.</th>
<th>Silent</th>
<th>Acquire</th>
<th>Silent</th>
<th>Acquire</th>
<th>Silent</th>
<th>Acquire</th>
<th>Silent</th>
<th>Acquire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory Stim.</td>
<td>ctl.</td>
<td>silent</td>
<td>stim.</td>
<td>silent</td>
<td>ctl.</td>
<td>silent</td>
<td>stim.</td>
<td>silent</td>
</tr>
<tr>
<td>Interval Time (sec)</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Running Time (sec)</td>
<td>0</td>
<td>5</td>
<td>11</td>
<td>16</td>
<td>22</td>
<td>27</td>
<td>33</td>
<td>38</td>
</tr>
</tbody>
</table>
‘How long have you had this ringing in the ears?’
fMRI in ‘Noisy’ Brains

- Tinnitus is typically a phantom auditory sensation in the ears/head. The patient may describe the sound as buzzing, ringing, roaring, hissing, chirping or clicking (Clark, 1984).
Epidemiology of Tinnitus

- According to the American Tinnitus Association (ATA), more than 50 million people have experienced tinnitus in the US.
- About 12 million people have tinnitus to such a severe degree that they seek some form of remediation.
The presence of an occasional tinnitus is reported by 90-95% of the otologically normal population (Clark, 1984).

According to the ATA, the United States Department of Veterans Affairs (VA) spent $1.1 billion to compensate veterans for disability related to tinnitus in 2009, while the available funding for tinnitus-related research was just $10 million.
Causes of Tinnitus

- There are multiple causes of tinnitus. No single cause can explain the phenomenon of tinnitus in all individuals.
- Sometimes, more than one cause can be present in one individual.
- Both cochlear and central causes have been implicated (Baguley, 2002).
Cochlear Models

- Spontaneous Otoacoustic Emissions (SOAEs)
- Discordant Damage of Inner Hair Cells and Outer Hair Cells
- Biochemical Models
Non-Cochlear Models-

- Neurophysiological Model (Jastreboff, 1996, 1999)
- Increased Neural Activity
- Synchronization of Spontaneous Neural Activity
- Medial efferent System Involvement
- Somatic Modulation
- Cortical Reorganization
Goal

- The aim of this study is to investigate differences in the auditory and limbic systems of individuals with and without tinnitus using fMRI.
Deliverables

- At this point, there is no known ‘cure’ for tinnitus. This is partly due to the fact that the underlying neurophysiological bases of tinnitus have not been properly understood.

- Auditory system involvement

- The limbic system is one of the areas of interest as memory and emotions are usually associated with tinnitus.
By studying the entire auditory pathway, we would like to determine which specific structure(s) are responsible for the percept of tinnitus.

This will also help in streamlining treatment modalities. For instance, repetitive transcranial magnetic stimulation (rTMS) and deep brain stimulation (DBS) may be used as focal treatment options in the future for subjects with tinnitus if the focus of activity is determined using fMRI.
“It’s a constant ringing in my ears. When I try to ignore it, they leave a message.”
Prevalence of HI

- According to the US Preventive Services Task Force (1996), the prevalence of congenital hearing impairment (HI) in the United States is 0.1-0.3%.
The National Center for Hearing Assessment and Management at Utah State University (NCHAM) estimates that 33 babies with hearing impairment are born each day in the United States making hearing impairment the most frequently occurring birth defect (White, 2004).
Identification and Intervention

- In the 1980's, the age at identification of hearing loss was as late as 2 years (Toward Equality, 1988).

- In recent years, the age at identification of hearing loss has decreased considerably and most infants with HI are identified at birth due to the newborn hearing screening program.
It has been shown (Yoshinaga-Itano, Sedey, Coulter, and Mehl, 1998) that children with HI who are identified before 6 months of age and provided with intervention before 8 months of age have better receptive and expressive language skills than those identified after 6 months.

Other studies (e.g. Kileny, Zwolan, and Ashbaugh, 2001; Moeller, 2000; O’Donoghue, Nikolopoulos and Archbold, 2000) have corroborated this finding.
The preferred treatment option for infants with severe to profound HI is some form of amplification (e.g. hearing aids) or a cochlear implant (CI).

Currently, more than 188,000 deaf people worldwide have received a CI.

Children implanted at an earlier age have better speech recognition skills (e.g. Kilery, Zwolan, and Ashbaugh, 2001).
Also, prolonged use of a CI has been shown to improve speech and language performance in children. For instance, Kileny et al (2001) administered various behavioral measures on 48 HI children implanted with the Nucleus CI22M cochlear implant testing their speech recognition performance. They found that the children's performance improved significantly with duration of implant use on most of the tests.
The long-term positive effects of the use of a CI are also well-documented. For instance, in a group of 30 profoundly hearing impaired children implanted at an average age of 5.2 years, Beadle et al., 2005 found that after ten years of CI use, 87% understood conversational speech without the help of lip reading; the speech of 77% of the children was intelligible to an average listener; and all of them were either studying or working in different settings.
These benefits are not uniform across all children.

What if we could predict the future performance of children before they get implanted?

The aim of the study we are undertaking is to investigate the relationship between pre-implant fMRI activation and post-implant speech-language-hearing tests in infants/toddlers with hearing impairment.
Preliminary Findings

- Feasibility of performing fMRI in hearing impaired children has been shown by our group in a recent study (Patel et al., 2007). They found that there was a significant activation in the auditory cortex of children with HI and that the post-implant hearing thresholds correlated strongly with the pre-implant fMRI activation.
In a group of thirteen infants/toddlers with congenital bilateral severe to profound sensorineural HI, our team (Robertson et al., 2011) found a significant positive correlation between the pre-implant fMRI activation in the auditory-language areas of the brain and the post-implant expressive language scores.
What about other ‘peeking’ techniques?

- **Electroencephalography (EEG) and Magnetoencephalography (MEG)** -
  - EEG is based on the electrical signals emitted by the brain while MEG is based on the magnetic signals emitted by the brain due to collective firing of neurons.
  - High temporal resolution (~1ms); spatial resolution (1mm)
Positron Emission Tomography (PET) -

- PET signal is based on the radioactive decay of the tracer injected in the bloodstream and picked up by the PET scanner
- Limited temporal resolution (2 min); limited spatial resolution (4-5 mm)
- Advantages - Silent (for auditory research); magnet-compatible (for CI users)
- Disadvantages - Radioactive tracer used, hence not advisable to use over repeated measurements
References


Acknowledgements

- Sigma Xi
- Dean, College of Allied Health Sciences, University of Cincinnati
- Scott Holland, Ph.D., CCHMC
- Robert Keith, Ph.D., UC
- Andrew Dimitrijevic, Ph.D., CCHMC
- Ravi Samy, M.D., UC
- Department of Communication Sciences and Disorders, UC
"That was a long winded conversation... I thought he'd never stop listening."