Plasticity in the developing auditory system

Karen A. Gordon
Cochlear Implant Team

DIRECTORS
- Blake Papsin
- Karen Gordon
- Vicky Papaioannou

RESEARCH ASSISTANT
- Stephanie Jewell

STUDENTS
- Daniel Wong
- Patrick Yoo
- Michael Deighton
- Salima Jiwani
- Parvaneh Abbasalipour
- Nikolaus Wolter
- Francis Manno
- Melissa Polonenko
- Morrison Steele
- Carol Duong
- Gurvinder Toor
- Hena Kazmi
- Katie McCann
- Brian Wong

TEAM CLINICIANS
- Sharon Cushing
- Adrian James
- Susan Blaser
- Gina Sohn
- Naureen Sohail
- Laurie MacDonald
- Mary Lynn Feness
- Pat Di Santos
- Valerie Simard
- Nancy Greenwald-Hood
- Susan Druker

COLLABORATORS
Local - SickKids
- Bob Harrison
- Tracy Stockley
- Mark Crawford
- Maureen Dennis

Local - external
- Sandra Trehub
- Frank Russo
International
- Robert Cowan
- Richard van Hoesel
Hearing loss
Cochlear implants and hearing aids “awaken” the auditory pathways

- Auditory Cortex
- Medial Geniculate Body
- Inferior Colliculus
- Lateral Lemniscus
- Superior Olivary Complex
What pathways are awakened and can they develop normally?

- Effects of bilateral deafness?
- Developmental plasticity?
What pathways are awakened and can they develop normally?

- Effects of bilateral deafness?
  - Abnormal cortical function
  - Effects of etiology

- Developmental plasticity?
  - Normal and abnormal auditory development
  - Effects of unilateral stimulation
Cortical effects of bilateral deafness in early development

<table>
<thead>
<tr>
<th>Reduced activity</th>
<th>Duration of deafness</th>
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<tbody>
<tr>
<td>6.5 yr</td>
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<td>6.5 yr</td>
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<tr>
<td>11.2 yr</td>
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<td>20.3 yr</td>
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Activity no longer reduced

Deafness allows reorganization of association areas of auditory cortex

Fine, et al., 2005
Neural competition in development


Phonak Latin American Pediatric Conference III, Buenos Aires, Argentina, October 11-13, 2012
Neural competition in development

Development

Maturity


Phonak Latin American Pediatric Conference III, Buenos Aires, Argentina, October 11-13, 2012
Synaptic pruning in developing human cortex

- Auditory cortex
- Visual cortex
- Prefrontal cortex

Conceptual Age (days)

Newborn
Adolescent
Adult

Synapses/100 µm³
Abnormal synaptic changes in congenitally deaf cats

Kral and O’Donaghue, NEJM, 2010
Deafness in children is not uniform

Aetiology of Deafness (n=72)

- GJB-2 mutation 21%
- CMV 7%
- Abnormal cochlea 15%
- Unknown etiology 57%
Multiple possible cochlear lesions

Kral and O'Donaghue, NEJM, 2010

Phonak Latin American Pediatric Conference III, Buenos Aires, Argentina, October 11-13, 2012
Effects of GJB-2 mutations on auditory nerves

Propst, et al., 2006
Effects of deafness on cortical responses
Responses from the deaf and immature auditory cortex

Gordon et al., *Clin Neurophys*, 2010

Phonak Latin American Pediatric Conference III, Buenos Aires, Argentina, October 11-13, 2012
Cortical responses reflect multiple effects of deafness in childhood

(144 cortical responses from 72 young children receiving bilateral CIs simultaneously)

- Non-significant demographic influences (p>0.05)
  - Age at implantation, duration of deafness, age at onset of bilateral deafness, duration of residual hearing, cochlear abnormalities, neonatal complications

Gordon et al., *Clin Neurophys*, 2010
Cortical immaturity predicted by GJB-2 deafness

Gordon et al., Clin Neurophys, 2010
Summary of effects of bilateral deafness

- Reorganization in thalamo-cortical areas
  - Due to competition from non-auditory inputs (visual, somatosensory)
- GJB-2 deafness is an important predictor of activity in auditory nerve and cortex
  - GJB-2 mutations predict uniform activity in auditory nerve and very early stage of cortical development
What pathways are awakened and can they develop normally?

- Effects of bilateral deafness
  - Abnormal cortical function
  - Effects of etiology

- Developmental plasticity?
  - Normal and abnormal auditory development
  - Effects of unilateral stimulation
Unilateral cochlear implants promote development in auditory brainstem

Salamy, 1980

Gordon et al., *Ear Hear*, 2003

Normal Hearing

Unilateral Cochlear Implant

31 weeks C.A.

33 weeks C.A.

35 weeks C.A.

37 weeks C.A.
Normal Hearing

Cochlear Implant

75 children
11 adults
Brainstem and thalamo-cortical responses mature with CI use

Brainstem responses

(Gordon et al., 2006)

Salima Jiwani, 2012
Brainstem and thalamo-cortical responses mature with CI use

Brainstem responses

(Gordon et al., 2006)

Middle latency responses

Salima Jiwani, 2012
Unilateral cochlear implants provided in early life promote cortical development

Gordon et al., *Clin Neurophys*, 2010

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**Diagram:**

- **Bilateral Deafness (n=144):**
  - Multi-peak response: 100%
  - Negative peak response: 80%
  - Positive peak response: 20%

- **Unilateral CI use (n=55):**
  - Multi-peak response: 10%
  - Negative peak response: 30%
  - Positive peak response: 60%
Unilateral cochlear implants provided in early life promote cortical development

Gordon et al., *Clin Neurophys*, 2010

Phonak Latin American Pediatric Conference III, Buenos Aires, Argentina, October 11-13, 2012
Cochlear implant stimulation promotes normal-like trajectory of cortical auditory development

Salima Jiwani, 2012
Auditory evoked cortical responses are abnormal in the second implanted ear.
Unilateral cochlear implant use

Gordon et al., *Ear and Hear*, 2003

Phonak Latin American Pediatric Conference III, Buenos Aires, Argentina, October 11-13, 2012
Imaging brain activity in cochlear implant users
Abnormal cortical activity after right unilateral cochlear implant

Clicks/pulses presented to right ear

- Left auditory cortex
- Right auditory cortex

Dipole Moment (nAm)

- Normal Hearing (n=7)
- Right CI Users (n=8)

% Activity in Left Auditory Cortex

\[\frac{(R-L)}{(R+L)} \times 100\]

Right CI Users (n=8)

Normal Hearing (n=7)
Binaural hearing

- Sound reach one ear before the other and at different levels

- These cues must be detected by the central auditory system
Neural competition in development

Development

Maturity in auditory brainstem with 2 years CI use


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Hypothesis: Unilaterally driven maturation will reduce plasticity in contralateral pathways.
Reorganization in auditory pathways after unilateral implant use

Left Auditory Cortex  Right Auditory Cortex

\[
\text{Lateralization Index} = \frac{R-L}{R+L}
\]

Unilateral CI use (n=8)

Normal Hearing (n=7)

Wong, et al., 2011
Simultaneous bilateral implantation protects the cortex against reorganization

Wong, et al., 2011
Bilateral implantation protects the cortex against reorganization if the delay is short

Unilateral CI use (n=8)

Short inter-implant delay (n=7)

Simultaneous bilateral CI (n=12)

Normal Hearing (n=7)

Wong, et al., 2011
Effects of unilateral CI use are not reversed by bilateral implantation

Left Auditory Cortex  Right Auditory Cortex

- Lateralization Index = \( \frac{R-L}{R+L} \)

- Unilateral CI use (n=8)

- Long inter-implant delay (n=9)

- Short inter-implant delay (n=7)

- Simultaneous bilateral CI (n=12)

- Normal Hearing (n=7)

Wong, et al., 2011
Symmetric auditory activity supports binaural processing
Abnormal binaural processing with unilateral implant use
What pathways are awakened and can they develop normally?

- **Effects of bilateral deafness**
  - Abnormal cortical reorganization if left untreated
  - Unique effects of BJG-2 associated hearing loss

- **Developmental plasticity**
  - Unilateral stimulation drives auditory development but also creates abnormalities in bilateral pathways.
Clinical implications for children with hearing loss

- Limit duration of bilateral auditory deprivation
- Understand the onset and cause of hearing loss in childhood
- Limit duration of unilateral auditory deprivation
Thank you to all of our participants