Percepción auditiva significativa (lenguaje, emociones y música), en niños con IC: papel de la plasticidad en el desarrollo del sistema auditivo

Meaningful auditory perception (language, emotion and music) after CI in children: the role of plasticity in the development of the auditory system
Reassembling the Auditory Environment in Children with Cochlear Implants
Cochlear Implant Research Team

DIRECTORS
- Karen Gordon
- Blake Papsin

RESEARCH ASSISTANTS
- Jerome Valero
- Stephanie Jewell

STUDENTS
- Daniel Wong
- Claire Salloum
- Sho Tanaka
- Patrick Yu
- Brad Hubbard
- Lauren Schofield
- Brittany Harrison
- Brooke Allemang

FELLOWS
- Talar Hopyan
- Neil Chadha
- James Ramsden

COLLABORATORS
- Paolo Campisi
- Vicky Papaioannou
- Mark Crawford
- Maureen Dennis
- Gina Sohn
- Naureen Sohail
- Laurie MacDonald
- Mary Lynn Fenness
- Pat Di Santos
- Nancy Greenwald-Hood
- Susan Druker

Local - external
- Sandra Trehub
- Frank Russo

International
- Robert Cowan
- Richard van Hoesel
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- Brooke Allemang

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- Talar Hopyan
- Neil Chadha
- James Ramsden

COLLABORATORS
Local - SickKids
- Bob Harrison
- Tracy Stockley
- Susan Blaser
- Adrian James

Local - external
- Sandra Trehub
- Frank Russo

International
- Robert Cowan
- Richard van Hoesel
The Three Questions

- do I run from it?
- do I eat it?
- do I mate with it?
Evolution in Our Time?

*Biston betularia f. typica*  
*Biston betularia f. carbonaria*
Human = Information Processor

audition
linguistic ability
executive function

olfaction
vision
motor skill
Human = Information Processor

- olfaction
- vision
- motor skill

- audition
- linguistic ability
- executive function
Human = Information Processor

- olfaction
- vision
- motor skill

- audition
- linguistic ability
- executive function
Auditory Cortex in Silence

Reduced activity

Activity no longer reduced

Reorganization of Auditory Cortex

Fine, et al., 2005
Human = Information Processor

IQ = 107

IQ = 7
Auditory Plasticity (Learning)

↑ representation of 8-16 kHz octave band (Stanton & Harrison 1996)
Capitalizing on Plasticity

![Diagram showing IT-MAIS score (%) vs Age (months) for different age groups: 6-12 months, 12-18 months, 19-23 months, and Normal hearing. The graph highlights an upward trend with age for all groups, emphasizing the importance of early intervention.]

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Developmental Plasticity

- adult map reorganization reported:
  - If animal is trained to attend to the stimulus

(Polley, Steinberg & Merzenich, 2006)
Senses

- collect data
- extract data
- orient
Senses

- illusory
- reassemble the world – most probable state
Vision and Audition

- fundamentally different
- bilateral pathways
- temporal relationships
Vision and Audition

- fundamentally different
  - bilateral pathways
  - temporal relationships

Diagram showing visual time and auditory time with decision points.
Spot the Difference
Spot the Difference
Visual Attention

- saccades scan visual environment
Auditory Processing

- must process environment in one pass
  - extract
  - identify
  - categorize
Feature Extraction

1. Free examination

2. Estimate material circumstances of the family

3. Give the ages of the people.

4. Surmise what the family had been doing before the arrival of the unexpected visitor.

5. Remember the clothes worn by the people.

6. Remember positions of people and objects in the room.

7. Estimate how long the visitor had been away from the family.

3 min. recordings of the same subject
Feature Extraction

- key to extraction missed by
  - Euclid, Archimedes, Da Vinci, Newton
Feature Extraction

- key to extraction missed by
  - Euclid, Archimedes, Da Vinci, Newton
- Wheatstone 1838
Feature Extraction

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- Wheatstone 1838
Feature Extraction

- key to extraction missed by
  - Euclid, Archimedes, Da Vinci, Newton
- Wheatstone 1838
  - “there is an essential difference between the impressions on the organs of sensation”
Importance of Stereoscopy

- the slight differences between the two eyes define orientation in space
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Development of Stereoscopy

- altricial

- Hubel and Wiesel
  - patched one side
    = all input neurons to one eye
  - patched both sides
    = all inputs neurons active
Can You Patch an Ear?

- paths cross early
- hearing occurs in utero
  - conductive loss models
Can You Patch an Ear?

- paths cross early
- hearing occurs in utero
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Can You Patch an Ear?

- paths cross early
- hearing occurs in utero
  - conductive loss models
Auditory Brainstem Development

EABR

EIII  eV

Initial Stimulation
Month 2
Month 6
Year 1

Latency (ms)

Sequential bilateral
Simultaneous bilateral

Ear and Hearing, 2003
Asymmetry at the Lateral Lemniscus

Wave eV, Electrode 20

Device activation  3 months bilateral use  9 months bilateral use

Latency relative to Right (ms)

Sequential bilateral

Simultaneous bilateral

Otology & NeuroOtology, 2007
Studying Binaural Perception
Studying Binaural Perception
Studying Binaural Perception

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

Left Auditory Cortex  Right Auditory Cortex

“Patching” the Ear

Normal Hearing

Unilateral

Blue: Left Stim
Red: Right Stim
“Patching” the Ear

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

- **Left Auditory Cortex**
- **Right Auditory Cortex**

- **Normal Hearing**
- **Simultaneous**
- **Unilateral**

- **Left Stim**
- **Right Stim**
"Patching" the Ear

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

Left Auditory Cortex  Right Auditory Cortex

Normal Hearing

Simultaneous

6-12 months delay

Unilateral

Blue: Left Stim

Red: Right Stim
“Patching” the Ear

Lateralization Index = (R - L) / (R + L)

- Normal Hearing
- Simultaneous
- 6-12 months delay
- > 2 years delay
- Unilateral

* p = 0.01
Effect of Unilateral Stimulation

- Normal
- Simultaneous
- Short Delay
- Long Delay
- Unilateral

Graphs showing the effect of unilateral stimulation over time in sound, age of recording, age of first implant, and duration of unilateral implant use.
Effect of Unilateral Stimulation

- Normal
- Simultaneous
- Short Delay
- Long Delay
- Unilateral

Graphs showing data over time in sound, age of recording, age of 1st implant, and duration of unilateral implant use.
Effect of Unilateral Stimulation

- Normal
- Simultaneous
- Short Delay
- Long Delay
- Unilateral

**Time in Sound (yrs)**

**Age of Recording (yrs)**

**Age of 1st Implant (yrs)**

**Duration of Unilateral Implant Use (yrs)**
Effect of Unilateral Stimulation

- Normal
- Simultaneous
- Short Delay
- Long Delay
- Unilateral

Graphs showing the effect of different stimulation types on IHAD% with varying time and age variables.
Effect of Unilateral Stimulation

- Normal
- Simultaneous
- Short Delay
- Long Delay
- Unilateral

Graphs showing the impact of different stimulation methods on IHAD% (Negative Value) over varying time periods.
Effect of Unilateral Stimulation

- Normal
- Simultaneous
- Short Delay
- Long Delay
- Unilateral

![Graph showing the effect of unilateral stimulation over time.](image)

IHAD% (Negative Value) vs. Duration of Unilateral Implant Use (yrs)

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Effect of Unilateral Stimulation

- Normal
- Simultaneous
- Short Delay
- Long Delay
- Unilateral

Long Delay (> 2 yrs)

IHAD% (Negative Value)

Duration of Unilateral Implant Use (yrs)

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Hubel and Wiesel

- explained their “patching” experimental outcomes
- “…early in life the functional integrity of the pathway may depend not only on the amount of afferent impulse activity, but also on the interrelationships between the various sets of afferents.”
Abnormal cortical organization is promoted by unilateral cochlear implant use.
Binaural Hearing

- sounds reach:
  - one ear before the other
  - at different levels
Binaural Hearing

- binaural processing occurs first at the level of the brainstem
- timing and level differences are compared (sound localization)
Cochlear Implants and Binaural Hearing

- effects of inter-implant place
- effects of inter-implant level cues
- effects of inter-implant timing cues
Binaural Interaction

Right Stimulation

Left Stimulation

Left + Right Added

Binaural Stimulation

Binaural Interaction
Binaural Interaction

Child A: Simultaneous

Child B: Long delay

Apical Electrode

Right
Left

Bilateral-A1
ΣL+R
Bilateral -A2
ΣL+R
Difference
A2
Binaural Interaction

- Device activation
- 3 months bilateral use
- 9 months bilateral use

Graph showing latency relative to Right (ms) with bars representing long delay, short delay, and simultaneous conditions.

Child B: Long delay

Graph showing waveforms with labeled peaks eIII and eV, indicating Right, Left, Bilateral-A1, ΣL+R, and Difference A1 and A2.
Development of Stereoscopy

- Hubel and Wiesel
  - patched one side = all input neurons to one eye
  - patched both sides = all inputs neurons active

- eso- or exotropia resulted in amblyopia
- the eye still could “see” but the cortex couldn’t
Development of Stereoscopy

- Hubel and Wiesel
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- the eye still could “see” but the cortex couldn’t
Coding of Inter-Implant Place

Matched Place

Large Mismatch in Place
Coding of Inter-Implant Level

![Graph showing the relationship between interimplant level difference and BD amplitude/mean unilateral eV.](image)

**Graph Details**
- **X-axis**: Interimplant level difference (dB)
- **Y-axis**: BD Amplitude / Mean Unilateral eV
- **Legend**:
  - BD
  - Mean
  - CI1, CI2
Development of Stereoscopy

- Hubel and Wiesel
  - patched one side = all input neurons to one eye
  - patched both sides = all inputs neurons active
Coding of Inter-Implant Timing

- ITD=0 ms
  - 0.2 ms

- ITD=-0.4 ms (R leads L)
  - 0.6 ms

- ITD=+0.4 ms (L leads R)
  - 0.2 ms
Coding of Inter-Implant Timing

ITD = 0 ms
0.2 ms

ITD = -0.4 ms (R leads L)
0.6 ms

ITD = +0.4 ms (L leads R)
0.2 ms

Interimplant Timing Difference
2.0 msec
1.0 msec
0.4 msec
0.0 msec
-0.4 msec
-1.0 msec
-2.0 msec
Coding of Inter-Implant Timing

ITD = 0 ms  0.2 ms

ITD = -0.4 ms (R leads L)  0.6 ms

ITD = +0.4 ms (L leads R)  0.2 ms

Interimplant Timing Difference
2.0 msec
1.0 msec
0.4 msec
0.0 msec
-0.4 msec
-1.0 msec
-2.0 msec
Coding of Inter-Implant Timing
Coding of Inter-Implant Timing
Coding of Inter-Implant Timing
Coding of Inter-Implant Timing

![Graph showing latency and amplitude as functions of inter-implant timing difference.](image)
Binaural Perception

- Hubel and Wiesel
  - in the blind eye edge perception still possible!
  - primary processor still perceives edge

- cortex stereo blind
- edges in audition are coded by timing
Behavioural Implications

Normal Hearing

Inter-aural level difference (dB)

Interaural Timing Difference (us)
Behavioural Implications

Normal Hearing

Inter-aural level difference (dB)

- Both
- Right
- Middle
- Left

Cochlear Implant

Inter-implant level difference (CU)

- Both
- CI-1
- Middle
- CI-2

Interaural Timing Difference (us)

- Both
- Right
- Middle
- Left

Cochlear Implant

Inter-implant Timing Difference (us)

- Both
- CI-1
- Middle
- CI-2
Reassembling the Auditory Environment
Emotion in Faces But Not in Speech

Hopyan et al. (2009), Child Neuropsychology

[Diagram showing comparison of emotion recognition in faces versus speech for two groups: Control and Cochlear Implant. Error bars indicate statistical significance (% Correct)]

$p < .001$
Reaction Time

Mean data

Mean improvements

Cochlear implant (n=24) vs Normal hearing (n=23)

Auditory only vs Auditory-Visual

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Enhanced Use of Visual Input

Mean accuracy % correct

Cochlear Implant
n=23

Normal Hearing
n=25

Mean age = 11.7 years

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Reaction Time & Visual Input

- Auditory only
- Auditory-visual

Mean age = 11.7 years

Median Reaction Time (ms)

Cochlear Implant
- n=23

Normal Hearing
- n=25

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Impact of vision

Standing on one foot

EYES OPEN

EYES CLOSED

VISION*GROUP INTERACTION

p=0.88

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Impact of vision

**Standing on one foot**

- **EYES OPEN**
- **EYES CLOSED**

**Standing on one foot on a balance beam**

- **IMPLANT**
- **CONTROL**

**VISION*GROUP INTERACTION**

\[ p=0.88 \]

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Implant ON vs. OFF

Mean Scale Score (max=30)

p=0.01

CONTROLS

NORMS

*p=0.01

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Implant ON vs. OFF

Mean Scale Score (max=30)

CONTROLS

NORMS

ON OFF

*p=0.01

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Summary

- sequential bilateral cochlear implantation
  - allows asymmetric auditory development
    - alters but does not eliminate binaural processing in the brainstem
  - compromises binaural processing in the auditory cortex
    - facilitates perception of inter-implant level, but not timing, cues
Summary

- simultaneous bilateral cochlear implantation
  - allows symmetric auditory brainstem development
  - protects the auditory cortex from reorganized lateralization
Conclusions

- there are multiple sensitive periods in auditory development

- duration of both bilateral and unilateral auditory deprivation should be limited in children