Awakening the Auditory System: Binaural Benefit Revisited

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Introduction

- plasticity and evolution

- feature extraction
  - the senses
  - stereoscopy/binaural hearing

- awakening the auditory system
Plasticity Evolved

*Biston betularia f. carbonaria*
Human = Information Processor

- audition
- linguistic ability
- executive function

- olfaction
- vision
- motor skill

6th International Pediatric Audiology Conference: Dec. 9, 2013
Human = Information Processor

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Human = Information Processor

- audition
- linguistic ability
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- vision
- motor skill
Human = Information Processor

IQ = 107

IQ = 7
Human = Information Processor

IQ = 107

IQ = 7
Auditory Cortex in Silence

Reduced activity

Activity no longer reduced

Auditory Plasticity (Learning)

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

![Graph showing IT-MAIS score (%) vs Age (months) for different age groups: 6-12 months, 12-18 months, and 19-23 months. The graph highlights the plasticity in auditory development.]
Ongoing Plasticity

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

(Polley, Steinberg & Merzenich, 2006)
The Three Questions

- do I run from it?
- do I eat it?
- do I mate with it?
Feature Extraction - Senses

- extract data
- collect data
- assemble data
Sensory Reassembly

- illusory

- reassemble the world – most probable state
Sensory Reassembly

- illusory
- reassemble the world – most probable state
Senses

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

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

- fundamentally different
  - separate pathways
  - temporal relationships

lateral geniculate nucleus
Vision and Audition

- fundamentally different
  - separate pathways
  - temporal relationships
Feature Extraction

- saccades scan visual environment
Vision and Audition

- fundamentally different
  - separate pathways
  - temporal relationships

Diagram:
- Visual time vs. Auditory time
  - Different paths and decision points
Auditory Processing

- must process environment in one pass
  - extract
  - identify
  - categorize
Importance of Stereoscopy

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

- 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
You Can “Patch” an Ear!

- paths cross early
- hearing occurs in utero
  - conductive loss models
And You Can “Unpatch” an Ear!

- paths cross early
- hearing occurs in utero
  - conductive loss models
Studying Binaural Perception
Studying Binaural Perception
Studying Binaural Perception

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

Wong et al. IEEE (2010)
Reorganization of Auditory Cortex

Lateralization of auditory activity (%)

Long Delay
(> 2 years)

Short Delay
(< 1.5 years)

Simultaneous

Normal

Left/CI-2 Stim
Bilateral
Right/CI-1 Stim

Lateralization %
Participant Group

* P<0.05

Reorganization of Auditory Cortex

Lateralization of auditory activity (%)

- Normal
- Simultaneous
- Short Delay (< 1.5 years)
- Long Delay (> 2 years)

Left cortex
Right cortex

* P<0.05

Summary

- sequential bilateral cochlear implantation
  - allows asymmetric auditory development
  - compromises binaural processing in the auditory cortex
Summary

● simultaneous bilateral cochlear implantation
  ● promotes **symmetric** auditory brainstem development
  ● protects the auditory cortex from reorganized lateralization
There is a Bilateral Advantage

![Graph showing differences in speech perception scores for first ear in noise, second ear in quiet, bilateral in quiet, and bilateral in noise. The graph compares simultaneous, short delay, long delay, and long deaf-long delay conditions.](image-url)
...But Then it Disappears!

Jewell et al. In Press
Asymmetric Speech Perception

Jewell et al. In Press
Asymmetry & Bilateral Benefit

Jewell et al. *In Press*
Binaural Hearing
Children Need Binaural Hearing
Calculation: spatial unmasking

(noise at 0°) vs. (noise at 90°)
Calculation: spatial unmasking
(noise at 0°) vs. (noise at 90°)
Benefits of Simultaneous Bilateral Hearing

Results: Inter-aural/implant Level Differences

Normal Hearing

- ILD Condition: Left +20 dB, +10 dB, 0 dB, -10 dB, -20 dB, Right
- Response Rate: 0, 20, 40, 60, 80, 100

CI - Sequential

- ILD Condition: CI2 +20 CU, +10 CU, 0 CU, -10 CU, -20 CU, CI1
- Response Rate: 0, 20, 40, 60, 80, 100

Results: Inter-aural/implant Level Differences

**Normal Hearing**

- Response Rate vs. Interaural Level Differences (ILD) Condition
- L (Blue) and R (Red) curves

**CI - Sequential**

- Response Rate vs. CI Level Differences (CU) Condition
- CI1 (Red) and CI2 (Blue) curves

**CI - Simultaneous**

- Response Rate vs. CI Level Differences (CU) Condition
- L (Blue) and R (Red) curves

References:

- Deighton et al. *In Press* (2013)
Results: Inter-aural/implant Timing Differences

![Graphs showing response rate for Normal Hearing and CI-Sequential conditions with ITD conditions ranging from +2000µs to -2000µs.](image)

**Normal Hearing**
- Blue line: L
- Red line: R

**CI-Sequential**
- Blue line: CI2
- Red line: CI1
Results: Inter-aural/implant Timing Differences

**Normal Hearing**

- **ITD Condition**: +2000us, +1000us, +400us, 0us, -400us, -1000us, -2000us
- **Response Rate**

**CI-Sequential**

- **ITD Condition**: +2000us, +1000us, +400us, 0us, -400us, -1000us, -2000us
- **Response Rate**

**CI - Simultaneous**

- **ITD Condition**: +2000us, +1000us, +400us, 0us, -400us, -1000us, -2000us
- **Response Rate**
Increased Effort & Increased P2 Amplitude

Increased reaction time - emotions in speech

** p<0.01


Reassembling the Auditory Environment
Summary

- aggressive bilateral cochlear stimulation
  - promotes:
    - symmetric auditory brainstem development
    - spatial unmasking
    - binaural processing
  - does not result in improved speech perception in test conditions
Edge of the Envelope

- auditory cortex develops “normally” with
  - bilateral stimulation
  - short period of deprivation (in children)

- study children implanted with short periods of deprivation
  - asymmetric hearing loss
  - unilateral hearing loss
8th International Symposium on objective measures in auditory implants

Toronto, Canada
October 15-19, 2014