Training Auditory Processing in Children with Autism Spectrum Disorders and other Developmental Disabilities

Martha S. Burns, Ph.D.

Selected References

Selected References (cont.)


Agenda

A. Neuroscience Update Neurocognitive networks involved in attention, perception, language, memory, and prefrontal lobe functions
B. Neurodevelopmental processes that affect auditory processing
C. How Auditory Processing development is altered in Autism Spectrum Disorders and other Developmental Disabilities
D. Evidence-Based intervention
DeHaene, 2009

Neuronal communication system
Network Theory

- Network theory is an expansion of connectionistic theory that:
  - Was proposed after early neuroimaging results (PET and MEG scanning) revealed that distributed cortical regions fire in parallel and simultaneously during standard cognitive tasks like language processing
  - Based on Hebbian stance that – neurons that fire together wire together
Who? What? A unified sound wave coming from an unseen talker is analyzed to produce two distinct percepts—Who spoke and What was said.

P K Kuhl Science 2011;333:529-530
Published by AAAS

Normal A1 development

Zhang, Bao & Merzenich, Nature Neuroscience, 2001
Categorical speech representation in human superior temporal gyrus

Edward F Chang, Jochen W Rieger, Keith Johnson, Mitchell S Berger, Nicholas M Barbaro & Robert T Knight

Nature Neuroscience
VOLUME 13 | NUMBER 11 | NOVEMBER 2010
But… with developmental problems another issue

- cortical thickness – does that change with age and experience?
- How do the cortical areas communicate with each other
  - How do the major subcortical networks develop the links
  - What is the role of genes vs. experience
- How can that be visualized with fMRI
Brain Morphometry

Plots of grey-matter density are based on data by Gogtay et al. 2004 and illustrate the local grey-matter density in the mid-dorsolateral prefrontal cortex in red, in the angular gyrus of the parietal cortex in blue, in the posterior superior temporal sulcus of the temporal cortex in purple, and in the occipital pole in green.

Grey-matter density

![Graph showing the changes in grey-matter density across different ages.](image-url)
The role of fiber tract connections

- Measures diffusion (motion) of protons in water molecules.
- Direction of proton motion within a voxel can be described by a “tensor”.
- Proton diffusion tends to be relatively isotropic in gray matter.
- The linear structure of fiber tracts constrains proton diffusion and produces anisotropy.
Fiber Tract Development Observable with DTI
(from Hermoye et al., 2006)
Rapidly Developing Tracts

Reach 90% of maximum FA before age 11 years

Inferior longitudinal fasciculus
Splenium corpus callosum
Genu corpus callosum
Superior fronto-occipital fas.
Inferior Longitudinal Fasciculus
– links vision to sound

Intermediate Tracts
Reach 90% of maximum FA from age 15-17 years

Superior longitudinal fasc.
Corticospinal tracts
Body corpus callosum
Inferior fronto-occipital fas.

FA

Age (years)

0.55
0.5
0.45
0.4

Male
Female
Turken and Dronkers (2010 in press)
speech, fluency and grammar pathways

![Diagram](image1)

**Figure 8.** Pathways associated with the BA47 ROI (left, blue). Streamline tractography results from two subjects are presented as examples. The inferior occipito-frontal fasciculus as well as a group of IOFF fibers associated with the posterior MTG ROI were identified.

Turken and Dronkers (2010) in press –
White Matter tracts underlying auditory speech processing

![Diagram](image2)

**Figure 13.** Fiber pathways passing through the white matter underlying the superior temporal sulcus. Five different fiber bundles were found to contribute fibers to this sulcal white matter region: (left, green). Direct and indirect segments of the **frontal fasciculus**, the **infratemporal fasciculus**, the **inferior longitudinal fasciculus** and the **tappetua** are shown for the two subjects chosen as examples.
Decreased Interhemispheric Functional Connectivity in Autism

- Jeffrey S. Anderson, T. Jason Druzgal, Alyson Froehlich, Molly B. DuBray, Nicholas Lange, Andrew L. Alexander, Tracy Abildskov, Jared A. Nielsen, Annahir N. Cariello, Jason R. Cooperrider, Erin D. Bigler and Janet E. Lainhart
- Cerebral Cortex Advance Access published October 12, 2010

• Examined resting-state blood oxygen level–dependent interhemispheric correlation in 53 males with high functioning autism and 39 typically developing males from late childhood through early adulthood

Anderson, et al., 2010

• found significantly reduced interhemispheric correlation specific to regions with functional relevance to autism:
  – sensorimotor cortex,
  – anterior insula,
  – fusiform gyrus,
  – superior temporal gyrus, and
  – superior parietal lobule

• Observed interhemispheric connectivity differences were better explained by diagnosis of autism than by potentially confounding neuropsychological metrics of language, IQ, or handedness.
Distortions and disconnections: disrupted brain connectivity in autism (Wass, 2011)

- Point to evidence that there is local over-connectivity
  - Perhaps leading to repetitive behaviors and savant characteristics
- Long Distance underconnectivity
  - Leading to problems with long fiber track networks for:
    - Language and problem solving
    - MNS and TOM (see tomorrow’s discussion)

Wass, 2011

- Review DTI studies that reveal inter-hemispheric structural under-connectivity in mature subjects with ASD
  - With younger subjects the results are more mixed
- Also evidence showing disruptions to and from frontal and temporal cortices may be most heavily disrupted in ASD
  - This is consistent with early relatively intact development becoming progressively more disrupted during the first two years of life
Wass, 2011

- fMRI and EEG studies show evidence of functional over-connectivity but with this regard DTI is more mixed
  - Strongest evidence of local over-connectivity comes from the micro-level from a small number of post-mortem studies
- Tantalizing evidence that increased short-range connectivity and decreased long-range may resemble that found in immature vs. mature typically developing children
- ASD may be partially due to failure to undergo typical developmental process
- SO – is this the primary pathogeneis or does it develop over time?

Fig. 1 (A) Mean voice-recognition performance of dyslexic and control listeners (error bars indicate SEM).
U.C. Davis: M.A.R.B.L.E.S

- MARBLES is a prospective investigation that follows women who already have had one child with autism, beginning early in or even before a subsequent pregnancy, to search for early markers that predict autism in the younger sibling.

NY Times review of M.I.N.D.

- Multimedia
  - Interactive Feature
  - Patient Voices: Autism
A camera operator observed Carmen and Saul Aguilar during a therapy session with their son Emilio at 7 months old. Emilio showed signs of autism, and his older brother, Diego, received a diagnosis at age 2.

By APRIL DEMBOSKY
Published: November 1, 2010

SACRAMENTO — In the three years since her son Diego was given a diagnosis of autism at age 2, Carmen Aguilar has made countless contributions to research on this perplexing disorder.
Part II: Auditory Processing

A. Development of perceptual systems
B. Alterations in development due to genetic and environmental variations
C. Developmental and Acquired neuropathologies of perception –
   1. developmental disturbances
   2. evidence-based interventions

New research on causes

- Origins of human impairment and illness
  - Merzenich, 2003 – animal research
  - A1 processing is “specialized” as the infant is exposed to specific sound stimuli – auditory cortex maps
  - Perinatally generated maps can be distorted and persist into adulthood
- Variations occur depending on
  - Input modulation rate
  - Input intensity
  - Complexity of stimuli
  - Continuous noise
The critical period is the cortical ‘setup’ epoch – Merzenich, 2006

1. Early exposure drives and shapes the initial form of the cortex’s processing machinery.

2. That machinery is “specialized” to process environmental inputs.

3. In babies, the primary sound processing specialization is for the child’s native language.

4. Cortical specialization crucially enables the development of selective attentional control.

5. Cortical specialization generates important functional changes that enable subsequent skill learning.

6. At the end of the critical period, cortical maturation is paralleled by (causes) the maturation of modulatory control systems that results in the subsequent dominance of attentionally-controlled plasticity.

7. From the end of the critical period forward to the end of life, cortical plasticity is powerfully gated by these modulatory control systems.
Variations occur by…

- input modulation rate
- input intensity
- Complexity of stimuli
- pulsed noise, variable rate
- continuous noise

Four ways to degrade sensory cortex (aural language and somatosensory cortex) development

- perinatal anoxia Strata et al (2005) PNAS
A1 does not mature in infants raised in continuous noise

- In continuous noise reared rats, the critical period remains open indefinitely

A1 does **NOT** mature in rats raised in **CONTINUOUS** noise.

Chang et al. (2003) ms submitted for publication
A1 processing is "specialized" as the infant rat is exposed to specific sound stimuli.

A learning context is **NOT** required --- as it is after the end of the critical period.

Zhang, Bao & Merzenich, Nature Neuroscience, 2001

---

Perinatally generated representational distortions in A1 tonotopy and input selectivity persist into adulthood.

Zhang, Bao & Merzenich, Nature Neuroscience, 2001
PCB poisoning radically alters cortical map development

Exactly the same bizarre typography seen in autism
PCB exposure in pregnant mothers .87 correlation with
% of autism – some regions of Texas – Merzenich, 2006

Auditory processing disorders in children with ASD (Russo, et al, 2009)

- *Journal of Autism and Developmental Disorders*
  **Volume 39, Number 8,** 1185-1196, 2009
- Provides new evidence of deficient auditory cortical processing of
  speech in noise in autism spectrum disorders (ASD):
  - Speech-evoked responses (~100–300 ms) in quiet and background
    noise were evaluated in typically-developing (TD) children and children
    with ASD.
  - ASD responses showed delayed timing (both conditions) and reduced
    amplitudes (quiet) compared to TD responses.
  - As expected, TD responses in noise were delayed and reduced
    compared to quiet responses. However, minimal quiet-to-noise
    response differences were found in children with ASD, presumably
    because quiet responses were already severely degraded.
  - Moreover, ASD quiet responses resembled TD noise responses,
    implying that children with ASD process speech in quiet only as well as
    TD children do in background noise.
A1 is dramatically altered by early exposure to complex (e.g., speech-like) stimuli.

Induced changes persist into adulthood.

---“jungle sounds”/speech exposures
Beyond early infancy, plasticity is modulated as a function of:

1. brightness
2. attention
3. judgment of error
4. punishment
5. Reward
6. et alia

Some practical implications of these cortical plasticity studies:

A.) Plasticity depends on integration of sensory, motor, motivational, contextual, and cognitive processes
B.) Traditional training approaches work because therapists have learned how to make goals and procedures “relevant” to context, experience and personal needs
C. New brain plasticity-based strategies can be designed to reverse or ameliorate the symptoms and expressions of abnormal development or damage.
D. Team intervention – OT, Psych, PT, Speech – can have the most powerful and immediate outcomes

See Kilgard & Merzenich, Science (1998)
What can be done about it?

- the immature auditory system can be modified
  - Plasticity in older brains is powerfully modulated as a function of behavioral context
  - Plastic changes can be induced on a grand scale

Different dimensions of adult cortical plasticity are enabled by the behaviorally-context-dependent release of:

- **acetylcholine** (focused attention/reward) \(^{(Kilgard, Bao)}\)
- **dopamine** (reward, novelty) \(^{(Bao)}\)
- **norepinephrine** (novelty) \(^{(Bollinger)}\)
- **serotonin** \(^{(Bollinger)}\)
- **et alia**

*In infants*, exposure-based plasticity is relatively uniform.  
*In adults*, learning-induced changes are complexly “nuanced” by differences in behavioral context that result in the differential release of 6 or 7 modulatory neurotransmitters.
Plasticity control is achieved by the learning-context-dependent release of chemical “neuromodulators”.

Plasticity enabled by the release of the modulatory neurotransmitter **acetylcholine**
Noradrenaline- (norepinephrine-) induced plasticity

9 kHz exposure

4 kHz exposure

CAPD Management – traditional approaches

- Signal enhancement
- Auditory training
- Environmental modifications
- Metacognitive [executive] strategies
- Linguistic strategies
- Metalinguistic strategies
- Collaboration
- Learning strategies
Recent Evidence Based Research on APD intervention

• Kraus et al., (2007); Kraus and Banai (2007); Billiet and Bellis (2011) JSHR

• Auditory training - children with abnormal BioMARK findings benefit from auditory training approaches

• Results of Billiet and Bellis (2011) suggest that the BioMARK may identify a subset of children who would not otherwise meet (C)APD diagnostic criteria through behavioral means of central auditory assessment but who would likely benefit from auditory-based intervention approaches.

• This study provides support for inclusion of the BioMARK as part of the central auditory test battery.

• Finally, the surprising finding that all 20 children with dyslexia exhibited some form of central auditory dysfunction via either behavioral testing, BioMARK testing, or a combination thereof provides strong support for the evaluation of central auditory function in children with language based learning disorders such as dyslexia.

Intensive Intervention (Fast ForWord) Exerts Strong Effects on Brain Function

Typically reading children
Children with dyslexia before remediation
Children with dyslexia after remediation

What about AIT, TLP, Etc.

• ASHA has issued cautionary provisions regarding many of the programs because of minimal controlled research
  – Developed largely to desensitize children who are hypersensitive to sound
  – They might be effective in helping to organize the auditory system of very impaired children
  – So far no scientific evidence of their efficacy with children with APD

Learning to Juggle Produces Transient Change in Cortical and Tract Morphology
(Draganski et al., Nature, 2004; Scholz et al., 2009)

• Normal volunteers with no juggling skills were scanned at baseline.
• Subjects were taught a simple juggling task to criterion and re-scanned.
• After 3 months (Draganski et al.) or 4 week (Scholz et al.) without practice, jugglers were scanned a third time.
• Focal increases in gray matter were observed in middle temporal and left intraparietal sulcus areas, FA was increased in underlying white matter, and these were apparently diminished after 3 months.
Fast ForWord with ASD Methods
Russo and Kraus, 2010

- 12 children diagnosed with an Autism Spectrum Disorder
  - 6 trained, 6 control
  - Age matched (Trained=9.17±1.47 years; Control= 9.0±1.47 years, n.s.)

- Brainstem neurophysiology tests
  - /da/ in quiet and background noise
  - rising and falling /ya/ in quiet

Pitch tracking and phase locking of F0 improved

![Graphs showing pitch tracking and phase locking of F0 improvements pre and post training.](image-url)
Pitch tracking to the harmonics improved

AUT10

Pre

Post

AUT16
Two-year-olds with autism orient to non-social contingencies rather than biological motion

- Ami Klin, David J. Lin, Phillip Gorrindo, Gordon Ramsay & Warren Jones
- Video demonstration

Two-year-olds with autism show no preferential attention to biological motion, whereas control children show significant preferences.

So what about reading?

Viking Press

December 2009

Listening to words versus reading words
How Learning to Read Changes the Cortical Networks for Vision and Language


**a** | Training for arithmetic problems leads to decreasing engagement of the inferior parietal cortex (shown in yellow) and increasing recruitment of the angular gyrus (shown in blue).

**b** | A moving time window of 200 scans and reveals that there are significant changes in activity of the angular gyrus (shown in green) after only approximately 8 repetitions of a problem.
Literacy enhances brain responses in three ways \cite{DeHaene2010}:

- Boosts organization of the visual cortex
- Allows practically the entire left hemisphere spoken language network to be activated by written sentences
- Refines spoken language processing by enhancing the phonological region