Update on Neuroscience Applications to Treating Speech, Language and Cognitive Disorders

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Selected Neural Plasticity References


Reference Source for More Specific Neural Plasticity Rehabilitation Research

References of Neurochemistry of Plasticity

• *Neuron* (2012) **76**(1) Reviews on Neuromodulatory Mechanisms
• Ott, T. *et al.* (2014) Dopamine receptors differentially enhance rule coding in primate prefrontal cortex neurons. *Neuron* **11.012**

How does the latest brain science inform us about how we can…

• Individualize services
• Help our clients
  – Improve auditory attention,
  – Develop self-regulation skills,
  – Complete assignments on time and
  – Meet their educational goals
• Maximize the effects of our interventions

How does neuroscience contribute to our clinical populations?

• New brain science helps us understand how and why
  – Brain maturation differences among some students, especially ASD and Dyslexia that affect learning
  – Attention and self-regulation pose primary learning challenges in the adolescent
  – Educational services can be individualized to meet each student’s unique needs
Moving beyond the older anatomical view of the human brain - Brodmann's area map and colored outlines by process.

All cognitive functions apparently involve distinctive networks – mapping out of those networks has been one ongoing goal of recent neuroscience research.

Hebbian Axiom – Neurons that fire together wire together in networks.
Understanding networks requires understanding how the regions are connected: The Neuronal communication system

Change in the Brain’s White Matter

It is the maturity of white matter tracts that defines maturation and differs in students with ASD and ADD or ADHD

White matter, the myelin sheaths and axon sheaths of neural axons may control the propagation of neural impulses in a manner that affects white matter processing.
Tracts mature at different rates

Experience-Dependent Plasticity of the Cerebral Cortex (Pekna, M., Pekny, M., Nilsson, M., 2012)

• "The ability to adapt in response to the changing environment is the most fundamental property of the nervous tissue and constitutes the basis for learning."

• Neural plasticity - neurobiological basis for ability to adapt & learn in an experience-dependent manner
  - At the structural level, neural plasticity could be defined in terms of
    - dendritic and axonal arborization,
    - spine density,
    - synapse number and size,
    - receptor density,
    - and in some brain regions also the number of neurons.

Cortical Map Rearrangements (Pekna, M., Pekny, M., Nilsson, M., 2012)

• When normal input to a specific area of the primary somatosensory cortex is altered because of genetics or because of experience
  - rapid structural and functional reorganization results in this area being activated by sensory stimulation of the surrounding intact body regions
Cortical Map Rearrangements

- Occurs in sensory systems within the cortex including auditory and visual
- The reorganization that occurs after rehabilitation is associated with upregulation chemical neuromodulators in relation to the parameters of the stimulation that occurred

But beyond early infancy, plasticity is modulated as a function of:

1. novelty
2. attention
3. judgment of error
4. punishment
5. Reward
6. et alia
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)  
  (Bolinger)
- serotonin  
  (Bolinger)
- 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.

In older animals and humans, the brain controls its own plasticity.

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Childhood Apraxia of Speech


Turken and Dronkers (2011) motor speech planning, fluency and grammar pathways

Cortical Thickness of Children with CAS

![Diagram of cortical thickness comparison](image)
Findings

- Only one significant difference was observed: children with idiopathic apraxia had significantly thicker left posterior supramarginal gyril than Controls.
- Left posterior supramarginal gyrus thickness did not correlate with any of the baseline measures of speech performance in the clinical group.
- In children receiving therapy for apraxia, ROI analyses revealed significant thinning in the posterior superior temporal gyrus, canonical Wernicke’s area.
- Decreasing thickness in Wernicke’s over the course of therapy was not significantly correlated to change scores on any of the standardized speech measures.
- The clinical significance of thicker left supramarginal gyril in children with idiopathic apraxia is not clear.

Remember Temple’s original research: We saw right hemisphere changes and did not understand why—now we are starting to understand that those changes are essential to benefitting from remediation.
So what is Autism Spectrum Disorder?

- Most brain research indicates that the brains of children with ASD mature differently
  - Long association fiber tracts do not mature like those of typical children (see especially Wolff et al., 2012) for complex reasons:
    - Certain genetics play a role – ASD is a polygenetic disorder (see especially Sanders, 2013 and State and Levitt, 2011)
    - Synaptic pruning deficits may lead to this altered maturation (Tang, G. et. al., 2014)
  - Hormonal dysregulation that may increase inflammation and cell death has been identified in boys with ASD (Al-Zaid et al., 2014)
- **Bottom line**: ASD is a very complex neurological disorder that is caused by genetic mutations that have various negative effects on brain development and maturation

![Figure 2. Identification of multiple De Novo mutations in the same gene reliably distinguishes ASD risk-associated mutations (Sanders et al., 2013)](image)

So what might these genetic mutations do?
FIGURE 2. Trajectories of Mean Fractional Anisotropy for High-Risk Groups, Corpus Callosum Subdivisions (Wolff et al, 2012)

FIGURE 1. Trajectories of Mean Fractional Anisotropy for High-Risk Groups, Limbic (Fornix) and Association (ILF and Uncinate) Fiber Tracts (J. Wolff et al, 2012)

FIGURE 3. Trajectories of Mean Fractional Anisotropy for High-Risk Groups, Projection Fiber Tracts (Wolff et al, 2012)
Summary of Wolff et al, 2012

- There is a distinct and pervasive aberrant course of white matter fiber tract development in High Risk (HR+) infants who went on to develop ASD
- Infants actually have greater FA at six months but that is followed by blunted development such that FA was lower by 24 months.

Conclusions (Wolff et al, 2012)

- The core behavioral manifestations of ASD are due to atypical patterns of connectivity that
  - Differ across systems and time
  - Are not specific to one brain region or behavioral domain

In the past year...

- New research is clarifying many of the genetic risks
- New research is clarifying the effect on many brain structures – especially white matter tracts and decreased pruning of dendritic spines
- New research continues to support the value of targeted therapeutic interventions (computerized + standard individualized treatment) that strategically build language and social skills as well as white matter tract development
So what would happen if the brain did not prune itself correctly?

- Imagine a rose bush that is not pruned — what happens — there are many long tendrils that don’t produce roses and choke off the blooms
- If a brain does not prune itself — it is disorganized - very noisy (stimuli that should not draw our attention now do)

Loss of mTOR-Dependent Macroautophagy Causes Autistic-like Synaptic Pruning Deficits


Dendritic Spine Pruning Defect in the ASD Brain (Tang, 2014)

- Increased dendritic spine density with reduced developmental spine pruning in layer V pyramidal neurons in postmortem ASD temporal lobe.
  - Layer V pyramidal neurons are the major excitatory neurons that form cortical-cortical and cortical-subcortical projections.
  - Temporal lobe pruning deficit will cause major problems with speech perception
Dendritic Spine Pruning Defect in the ASD Brain

- Dr. Merzenich was the first to propose a problem with excitatory connectivity in ASD.
- Enhanced local excitatory connectivity, a feature of ASD, is proposed to cause:
  - Failure in differentiating signals from noise,
  - Prevention of development of normal long range cortical-cortical and cortical-subcortical communications,
  - And underlie neocortical excitation/inhibition imbalance.
- Fast ForWord products are designed to balance excitatory/inhibitory connectivity.

And just three weeks ago...

**More Differences Than Similarities Are Found in Autistic Siblings**

NYTimes review by BENEDICT CAREY JAN. 26, 2015

Whole-genome sequencing of quartet families with autism spectrum disorder

Ryan K C Yue et al. (2015) Nature Medicine

doi:10.1038/nm.3792 Published online 26 January 2015

Among their many behavioral differences, Thomas South, above, loves to explore, while his brother Cameron prefers to stay put. Credit: J. Adam Huggins for The New York Times.

The good news!

- ASD is very heterogeneous and variable
- The commonality is that it affects white matter development — and that is amenable to “experience driven plasticity”
- Educational, speech, language, OT and social interventions drive neuroplastic changes in white matter development
- Specific interventions combined with Fast ForWord Products work
Fast ForWord Language enhances language skills for children with ASDs

What are the neurological factors that lead to other learning problems?

ARCHIVAL REPORT
Disruption of Functional Networks in Dyslexia: A Whole-Brain, Data-Driven Analysis of Connectivity

- Emily S. Finn, Xilin Shen, John M. Holahan, Dustin Scheinost, Cheryl Lacadie, Xenophon Papademetris, Sally E. Shaywitz, Bennett A. Shaywitz, and R. Todd Constable (2014) BIOLOGICAL PSYCHIATRY 2014;76:397–404
“Nodes” could be determined that persist in 20 year olds with reading problems

NI DYS ("NI") network are shown in red, and nodes more strongly connected to the seed in the DYS NI ("DYS") network are shown in blue

(A) left inferior parietal lobule/BA 7 (node J); (B) left anterior inferior frontal gyrus/BA 46 (node Q); and (C) left fusiform gyrus/visual word-form area (node R).

Two weeks ago……

- FEBRUARY 11, 2015
- THE NEW YORKER
- How Children Learn To Read
- BY MARIA KONNIKOVA
- Maria writes a weekly blog focusing on psychology and science.

Chelsea A. Myers, Maaike Vandermosten, Emily A. Farris, Roeland Hancock, Paul Gimenez, Jessica M. Black, Brandi Casto, Miroslav Drahos, Mandeep Tumber, Robert L. Hendren, Charles Hulme and Fumiko Hoeft (2014) White Matter Morphometric Changes Uniquely Predict Children’s Reading Acquisition

PSYCHOLOGICAL SCIENCE
PUBLISHED ONLINE 11 SEPTEMBER 2014
Myers et al (2014) Summary

• Examined whether variations in brain development between kindergarten and Grade 3 predicted individual differences in reading ability at Grade 3.

Factors above and beyond family history, socioeconomic status, and cognitive and preliteracy measures at baseline.

Myers et al (2014)

• Structural MRI measurements indicated that increases in the volume of two left temporo-parietal white matter clusters are unique predictors of reading outcomes
• Using diffusion MRI, we identified the left arcuate fasciculus and superior corona radiata as key fibers within the two clusters.

White matter changes predict children’s reading acquisition
“Variations in brain development between kindergarten and grade 3 predicted differences in reading ability”

Myers et al (2014)

• “Volume changes in temporo-parietal white matter, together with preliteracy measures, predicted 56% of the variance in reading outcomes.”
• “Demonstrate(s) the important contribution of developmental differences in areas of left dorsal white matter, often implicated in phonological processing, as a sensitive early biomarker for later reading abilities, and by extension, reading difficulties.”

And Feb. 12……...

Group differences were found for all linguistic and nonlinguistic conditions for both temporal and spectral parameters. Auditory deficits were identified in most but not all participants with dyslexia.

These deficits were not restricted to speech stimuli—they were also found for nonspeech stimuli with equal and lower complexity compared with the vowel stimuli.

Summary: Christmann, C A.; Lachmann, T. & Steinbrink, C (2015)

- As these deficits are found prior to school entry, they can be regarded as predictors of the following reading-related skills
- Studies with samples at risk for dyslexia also revealed impaired temporal (Plakas, van Zuijen, van Leeuwen, Thomson, & van der Leij, 2013) and spectral (Maurer, Bucher, Brem, & Brandeis, 2003; Plakas et al., 2013) processing as risk factors of dyslexia

This is very consistent with earlier independent research on use of FFWD Language with Dyslexia and Auditory Processing (Temple et al., 2001; Gaab, 2008)
And the effects of Fast ForWord indicate functional connections seen in non-impaired readers are achieved (DeHaene, Reading in the Brain, pp 260).

**Visual Word Form Area**

**Inferior Frontal Region**

**Phonological area**

**Attention** – typical maturation allows for changing from global to focused (selective attention)

*Attentional maturation* depends upon maturity of the *dorsolateral prefrontal cortex* – it is a core component of cognitive control.

Neural mechanisms of selective auditory attention are enhanced by computerized training: Electrophysiological evidence from language-impaired and typically developing children.

Courtney Stevens, Jessica Fanning, Donna Coch, Lisa Sanders, and Helen Neville

*Brain Res.* 2008 April 18; 1205: 55–69.
The ERP selective auditory attention paradigm.

Figure 2. All students who received FFWD Language compared to controls improved in language skills – even typical students and those who did not receive FFWD language showed no gains.

Figure 5. All students who received FFWD intervention showed significant gains in the ERP attention effect. The FFW-L group showed significant increases from pre- to post-testing, with the FFW-TD group showing a similar trend.
Figure 6. Change in mean amplitude of ERP response (100–200 msec) to attended and unattended probes in children receiving FFW training (combined group of children with SLI and typically developing children, FFW-L and FFW-TD). Only changes in the response to attended stimuli were significant from pre- to post-testing.

Fast ForWord Language improves language scores and auditory attention – with decreased distraction

Attentional vs. Memory or Auditory Processing Problems

- Poor listener or tunes out (could be an auditory processing problem)
- Looks around to see what others are doing when teacher provides instructions – working memory or APD
- Fidgets, impulsive, intrusive, yells out answers, lack of self control -- ADHD
- Frequently asks – Huh? or What? when given instructions – working memory

Working Memory:
Your RAM and closely related to General Intelligence

It is a core component of Executive Function and exercised in almost all of the FFW exercises as well as Reading Assistant.
Working Memory can be trained and, when trained, helps reasoning skills.

Fluid Cognitive Skills Also Predict Test Scores

Education may be catching up on the importance of these underlying cognitive capacities — new research from Gabrielli’s team

- West et al. (2014) What Effective Schools Do. Education Next. FALL / VOL. 14, NO. 4
How working memory problems present in the classroom

- Slow on multiple choice tests even though they know the material
- Re-read passages frequently
- Trouble with memorization activities but get the key ideas
- Take much longer to complete homework and in class assignments
- Word-finding problems
- Problems with spelling
Children with Attentional problems and Working Memory problems also exhibit problems with Cognitive Control!

Two different information-processing systems in the brain battle for control of our response to temptation:

- impulses aimed at immediate gratification,
- and reason, which helps us pursue long-term objectives.

Drains on cognitive resources, such as working memory, can render us less able to withstand temptation.

Cognitive Control

The dual-systems model of self-control

1. Failure at low levels of self-control may stem from strong impulses (impulsivity) regions involved in reward (e.g., ventral striatum) and social information (e.g., medial prefrontal cortex)

2. Failure at higher levels (DLPFC) may result from weak control (poor effortful control/constraint) See especially, Albert & Steinberg, (2011) Too, Wong, Fan and Goo (2014)

Components of the Dual Systems Model of Self-Control — Low Level (Albert & Steinberg, 2011)

1. Central to the incentive processing system is the ventral striatum (VS) involved in reward, and the medial prefrontal cortex (mPFC) especially involved in aspects of social processing – these are integral parts of the limbic system - the early developing, primitive emotional/reward processing systems of the brain
Components of the Dual Systems Model of Self-Control – High Level: Dorsolateral Pre-frontal Cortex (DLPFC) (Albert & Steinberg, 2011)

2. Prolonged refinements over the course of childhood (Tos et al., 2014) and adolescence (Cerny et al., 2008) in DLPFC and posterior parietal lobe associated with Cognitive Control are thought to support reasoned behavior and adolescents’ emerging capacity for behavior regulation.

Plots of grey-matter density are based on data by Gogtay et al. 2004 illustrate the local grey-matter density in the mid-dorsolateral prefrontal cortex in red and the posterior parietal lobe in blue compared with other regions of students with typical brain maturation.

These are two of the cognitive systems we can drive using FFWD & RA.

Components of Cognitive Control Network

- Integral components of Fast ForWord Design
- Selective and Sustained Attention
- Working memory
- Integral components of FFWD & Reading Assistant – depending on how we use them
- Self-regulation
- Goal setting
How can we use FFWD and RA to increase Cognitive Control?

• To a great extent, the exercises drive regulation by decreasing impulsivity (especially if we provide strategies to the students to decrease “happy clicking”)
• The self control required to press the start button, wait, listen, think, respond builds cognitive control

Cognitive Control

• Teaching goal setting can also be included in Fast ForWord and Reading Assistant
  – **Token Economy** - try giving incentives for steps achieved with FFGD or RA step completion before beginning
  – Try a prediction sheet where students an RA goal with specific advantages for overachieving the goal

New Research on “Intelligent Tutoring Systems”

  – **Because in today’s economic climate classroom sizes are increasing not decreasing**
  – **And the expense of one-on-one tutoring is formidable**
How best to accomplish this?

• “It has long been recognized that individualized learning is much more effective than classroom learning”. Desmarais & Baker, 2012
• Students who receive one-on-one tutoring from an expert tutor score two standard deviations higher on standardized achievement tests than an average student who receives traditional group-based instruction. Bloom, 1984
• If they could, all teachers would love to work with children one-on-one

The Role of Technology – “Intelligent Tutoring Systems”

• Well designed neuroscience-based technology brings a one-on-one tutor to every student.

The Future

• Where is Neuroscience Going Next?
• Predicting which students will benefit from intervention
Neuroscience
John D.E. Gabrieli, Satrajit S. Ghosh, Susan Whitfield-Gabrieli
Neuron
Volume 85, Issue 1, Pages 11-26
(January 2015)

Region that distinguishes dyslexic children who benefit from intervention from those who do not

And what are the effects of Fast ForWord on brains of dyslexic children and adults?
Remember Temple’s original research – we saw right hemisphere changes and did not understand why – now we are starting to understand that those changes are essential to benefitting from remediation.

Temple, et al. 2003

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In Summary

- **All the new neuroscience research** continues to confirm the value of Fast ForWord in remediation of underlying brain systems that support:
  - Maturation of brain connection pathways
  - Perception of speech
  - Apraxia of Speech – neurological components
  - Autism Spectrum Disorders
  - Auditory Processing Disorders
  - Language
  - Reading
  - Cognitive control mechanisms of attention & working memory

- **New Research on Intelligent Tutoring Systems** supports the value of self-adaptive computerized interventions that bring one-on-one interventions to every student.