Targeted Cognitive Intervention @ The Carroll School

How can cognitive neuroscience inform educational practice? The implications of a cognitive-neuroscientific framework of reading in the brain

Cognitive neuroscience is a rapidly growing discipline that integrates psychology and neuroscience in order to arrive at an understanding of how complex cognitive functions such as perception, memory, language, emotion, and higher-level thought processes are organized in the brain. Research evidence from brain imaging, genetics, and studies of brain injury and dysfunction have allowed scientists to map patterns of neural activity onto certain cognitive behaviors. This has enabled an increasing understanding of how various brain regions communicate to produce networks that carry out the demands of important tasks such as those required by an academic setting. There is thus growing consensus that a deeper understanding of how the young brain develops these crucial networks is key to optimizing educational instruction. In particular, language and reading networks in the brain have extended developmental trajectories that leave them both vulnerable to disruption and simultaneously amenable to effective intervention.

Successful Reading Acquisition Requires Neuroplasticity

Much of recent cognitive neuroscience research has focused on neuroplasticity - the brain's ability to change and reorganize in response to its surrounding environment. Repeated external stimuli rewire the firing of neuronal cells, altering and strengthening existing patterns of activation and communication. Learning, then, *is* the brain literally changing. Perhaps the best example of this remarkable ability to change is reading - a skill that developed relatively recently in human evolutionary history, and one which required the creation of entirely new neural pathways. Three decades of brain-imaging research have shown that the formation of a novel brain network linking spoken language areas to visual-spatial regions is necessary for successful reading acquisition (Norton, Beach, & Gabrieli, 2015; Ozernov-Palchik, Yu, Wang, & Gaab, 2016; Rueckl et al., 2015). The brain literally learns to "hear with the eyes" by creating strong links between an evolutionarily new visual word form area (VWFA) and existing oral language areas (Gori & Facoetti, 2014; Kronschnabel, Brem, Maurer, & Brandeis, 2014).

An important part of this network-formation process is myelination - the production of a fatty white lipid substance that wraps around neurons and acts as a kind of electrical insulator, improving cognitive performance by increasing the speed of nerve impulses. A critical underlying feature of fluent reading, therefore, is enhanced myelination of the large tracts linking visual, language, and attentional brain regions (Barquero, Davis, & Cutting, 2014; Myers et al., 2014; Yeatman, Dougherty, Ben-Shachar, & Wandell, 2012). By facilitating communication between these visual and spoken language areas, myelination enables faster and more accurate word recognition. It is thus crucial to the adaptive plasticity required for typical reading acquisition.

Like the formation of synaptic connections in the brain, myelination is a process of experience-dependent neuroplasticity. In other words, the extent to which an individual's neuronal connections develop and become myelinated relies largely upon external influences. Research has shown that animals raised in barren, unengaging environments develop fewer and less complex connections than those raised in rich, complex, and stimulating environments (Diamond et al., 1966; Diamond et al., 1975; Greenough et al., 1973; Volkmar & Greenough, 1972).

This understanding of the brain's fundamental learning processes allows one to recognize reading fluency as simultaneously complex and cohesive; multifaceted yet integrated. Multiple parts of the brain - each of which is responsible for specific component and subcomponent skills - must *communicate efficiently* in order for a student to read fluently.

Contemporary approaches to special education often result in incomplete remediation

Children with dyslexia, however, often fail to properly form the necessary reading circuits in response to elementary education (Shaywitz & Shaywitz, 2008). Despite access to standard reading instruction, they may remain unable to efficiently identify letters, link these letters to the sounds they encode, or combine the decoded sounds into words. This lack of integration is consistent with numerous studies showing less myelination and poorer organization of the white matter tracts linking visual identification, auditory processing, and attentional areas in dyslexics (van der Leij et al., 2013; Vandermosten, Boets, Poelmans, et al., 2012; Yeatman et al., 2012). Perhaps because they do not undergo the necessary neuroplastic changes, children and adults with dyslexia read using different and less efficient brain networks (Shaywitz & Shaywitz, 2008) that result in more effort and less speed.

Why might this be? In the broad view, many contemporary approaches to special education and reading remediation focus primarily on *component skills* of reading. Dyslexic students' struggle with accurate word identification, for example, inspired the Carroll School's founding nearly 50 years ago, and is the primary target of

Orton-Gillingham practice. This kind of specific skill instruction generally occurs at the word or phoneme level - in other words, its emphasis is ensuring that students properly learn how to link sounds (phonemes) with their symbols (letters). Letter identification, phonemic awareness (the ability to discriminate sounds), and the ability to link the two are crucial building blocks of reading. They help enable faster and more accurate word identification and decoding skills, critical components of reading. Despite successfully improving these skills, however, many traditional approaches have been unable to fully remediate dyslexics' inability to read rapidly, fluently, and with good comprehension. Carroll and other state-of-the-art educational environments help dyslexic students become readers, but these dyslexic readers continue to differ in the brain-basis of their reading (Shaywitz & Shaywitz, 2008). They tend to read more slowly, less accurately and are more easily fatigued than typical readers (Adams, 1990; Wolf & Katzir-Cohen, 2001).

A cognitive framework of reading, on the other hand, enables the examination and development of integrative capacities necessary for fluent, *connected-text* reading at the sentence and passage level. If word identification and decoding can be considered core "building blocks" of reading ability, **fluency** and **comprehension** are what we might call the "*endpoints*" of literacy. Carroll's desire to better meet the needs of its students led to a five year effort to identify new, brain-based instructional approaches that could target these endpoints. This ultimately resulted in the development of a unique, remediative, cognitive training program called Targeted Cognitive Intervention (TCI).

Cognitive instruction improves connections among particular multifunctional hubs

In order to create the TCI program, Carroll's Cognitive Intervention & Research team engaged in an effort to articulate a framework of reading in the brain that is based upon a vocabulary of communication between dynamic, integrative hubs linked by large white-matter tracts (Hudson, Pullen, Lane & Torgesen). These "rich hubs" are multifunctional, multisensory regions of the brain that subserve the crucial components of reading - including oral language (speech), visual letter recognition (orthography), and grammar/syntax (Sporns & Betzel.) Previous cognitive interventions have been shown to stimulate synaptic formation and myelination. Similarly, by utilizing a network model of reading in the brain, TCI aims to drive communication between these critical neural regions, ultimately improving word identification and reading fluency. It targets the neural connections that bind together the building blocks of reading - effectively accessing those thus-far elusive "endpoints" - in order to produce literacy.

This method of intervention builds capacities, not specific skills. By improving the brain's ability to function efficiently and integratively, TCI hands students a cognitive "toolbox" that will carry them through their academic careers. In short, TCI instruction does not teach specific content, but builds the cognitive capacities necessary to access *any* content/material that a student may encounter.

Targeted Cognitive Intervention (TCI) at Carroll

Assessment

TCI is based upon a cyclical model of assessment, instruction, and re-assessment/analysis. Students' cognitive abilities are first assessed with battery of computer-based tasks that measure the major brain capacities required by reading. Performance on these tasks produces scores for the following cognitive domains: Reaction Time, Processing Speed, Executive Function, and Working Memory. Unlike many standardized tests (including the SAT, for example), these measures are not content-specific - they do not test students on any kind of learnt material. Rather, they give an idea of the brain's *underlying ability* to perform different cognitive functions, all of which are important for learning in *any* subject. From these assessment results, individual cognitive profiles are generated. These profiles provide a deeper understanding of students' individual strengths and weaknesses as well as population and subpopulation-level patterns of cognitive ability within the larger student body. At Carroll for example, most students demonstrate a weakness in more than one cognitive area. Almost 60% of Carroll students have a weakness in reaction time, around 25% have a weakness in working memory and processing speed, and just over 20% have a weakness in executive function.

Assignment + Implementation: Differentiating instruction based on cognitive-academic profiles

Based on a student's cognitive profile, he/she is assigned a specific program comprised of computer-based games designed to improve his/her area of greatest need - or, in other words, the most significant cognitive weakness. Students complete 30 sessions of TCI training, spread out over the course of several weeks. At the end of the training period, students are re-assessed on the same measures to determine any changes in cognitive scores. Students' cognitive profiles are further related to their academic strengths and weaknesses (as well as social-emotional and behavioral factors) to create robust learning profiles that continue to help target effective instruction.

TCI in the classroom: Coaching, Progress Monitoring, Adjustment

Student activity data is tracked throughout TCI, allowing educators in the classroom to continually monitor individual progress and make adjustments where needed. TCI specialists who have been trained in the curriculum are able to note the specific games and levels with which students are struggling and/or excelling. They coach students through difficult sticking points, work to develop strategies, and adjust programs to suit each student's needs. These processes of progress monitoring, coaching, and individualization are essential to the integrity and success of TCI.

Results: TCI Results in Improved Reading Fluency

5 years of Carroll students' data demonstrates that TCI improves not only cognitive scores but academic results too. Findings clearly indicate that students' reaction time scores are most closely correlated with their reading fluency abilities (See Fig. 1). Reaction time - a student's ability to respond quickly and accurately to a stimulus - is an integral element of fluent reading. With the addition of TCI to the standard Carroll curriculum, students' performance on reaction time tasks has improved significantly - and, perhaps more importantly, this has translated into significant improvements in reading fluency (See Figure 3).

Multiple rounds of TCI prove to result in even greater gains. Classes that underwent three rounds of TCI experienced steeper rates of improvements than those with only two years of the intervention (Figure 3). In the 2017 graduating class, the percent of students with no significant cognitive weaknesses had increased from 31% to 56% after three consecutive years of TCI (See Figure 2). Additionally, the rate of this increase was significantly greater *during* intervention periods (Figure 2). Not only is TCI effective, but its benefit seems to be cumulative.

Creating cognitive-academic profiles: Implications for instruction in the classroom and beyond

So why does cognitive training result in improved academic outcomes? How can students perform better without specific skill instruction? As discussed earlier, multifunctional hubs in the brain explain the common basis between cognitive and academic struggles in people with dyslexia. Because reading acquisition and proficiency (i.e. fluency) depend on the development of broad cognitive capacities - as do *all* academic skills - a non-academic program that drives integration between crucial brain regions enables students to better access and engage in their schoolwork. By mapping the cognitive components of learning onto the underlying structure of neural networks, TCI programs hit upon precise regions of weakness at an academic, cognitive, *and* neural level. **What makes TCI unique is precisely this - its ability to target the *cause* of students' learning struggles rather than the symptom.**

Crucial to the success of TCI is the coupling and simultaneous examination of both cognitive and academic data. TCI utilizes multiple sources of information to create powerful, dynamic profiles that inform a student's development in and out of the classroom.This compilation of academic and cognitive assessments represents an interdisciplinary and data-driven approach to education that is key to bridging the gap between research and practice. Carroll believes that the future success of all cognitive-based curriculum relies upon this - the effective marriage of neuroscience and educational practice.

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Appendix

Mean Reaction Time Scores of Carroll School 5th - 7th Grade Students By Reading Fluency Bands

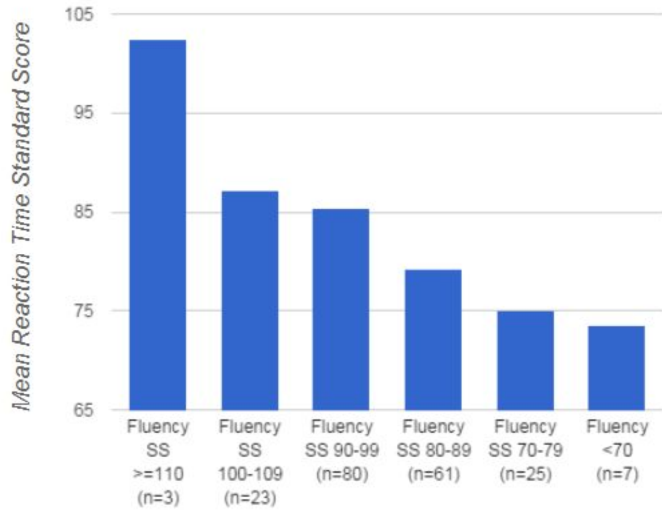

Fig. 1 Mean Reaction Time Scores of Carroll School 5th - 7th Grade Students By Reading Fluency Bands (n= 199). Reaction time scores and reading Fluency scores are highly correlated.

Percent of Students with No Weaknesses (SS<90) in Reaction Time, Processing Speed, Executive Functioning, or Visual Working Memory

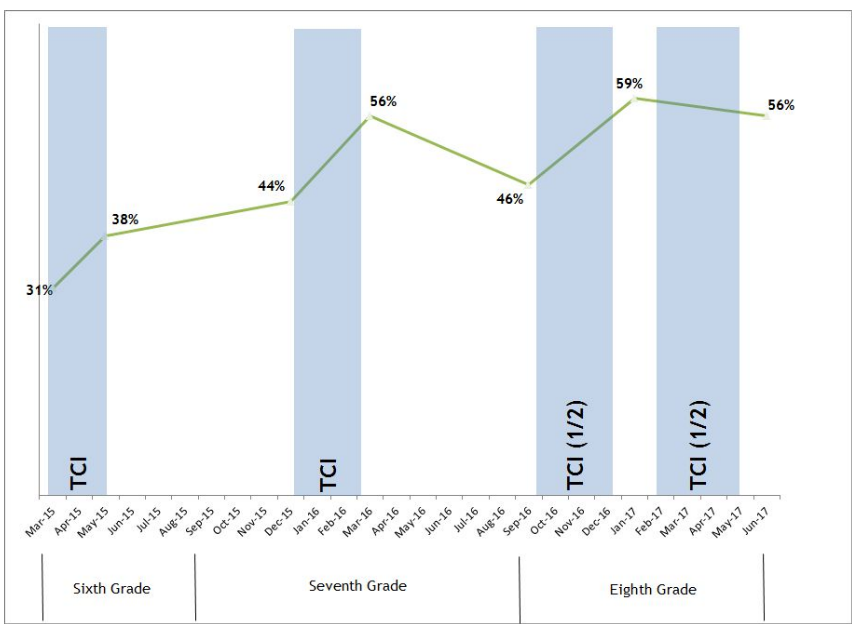

Fig. 2 Percent of Students with No Weaknesses (SS<90) in Reaction Time, Processing Speed, Executive Functioning, or Visual Working Memory. N = 39 students from the Carroll School class of 2017

who had scores in all 4 major cognitive domains in each of 7 testing periods, from March, 2015 (mid-6th grade) to June, 2017 (end-8th Grade).

Carroll Students Oral Reading Fluency Growth Improves with TCI

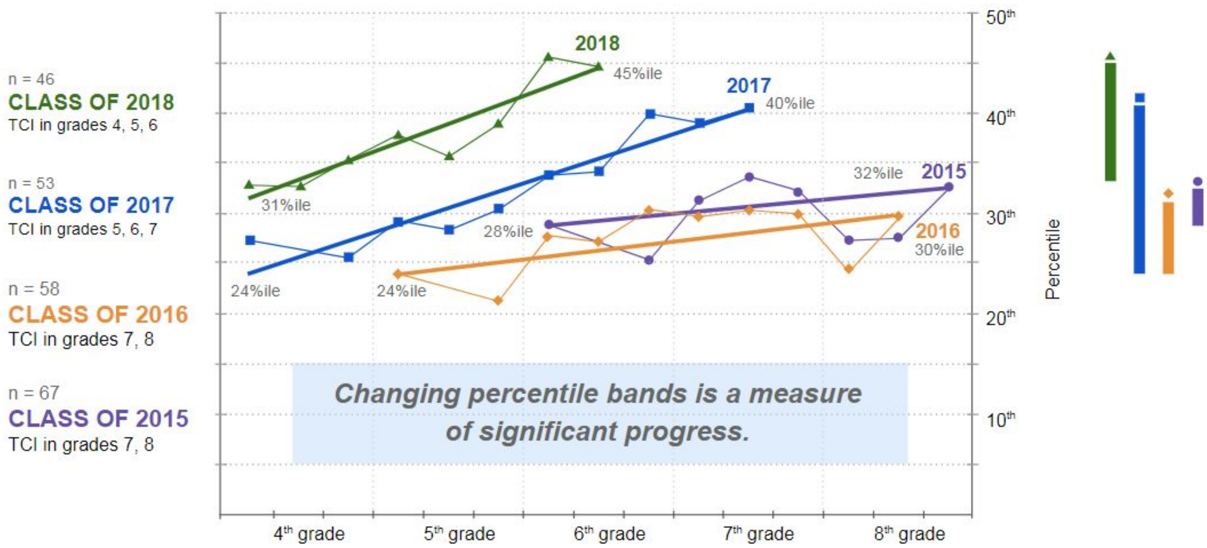

Fig. 3 Mean Oral Fluency Reading Scores of Carroll Students (Carroll School *Read Naturally* Assessment). Mean oral reading fluency scores improve more with additional years of TCI.

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