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## The Utility of Neuroimaging Studies for Informing Educational Practice and Policy in Reading Disorders

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### Abstract

Educational neuroscience is an emerging scientific field that brings together researchers from neuroscience, psychology, and education to explore the neurocognitive processes underlying educational practice and theory. In this brief article, we take reading disorder (RD, also known as developmental dyslexia) as an example, and explore trends in neuroimaging research, which may have future implications for educational practice and policy. Specifically, we present two examples that have been central to research efforts in our laboratory: (a) utilizing multimodal neuroimaging to optimize criteria to diagnose RD, and (b) identifying neuroimaging markers that predict future academic outcomes. Such research is faced with important challenges, and rigorous validation is necessary before any claims of the widespread practical utility of neuroimaging can be made. Nevertheless, we contend that neuroimaging studies offer opportunities for providing critical information that could lead to advancing theory of reading and RD. This could in turn lead to better diagnostic criteria and more accurate and earlier identification of RD.

### Introduction

Although reading brings joy to many children, for a subset of students who struggle to read, it can lead to a cascade of negative self-perceptions and reduced access to educational content. Reading disorder (RD) is neurobiological in origin (Lyon, Shaywitz, & Shaywitz, 2003) and affects 5–17% of all children (Fletcher, Lyon, Fuchs, & Barnes, 2007). Neuroimaging research has substantially enhanced our understanding of the mechanisms of (a)typical reading development. Further, imaging findings provide a neurocognitive explanation for existing reading pedagogy and promote neuroscience evidence-based practice. In the coming pages, we emphasize our work and others' to provide two examples of the potential usefulness of neuroimaging to: (a) improve diagnostic criteria for RD and (b) supplement current practice of predicting reading outcomes. We conclude with limitations of neuroimaging and cognitive neuroscience.

## Example 1: Validating and Optimizing Identification Criteria for RD Informed by Neuroimaging

RD is an unexpected difficulty in learning to read that cannot be explained by other cognitive, motivational, or environmental factors (Lyon et al., 2003; Shaywitz, Morris, & Shaywitz, 2008). This “unexpectedness” of RD has led to a cross-discipline search as to how to best characterize it—a challenging pursuit—as RD lies on a continuum with considerable variability. Despite a number of studies showing functional and structural brain anomalies and substantial genetic linkages, there is currently not a robust and universal diagnostic criterion. This ambiguity leads to a predicament in public health where a number of struggling students are unable to receive services and others are being misdiagnosed.

Historically, research efforts have been instrumental in guiding the criteria set forth by the Individuals with Disabilities Act (IDEA) originally enacted in 1975 (then the Education for All Children Act) to ensure children with disabilities educational rights. Prior to amendments to the IDEA in 2004, it was generally accepted that intraindividual discrepancy between aptitude and achievement should be used for the diagnostic criteria in RD, where intelligence (IQ) is often used as a proxy for aptitude (though some have proposed other measures such as listening comprehension) (Stanovich, 1991). The discrepancy model has led to a number of criticisms. For example, studies have since shown that poor readers with and without discrepancy perform similarly on phonological processing skills important for reading (Hoskyn & Swanson, 2000; Stuebing et al., 2002), and respond to interventions similarly (Stuebing, Barth, Molfese, Weiss, & Fletcher, 2009). Therefore with the reauthorization of IDEA in 2004, federal policy no longer mandates that discrepancy be present for a diagnosis of RD (Fletcher et al., 2007).

Low achievement has been suggested as an alternative criterion for diagnosis. However, its usage has not been straightforward either. Namely, there are complexities in utilizing low achievement on its own, such as distinguishing a low achiever from someone who hasn't received proper instruction. There is minimal solid neurobiological evidence that favors low achievement over discrepancy; some have shown that RD individuals who fit low achievement criteria show less homogeneity, genetic heritability, and treatment resistance (Stanovich, 1991; Wadsworth, Olson, Pennington, & DeFries, 2000; Willcutt et al., 2010).

A more recent classification approach, included in the IDEA, is the multitiered intervention structure, implemented within the school system, known as the response to intervention (RTI) model. RTI overcomes the difficulty in dissociating those poor readers who lack adequate reading instruction. In RTI, criteria for RD are met if an individual does not respond to increasingly intense intervention, typically assessed repeatedly through curriculum-based measures (Denton, 2012). Though promising, RTI is not without difficulties, as it requires cut-points of responsiveness, which vary across research studies (Denton, 2012; Fuchs & Deshler, 2007).

Despite robust behavioral research efforts, the ambiguity of diagnosis of RD is without question. Thus, the role of neuroimaging in diagnosis criteria may be twofold: (a) providing neurobiological support for or against existing theories that may be controversial, and (b)

providing unique and sensitive insight not explained by behavioral measures on their own. It is important to note that it is typically difficult to perform neuroimaging studies of different RD identification criteria using a population-based sample because of factors such as high cost of imaging and ascertainment bias. Nevertheless, there are several studies that have examined different *experimental* models of RD identification criteria (Rezaie et al., 2011; Simos, Fletcher, Rezaie, & Papanicolaou, 2014; Tanaka et al., 2011).

For example, a magnetoencephalography (MEG) study, with implications for understanding RTI, found baseline differences in neural activity between children with RD who did and did not respond to interventions. Future responders showed greater activity in the left temporo-parietal region, important for grapheme–phoneme integration and phonological processing. The amount of activity in the temporo-parietal region prior to intervention was predictive of gains in reading fluency post intervention (Rezaie et al., 2011). Further, our group performed a functional magnetic resonance imaging study (fMRI) of phonological processing to investigate whether low achievers exhibited similar brain activation patterns as those with discrepancy. Such evidence would support behavioral literature debunking the discrepancy model (Tanaka et al., 2011). We found no reliable functional brain differences between the low achievement (poor reading and poor IQ) and discrepant poor readers (poor reading but discrepant and typical IQ). A more recent study involving an overt decoding task during MEG, requiring phonological processing, showed converging evidence (Simos et al., 2014). Thus, neuroimaging findings generally support behavioral evidence that identification of RD based on low achievement and RTI seems neurobiologically most plausible.

In addition to continuing these efforts of providing neurocognitive information to *validate* diagnostic criteria, the next frontier is to utilize neuroimaging to *refine* identification criteria. Perhaps most important to this effort is the notion that neuroimaging data are considered intermediate (endophenotype) to genetics and behavior with greater sensitivity than behavior in identifying the cause of RD (Cannon & Keller, 2006). This potential sensitivity of neuroimaging data may also prove to be useful in early identification and intervention.

## **Example 2: Neuroimaging in Aiding Prediction of Reading Outcomes and Potential for Early Identification and Intervention**

Children with RD, especially when intervened early, can make substantive gains in reading (Al Otaiba & Fuchs, 2006; Fletcher et al., 2007; Shaywitz et al., 2008). Early identification and intervention can also reduce socioemotional problems secondary to reading struggle (Gerber et al., 1990; Ofiesh & Mather, 2013). Currently, family history is one of the strongest risk factors for developing RD, especially in early years where preliterate measures such as letter knowledge, vocabulary, phonological awareness, and rapid naming cannot be reliably obtained (Caravolas et al., 2012; Lefly & Pennington, 2000). Therefore, it will be useful to have reliable early markers that will identify which of those with family history will develop RD, as well as early markers for those without genetic risk for developing RD.

The potential power of imaging is the ability to measure reading-related precursors in the brain prior to children developing the skills necessary for traditional behavioral assessment. For example, findings from event-related potential (ERP) studies, measuring the electrical activity of the brain, show that infants' ERP patterns predict preliteracy and reading in school-aged children (Espy, Molfese, Molfese, & Modglin, 2004; Leppanen et al., 2012). The advantages of ERP over other imaging modalities is its cost-effectiveness, widespread accessibility, and noninvasiveness, hence allowing tests for markers of early reading difficulties in newborns.

A number of imaging techniques, including MRI, examining children as they start to develop literacy skills or once they are proficient have surfaced in the past decade. Although MRI may not be a cost-effective widespread means for early identification and prediction of therapeutic response, its potential advantage is in the ability for large spatial coverage, including deeper brain structures. Further, there is potential to transfer knowledge to other more accessible imaging modalities (e.g., near-infrared spectroscopy; Cui, Bray, Bryant, Glover, & Reiss, 2011).

Our group and others have found that functional and/or structural imaging data not only predict reading outcome (Linkersdorfer et al., 2014; McNorgan, Alvarez, Bhullar, Gayda, & Booth, 2011; Yeatman, Dougherty, Ben-Shachar, & Wandell, 2012), but also predict outcome when standard reading-related measures do not (Hoeft et al., 2011). Additionally, imaging data can add nonredundant information to standard reading-related scores predicting reading acquisition and outcome, explaining an additional 12–24% of the total variance (Bach, Richardson, Brandeis, Martin, & Brem, 2013; Hoeft et al., 2007; Maurer et al., 2009; Myers et al., 2014).

Although recent attempts to use neuroimaging as biomarkers are seemingly promising, there are important caveats that should be understood. First, neuroimaging studies will not reveal the cause of RD, although it may be an ideal tool to measure the interactive effect of environment and genetics on reading behavior. Second, most studies follow children only for a short period of time (1–3 years). Third, sample sizes are small and biased, as in other neuroimaging studies. Further, often cross-validation is not performed, which reduces the chance of the models to generalize to other samples. Ultimately, studies that include population-based samples with proper validation methods that perform cost–benefit analyses and measures of stability and psychometric properties of the instrument and data are required.

## Future Direction

Neuroimaging has greatly enhanced our understanding of the brain basis of RD, definition and identification. We now consider three important next steps in RD neuroimaging work, each with implications for policy and practice. First, there is a possibility of examining the developmental trajectories, or “growth charts,” of reading circuits to better predict outcome and to dissociate often intertwined effects of maturational delay from dysfunction. Second, there is increased importance of considering parental information to better understand intergenerational transmission patterns of RD (van Bergen, van der Leij, & de Jong, 2014).

To this end, neuroimaging of the parents may fuel this endeavor and lead to better understanding of the mechanisms of RD. In doing so, we should include measures of environment (e.g., prenatal, school) and socioemotional factors (e.g., motivation) that will allow comprehensive assessment of each child. This should in turn lead to improving reading as well as nonreading interventions for RD. While neuroimaging will continue to take a relatively indirect role in practice, cross-discipline avenues of work that include neuroimaging have the potential to fuel personalized education, meeting the children where they are in terms of neurobiology, cognitive skills, and environmental influences to enhance outcome.

In sum, we present here a brief overview of examples of how neuroimaging may have (in)direct implications for educational practice. We cannot say with certainty where the field of RD research and practice will head, but given the deleterious effects on both individuals and society, future efforts in the field must aim for prevention, earlier identification, and intervention. The chances of success in these areas are clearly increased with fluid collaboration between practice and research to inform policy and treatment.

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