CHAPTER 5

Early Identification of Children at Risk for Reading Difficulty

Neurobiology, Screening and Evidence-Based Response, and Educational Technology

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SUMMARY

Proficiency in reading is crucial for academic and vocational success. In the United States, 63% of children in the fourth grade are reading below grade level, and about 5%–12% are diagnosed with dyslexia. Many of these children are not "flagged" in the school system until after reading instruction has begun and they have repeatedly failed in learning to read. This is often detrimental to the child's development because repeated failure to learn to read can lead to severe academic and psychological harm. Also, reading interventions are more effective in curbing reading failure when begun early (see Lovett et al., 2017), when the gap in proficiency compared to typically developing children is still small and the secondary implications of reading failure (e.g., reduced vocabulary, reduced background knowledge) are minimal. Atypical brain development in certain brain regions has been evinced in prereading children who subsequently manifested reading disability, which has helped to shed light on the underlying mechanisms of reading failure and provided an impetus for the development of early screening programs to identify children at risk for reading impairments. Screening children individually for risk of reading disability can be accomplished through behavioral assessment of preliteracy abilities, which are strong predictors of later reading disability, including phonological awareness, letter–sound knowledge, rapid automatic naming (RAN), vocabulary, and oral language comprehension. As such, the first step toward preventing reading failure is to assess these abilities in children prior to formal reading instruction. The second step is for educators to be immediately directed to an evidence-based response to screening protocol (EBRS), similar to a response to intervention (RTI) multi-tiered approach that is customized to the specific preliteracy deficits identified in the screening step, and then monitored for progress. Thus, the "failure model" of screening and intervention is replaced by a "support model." This proactive support model is paramount in preventing both repeated failures in learning to read and the academic and psychosocial consequences of those failures.

INTRODUCTION

The development of skilled reading requires a complex network of competencies. Beginning in utero and through the first years of life, children

typically start developing skills that lay the groundwork for later literacy. A child's auditory and visual processing skills develop through interactions with the environment, and these become a cornerstone for the acquisition of oral language skills, including phonological processing skills and letter recognition ability—critical precursors to reading—as the child approaches school age. Children discern the relationship between the sounds of words and the letters that represent them (known as phoneme–grapheme mapping); this underpins decoding and recognition of single words. These word recognition skills become increasingly automatic and coalesce with developing language skills (e.g., mastery of complex syntax, semantics, vocabulary); together, these skills serve as the foundation for fluent reading of sentences and complex text for comprehension. In this way, reading can be thought of as a rope composed of many fine strands woven inextricably together to produce skilled reading (Scarborough, 2001). Through this developmental process, children can progress from effortful training in reading, to using reading as a tool to facilitate new learning. In simpler terms, they can progress from a stage of learning to read, to a stage of reading to learn. The completion of this transition is crucial for later life success, both academic and vocational.

Indeed, the development of basic reading skills is one of the primary goals of elementary education. However, a National Assessment of Educational Progress [NAEP] report conducted by the National Center for Education Statistics (NCES) in the United States indicated that 63% of children in fourth grade are reading below grade-level proficiency, and fourth-grade reading levels in the United States have been consistently below proficiency since 1992 (NCES, 2017). In addition, 70% of children who are poor readers at the start of elementary school remain poor readers in eighth grade (Foorman, Francis, Shaywitz, Shaywitz, & Fletcher, 1997). Reading difficulty has been shown to lead to a cascade of socioemotional difficulties in children, including low self-esteem; depression; and feelings of shame, inadequacy, and helplessness (Valas, 1999). Children with learning disabilities are less likely to complete high school and are increasingly at risk of entering the juvenile justice system (Mallett, Stoddard-Dare, & Workman-Crewnshaw, 2011). Even larger scale socioeconomic effects of reading failure have been noted: 92% of those with learning disabilities have annual incomes of less than $50,000 (USD) within 8 years of finishing high school, and 67% earn less than $25,000 per year (Cortiella & Horowitz, 2014). A screening and early intervention system that identifies children at risk for reading difficulty with high sensitivity and specificity and works to preemptively counteract reading failure in school through EBRS in preschool and early kindergarten would thus be of great long-term benefit to these students.

The etiologies of reading disability are complex, and there is a debate as to the classification of reading disabilities (The Dyslexia Debate; see Elliott & Grigorenko, 2014) and the use of terms such as *dyslexia* and

reading disability (e.g., Ramus, 2014). Developmental dyslexia is described as a specific and heritable learning disability with a known neurobiological origin, affecting 5%–10% of children. It is characterized by deficits in phonological processing and cannot be explained by any sensory deficit or lack of opportunity or motivation (Fisher & DeFries, 2002). In the past, a diagnosis of dyslexia was contingent on a discrepancy between IQ and reading scores, so children with high IQ and low reading scores received a diagnosis but children with low IQ and low reading scores did not. It is important to note, however, that behavioral and neuroimaging evidence has indicated that poor readers experience similar patterns of reading difficulty regardless of IQ (e.g., Fletcher, 2009).

Reading difficulty in general, unlike dyslexia, is more often thought of as the result of perceptual, cognitive, or environmental deficits or impoverishment. For example, 80% of fourth grade students from low socioeconomic status (SES) backgrounds have been shown to read below grade-level proficiency (NCES, 2017). We will not solve the dyslexia debate in this chapter, as atypical reading development is variable and multifactorial, with biological, psychological, and/or environmental causes and, as such, requires multifactorial strategies for screening and accommodation (Catts & Petscher, 2018). However, we have the responsibility to find every struggling reader regardless of the cause of the difficulty and to design screening and EBRS with this variability in mind. Regardless of the way in which a reading disability is classified, all children who experience reading failure experience similar psychosocial implications and are often responsive to the same interventions (Kilpatrick, 2018).

Research has shown that the most effective window for early reading interventions is in kindergarten and first grade (Wanzek & Vaughn, 2007), most likely even earlier. However, a child with a reading disability is often not diagnosed and does not receive intensive services until several years after formal reading instruction begins (see overview in Ozernov-Palchik, Norton, et al., 2016), when the child has already failed to learn to read and the most effective intervention window has passed. By this time, per the Matthew effect (Stanovich, 1986), the child has already fallen behind his or her peers both in reading ability and in the use of reading to learn new content; as time passes, it becomes continuously more difficult for the child to catch up. Conversely, when at-risk beginning readers received intensive reading instruction, 56%–92% (across six research studies) achieved average reading ability (Torgesen, 2004).

A crucial component of alleviating the burden of reading disability is to design, implement, and scale efficient and effective screening and intervention programs for at-risk children. The failure of some existing RTI programs can be partially attributed to inappropriate universal screening instruments, poor sensitivity and specificity of screening methods, and/or inadequate or unspecific response to screening (e.g., providing remedial training in phonological awareness when the child's

deficit is a lack of developmentally appropriate vocabulary), or the delivery method, quantity, and/or quality of the early intervention. Although RTI is crucial for implementing targeted instruction and monitoring ongoing student progress, EBRS resources can proceed and supplement RTI by empowering the general education teacher and can provide professional development that will benefit the quality and fidelity of RTI approaches.

ATYPICAL READING DEVELOPMENT AND ITS NEUROBIOLOGY

Reading is a cultural invention, dating back roughly 5,400 years. Because this is relatively recent, it is highly unlikely that specific brain regions or mechanisms evolved for reading (Dehaene, 2004; Wolf, 2008). Instead, researchers think that brain regions or mechanisms that evolved to serve other functions were repurposed for reading (Dehaene, 2004). This "neuronal recycling" hypothesis has since been evinced by studies of exilliterates (adults who learned to read later in life), who exhibited greater activation than illiterates in response to orthographic stimuli in the same brain region and weaker activation than illiterates in response to objects and faces (Dehaene et al., 2010).

Reading in typically developing children and adults is primarily supported by left hemisphere brain areas (Martin, Schurz, Kronbichler, & Richlan, 2015), including inferior frontal cortex for phonological and semantic processing of words, temporoparietal cortex for grapheme–phoneme conversion, and occipitotemporal cortex for whole-word recognition (Eden, Olulade, Evans, Krafnick, & Alkire, 2016). Developmental dyslexia has been consistently associated with structural and functional atypicalities in these brain regions (Ozernov-Palchik & Gaab, 2016), including reduced gray matter volume (Richlan, Kronbichler, & Wimmer, 2013), hypoactivations in response to reading-related functional magnetic resonance imaging (fMRI) tasks (Richlan, Kronbichler, & Wimmer, 2011), and weaker functional connectivity (Schurz et al., 2015). These hypoactivations were present in children with low reading scores, some of whom had low and some high IQ scores, thereby opposing discrepancy-based definitions of dyslexia (Tanaka et al., 2011). In addition, white matter tracts connecting these brain regions have also exhibited atypicalities, most consistently reduced microstructure in the left arcuate fasciculus (AF) as well as superior longitudinal fasciculus (SLF) and inferior longitudinal fasciculus (ILF) (Vandermosten, Boets, Wouters, & Ghesquière, 2012).

A remaining question in understanding the brain bases of dyslexia is whether these observed atypicalities reflect the underlying cause of dyslexia or the consequence of reduced reading experience that often accompanies reading difficulty. Reading level–matched designs, in which a cohort of children with dyslexia are contrasted with a cohort matched for reading ability rather than age, have been employed to address this question. For instance, one study reported that children with dyslexia exhibited

similar reductions in activation of left temporoparietal and occipitotemporal regions and reductions of gray matter volume in the left temporoparietal cortex when compared with both age- and reading level–matched (younger by 2–4 years) children (Hoeft et al., 2007). This was bolstered by a finding showing atypical gray and white matter morphology common to children with different types of reading disability (e.g., poor comprehension, poor decoding), suggesting that qualitatively different reading experiences under the umbrella of reading impairments do not alter the brain bases of reading disability (Eckert et al., 2017). Overall, these findings point to dyslexia as caused by a fundamental difference in the developmental trajectories of certain brain regions and altered developmental trajectories as a consequence of reduced reading experience.

EARLY MARKERS OF READING DIFFICULTIES BEFORE READING ONSET

Another means of disambiguating cause and consequence is to conduct studies in prereading children and infants with hereditary risk of developmental dyslexia. Family studies suggest that dyslexia is strongly heritable, occurring on average in 45% of children who have a first-degree relative with dyslexia (Snowling & Melby-Lervåg, 2016). Consistent with this, several genes have been reported as candidates for dyslexia susceptibility, and it has been suggested that the majority of these genes play a role in early brain development (Galaburda, LoTurco, Ramus, Fitch, & Rosen, 2006). Furthermore, there are indications that these genes are also associated with language processes other than phonological processing or reading specifically (i.e., pleiotropy; Mascheretti et al., 2014; Stein et al., 2004), which fits with the concept of multiple cognitive profiles of early reading (Ozernov-Palchik, Norton, et al., 2016) and bolsters the hypothesis that dyslexia arises from multiple cognitive deficits (Ozernov-Palchik, Yu, Wang, & Gaab, 2016; Pennington, 2006; van Bergen, van der Leij, & de Jong, 2014). Given the complicated and highly debated role of genes in dyslexia (Paracchini, Scerri, & Monaco, 2007), it is critical to examine early and prenatally determined developmental trajectories.

Given the heritability estimates of 0.4–0.6 for dyslexia, this can be (partially) accomplished by examining brain function and structure in preschool-age prereading children with (FHD+) and without (FHD−) family history of dyslexia. In studies of brain function, we have observed that FHD+ children exhibited reduced activation on a task of phonological processing in left temporoparietal and bilateral occipitotemporal regions compared with FHD− prereaders (Raschle, Zuk, & Gaab, 2012). Likewise, studies of brain structure have indicated that FHD+ prereaders exhibited reduced gray matter volume in bilateral temporoparietal and occipitotemporal cortices compared with FHD− prereaders (Raschle, Chang, & Gaab, 2011). Also, compared with children without dyslexia, children with

dyslexia and FHD+ prereaders exhibited decreased similarity in sulcal pattern (Im, Raschle, Smith, Grant, & Gaab, 2016), a feature of the human brain determined primarily prenatally (Chi, Dooling, & Gilles, 1977) and hypothesized to relate to optimal organization of cortical function and white matter connectivity (e.g., Van Essen, 1997); furthermore, sulcal pattern similarity estimates positively correlated with reading ability, suggesting that atypicalities in dyslexia may begin in utero (Im et al., 2016).

White matter pathways commonly related to reading, including left AF, inferior fronto-occipital fasciculus (IFOF), ILF, and SLF, have also been examined. Using diffusion tensor imaging (DTI), these pathways were assessed on measures of fractional anisotropy (FA), which are thought to reflect microstructural measures, including tract density, myelination, and axonal diameter. Prereading FHD+ children (~5 years of age) exhibited lower (uncorrected) FA in left IFOF compared with age-matched FHD− children (Vandermosten et al., 2015). Left hemisphere atypicalities were again found as part of a longitudinal study (with time points at prereading, beginning reading, and fluent reading stages); here, FHD+ children exhibited reduced FA in the left AF compared with FHD− children at all time points. In addition, the rate of FA development in the left AF 1) correlated with gains in reading performance and 2) differed between FHD+ children who subsequently became good or poor readers (Wang et al., 2017). Consistent with this, earlier studies have demonstrated that auditory event-related potential (ERP) responses to speech and nonspeech stimuli measured in FHD+ prereaders predict reading skills at school-age (Hämäläinen et al., 2013; Maurer et al., 2009). Furthermore, reading ability outcomes have been modeled using familial risk of dyslexia, psychometric measures at the prereading stage, and rates of FA development in left AF and SLF (Wang et al., 2017) or ERP responses (Maurer et al., 2009).

Although these models capture the heritability component of dyslexia, they do not incorporate the adverse environmental circumstances that can contribute to reading disability. Another study through a collaboration between our group and Massachusetts Institute of Technology (Project READ) consisted of a socioeconomically and ethnically diverse sample. This study showed that prevalence of prereading skill profiles differs based on SES (Ozernov-Palchik, Norton, et al., 2016), but white matter microstructural measures in this study showed a strong correlation with phonological awareness in kindergarten, suggesting similar atypical brain development in this very diverse sample of children (Saygin et al., 2013). Previous work has demonstrated that SES is associated with alterations in brain structure (Noble, Houston, Kan, & Sowell, 2012) and function (Kim et al., 2013). In a recent study, we showed a positive association between SES and FA in bilateral ILF in kindergarten (Ozernov-Palchik et al., 2018). Furthermore, SES moderated the association between kindergarten FA in ILF and second-grade reading performance such that the association was positive in children with lower SES but not significant in children with higher SES.

DETECTING INFANTS AT RISK FOR LATER READING DIFFICULTY

Although it has been demonstrated that preschool-age children at risk for dyslexia exhibit atypicalities in brain function and structure compared with children not at risk for dyslexia, it is unclear whether these result from 1) atypical development beginning in the first years of life in close interaction with language development, 2) a congenitally less optimal brain to learn to read, or 3) a combination of the two. Several studies have identified brain-based atypicalities related to dyslexia in infants. For instance, atypical ERP responses to basic speech sounds have been observed in FHD+ infants compared with FHD− infants (Lyytinen et al., 2004; van Leeuwen et al., 2008), and in infants later characterized as having dyslexia or being poor readers compared with infants later characterized as being typically developing or good readers (Molfese, 2000; van Zuijen, Plakas, Maassen, Maurits, & van der Leij, 2013). Nevertheless, how the effects observed in infancy develop into the structural and functional atypicalities observed later in children with dyslexia (i.e., developmental trajectories) remains unknown.

We started to examine this with a series of longitudinal MRI measurements in children from infancy to school age using the natural sleep paradigm for infants (Raschle, Zuk, Ortiz-Mantilla, et al., 2012). So far, white matter atypicalities have been identified in FHD+ 5- to 17-month-old infants (Langer et al., 2017), suggesting that the white matter atypicalities observed in preschool-age children (Wang et al., 2017) are present as early as infancy. Taken together, many brain regions shown to exhibit FHD-related atypicalities in brain structure and function at preschool age and later exhibit similar atypicalities in infancy.

Although it is expected that further understanding of the emergence of these atypicalities will be gleaned once it is known which of the infants participating in these longitudinal studies develop dyslexia, it is unlikely that brain imaging methods described here are capable of the sensitivity or specificity required to effectively screen for reading disability. Therefore, efforts should be aimed toward improving sensitivity and specificity of behavioral screening approaches, which have already been shown to predict reading disability with some success (see the next section for details) and are far less expensive.

EARLY SCREENING AND EVIDENCE-BASED RESPONSE TO SCREENING

Although the underlying mechanisms of atypical reading development have been illuminated by neurobiological evidence, studies of behavior indicate that many cognitive, linguistic, and preliteracy characteristics that are predictive of later reading problems can be observed at a prereading age. Prereading children who go on to develop reading disability tend to struggle with phonological awareness, pseudoword repetition,

letter–sound knowledge, RAN, expressive and receptive vocabulary, and oral language comprehension, and they tend to have less literacy-rich home environments (e.g., Compton, Fuchs, Fuchs, & Bryant, 2006). Letter–sound knowledge and RAN determine a child's ability to associate a visual cue with an auditory representation; RAN further assesses automaticity of retrieval paired with an oral output and has been shown to be a strong predictor of later reading fluency. Oral language comprehension and vocabulary tasks test language skills that serve as the foundation for word decoding and reading comprehension, fluency, and automaticity. Phonological awareness and pseudoword repetition tasks assess ability to manipulate the aural components of words. Thus, a weakness in any of these tasks indicates a susceptibility to later reading disability. Given that children at risk for dyslexia begin school with brains that are less optimized to learn to read, and that some indicators of later reading difficulties can be identified well before reading instruction begins, society has the responsibility to identify these children before reading instruction begins so that appropriate and timely interventions can be put into place to facilitate literacy development.

Although early screeners do exist, most lack the sensitivity and specificity to be effective in identifying children at risk for reading disability. That is, they yield an unacceptably high rate of false negatives (poor sensitivity; i.e., children who are at risk but are not identified as such) and false positives (poor specificity; i.e., children who are not at risk but are identified as being at risk). Many screeners do not comprehensively assess all the predictive components of reading disability (or strands that make up the "reading rope"). A screener that identifies specific deficits in prereading cognitive and linguistic abilities offers the opportunity to target those specific deficits as early as possible. A comprehensive screener would also reduce the number of false negatives in screening; by reducing the number of "misses," a comprehensive screener ensures that more students who would benefit from EBRS will receive the appropriate resources in the classroom. However, a comprehensive screener still may present the problem of poor specificity, or overidentification of children at risk for reading disability. Although this is a concern, ultimately it is more egregious to fail to identify a child with reading disability than it is to provide extra resources to a child needlessly, and the problem of poor specificity can be mitigated by strategic allocation of resources in the classroom (Poulsen, 2018).

Other screeners have been designed for children who have already begun to develop some reading skills, although ideally screeners would be designed for younger children whose problems can be addressed before reading instruction begins. Just as a patient at risk for heart disease should be screened and monitored over time and should be provided the behavioral changes/intervention necessary to prevent or mitigate heart disease to every extent possible, so too should children at risk for reading

disability be identified prior to the onset of reading difficulty and responded to in an attempt to prevent reading disability. The few screeners that are sufficiently comprehensive and administered early enough are also often prohibitively lengthy or expensive, rendering them inaccessible to the majority of children. An effective screener will comprehensively assess proficiency in the evidence-based preliteracy predictors listed previously: it will be developmentally appropriate (i.e., a screener designed for a 4-year-old will assess preliteracy skills typical of a 4-year-old and not reading comprehension or nonword reading); be normed among an appropriate, diverse, norming group; be quick and inexpensive; and be readily accessible such that it could be administered at home, at school, in the pediatrician's office, or elsewhere. A screener with these characteristics has the potential to benefit all children at risk for developing problems with reading (e.g., Kilpatrick, 2018). In selecting the appropriate screener, a school district or other organization should also consider contextual factors, such as financial resources, demographics of the student population (e.g., socioeconomic factors, the number of English language learners, the number of dialect speakers), personnel available to administer screening and intervention approaches, and assessment tools and other resources already available within the institution.

Of course, screening is only impactful when followed up with EBRS and intervention approaches. An EBRS program can provide parents and teachers with resources and strategies to address any identified preliteracy weakness, even without a formal diagnosis of dyslexia or reading disability and before reading instruction begins. Such a strategy will create a support model that will facilitate a child's reading development beginning at a prereading age. EBRS can proceed and supplement an RTI framework, which involves follow-up screening at appropriate intervals to monitor progress, which can identify improvements in skills (or lack thereof) as well as new deficits that may appear as skills develop (Poulsen, 2018). The advent of computer-assisted technology has provided the potential to create screening and response-to-screening platforms that are more comprehensive than ever (e.g., by allowing for the automatic recording and scoring of spoken responses) and has provided a platform for gamification, which can facilitate user motivation and enjoyment (Catts & Petscher, 2018).

The primary goal of a widespread early literacy screening and EBRS and intervention regimen should be to identify and reduce the number of children who experience reading difficulty. Children identified as being at risk do not need to be sent to special education; rather, evidenced-based, structured, explicit, and cumulative instruction should be implemented in the general education curriculum by empowered and trained general education teachers. A successful program could engender many clinical, educational, and economic benefits. For instance, it is more cost effective to provide professional development to general education teachers so that they can teach children at risk rather than addressing reading disability

after it has manifested and secondary mental health issues after they have arisen. This instruction will benefit all children in the classroom, not just those who are at risk. Policy changes that arise from successful early screening would lead to resource savings, in addition to the economic benefits derived from higher rates of literacy among populations.

Perhaps the most immediate implication of successful screening and intervention of reading difficulty will be mitigation or even prevention of the harmful social and psychological effects of reading failure. By allocating resources to children at risk for reading difficulty even before reading instruction begins, supports can be put in place to prevent reading failure in school and to prevent the Matthew effect that subjects struggling readers to a series of compounding social, educational, and vocational disadvantages. An improvement in literacy would thus not only facilitate academic success among students, but it would also promote a healthier and more productive society.

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