Research in Developmental Disabilities 59 (2016) 24–34

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Review article

# Network dynamics in dyslexia: Review and implications for remediation

John R. Kershner (Ph.D)

*University of Toronto, Toronto, ON M5 S 1A1, Canada*

A R T I C L E I N F O

*Article history:*
Received 30 November 2015
Received in revised form 22 May 2016
Accepted 27 July 2016
Number of reviews completed is 2

*Keywords:*
Dyslexia
Cognitive control
Corpus callosum
Arcuate fasciculus
Interactive specialization

A B S T R A C T

Extant neurobiological theories of dyslexia appear fractional in focusing on isolated brain regions, mechanisms, and functional pathways. A synthesis of current research shows support for an Interactive Specialization (IS) model of dyslexia involving the dysfunctional orchestration of a widely-distributed, attentionally-controlled, hierarchical, and interhemispheric circuit of intercommunicating neuronal networks. This circuitry is comprised principally of the frontostriatal-parietal cognitive control system of networks, the posterior corpus callosum, and the left arcuate fasciculus. During development, the coalescence of these functionally specialized regions, acting together, may be essential to preventing the core phonemic and phonological processing deficits defining the dyslexic phenotype. Research demonstrating an association of each with processing phonology presents the foundational outline for a comprehensive, integrative theory of dyslexia and suggests the importance of inclusive remedial efforts aimed at promoting interactions among all three networking territories.



**Contents**



## What does this paper add?

This research review and synthesis demonstrates the validity of viewing dyslexia within Johnson's (Johnson, 2001, 2011) Interactive Specialization (IS) theoretical framework of neurocognitive development. Such a model tentatively establishes dyslexia as a learning disorder of changes in brain circuitry. The paper identifies three interconnected networking territo-

*E-mail address:* john.kershner@utoronto.ca

http://dx.doi.org/10.1016/j.ridd.2016.07.014

ries dedicated to processing phonology, and presents an evidentiary argument that a primary cause of dyslexia may be a developmental aberration reciprocally affecting this circuit's emerging dynamics. The paper recommends modifications in remedial strategies to include exercises to improve the functions of all three networking territories and their interaction.

## 1. Introduction

Developmental dyslexia is a hereditary, neurocognitive-based learning difficulty, usually encountered early in children's primary education when young children struggle to acquire proficiency in beginning reading skills. Prevalence estimates vary, ranging from 5% to as high as 20% (Pugh et al., 2013). After more than a century of research and the implementation of a broad spectrum of remedial strategies, this disability, which affects individuals irrespective of their level of intelligence, motivation to learn, and adequate educational and social circumstances, remains relatively intransigent to educational approaches. The reading, spelling, and array of related cognitive difficulties found in children with dyslexia persist into adulthood (Kudo, Lussier, & Swanson, 2015). Familial studies indicate a little understood etiology involving an intricate interplay of neurological, genetic, epigenetic, and environmental factors (Carrion-Castillo, Franke, & Fisher, 2013).

Although neuroimaging studies investigating the effectiveness of various instructional programs have shown encouraging improvement in some children in reading skills accompanied by trends toward normalization of brain activation patterns (Aylward et al., 2003; Eden, Jones, Cappell, Gareau, & Wood, 2004; Horowitz-Kraus, 2015; Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008; Penolazzi, Spironelli, Vio, & Angulli, 2010; Richards & Berninger, 2008; Shaywitz et al., 2004; Simos et al., 2002; Spironelli, Penolazzi, Vio, & Angrilli, 2010; Temple et al., 2003), even the most successful students continue to demonstrate serious impairments in reading fluency (Torgesen et al., 2001). Fluency, defined as reading quickly, with accuracy and text appropriate expression can be considered the "gold standard" for remedial programming. In my experience, university students who have attained significant age-adjusted gains compared to their childhood reading levels, view reading as a stressful task. Invariably, they avoid reading for pleasure. Even individuals who have achieved extraordinary career success continue to struggle with reading fluently (Gerber & Raskind, 2014). An important point to consider is whether neural models of language and dyslexia (e.g., Elliot & Gregorenko, 2014; Wandell & Yeatman, 2013) are developed to the degree required for providing guidelines for maximally effective remedial educational strategies (Kershner, 2015). Such modelling focuses on discrete left hemisphere areas in inferior frontal, posterior ventral and dorsal cortex and their major white matter tracts containing axons which communicate between these regions. Conspicuously absent are overtures to right hemisphere and interhemispheric processes, suggesting a vast untapped potential for comprehensive remedial programming to challenge integrative processing bilaterally across the entire brain.

The present synthesis of selective research offers an alternative theoretical orientation to models of dyslexia that focus exclusively on isolated impairments in localized brain regions and mechanisms. This review suggests the appropriateness of conceptualizing dyslexia from the broader neurobiological matrix of cognitive development provided by Johnson's (Johnson, 2001, 2011) Interactive Specialization (IS) theory. According to this domain-general framework, cognitive development is assumed to follow a self-organizing, activity-dependent, and emerging pathway. Response properties of cortical regions are determined through reciprocal competitive interactions within and between interconnected networks and network systems. The sine qua non of IS theory proposes a dynamic course of development that achieves complimentarity between the neuronal processes of segregation (decreasing short-range connections) and integration (increasing long-range connections). The neural representations of each specialized territory within a circuitry of dedicated processing territories are partly determined by patterns of connectivity to other co-activating regions of the circuit.

Promoting segregation, functionally related regions or nodes become instantiated within modules of high density interconnectiveness which become increasingly statistically independent. As an example, the right temporoparietal junction, which integrates early stimulus-driven, bottom-up information with higher-order, top-down computations controlling cognitive processes (Wu et al., 2015), has been parcellated into subregions serving different cortical networks. Based on its local and distant structural and functional connectivity, three modular subregions have been identified, with each connecting to areas of frontal cortex (Mars et al., 2011). Functional integration is promoted by global long-range interconnections across nodes. Coordination is achieved by convergent networks that are co-activated by specific task requirements. Much remains to be discovered as such processes implicate the mapping of chains of long-range, fibre tract synaptic communications. Nonetheless, investigative research on the left prefrontal cortex presents another instructive example. A graph theory approach to neuroimaging data revealed wide-spread, functionally significant connections of the left prefrontal cortex throughout the brain, suggesting a key combinatorial role in the cognitive control of multiple networks (Cole, Yarkoni, Repovs, Anticevic, & Brever, 2012).

The IS model suggests that the core deficit in dyslexia may inhere in a breakdown in the dynamic interplay of widely-distributed multiple processing networks. Specifically, this review identifies three key co-activating brain regions and structures, implicating multiple networks which appear to be central to the metacognitive modulation of phonological processing in typical readers and in individuals with dyslexia. Such complexity suggests a more comprehensive, integrative theoretical platform for remedial programming initiatives. This review proposes that the neural networks and network systems involved are functionally specialized by virtue of their modular contributions, on different time-scales, to decoding and comprehending written language. Because reading is a relatively recent cultural invention in evolution, we can assume that each processing region necessarily cross-participates in a plurality of networks extending beyond phonological processing. Of note, however, the existence of singular structures with overlapping functions does not invalidate the possibility