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Neurobiological And Genetic Bases Of Reading Difficulty In Older Children: Implications For Developmental Intervention

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ABSTRACT

Reading difficulty in older children often persists beyond the early stages of literacy acquisition and becomes increasingly evident as academic demands shift toward independent reading and written work. In many affected individuals, reading remains slow and inconsistent despite appropriate instruction, indicating differences in underlying neurodevelopment rather than delayed learning alone. This conceptual paper addresses reading difficulty from a biological perspective, with a specific focus on neural and genetic factors associated with its persistence in later childhood. Reading is an acquired skill that depends on the coordinated activity of distributed brain systems supporting visual processing, phonological analysis, and language integration. Differences in the organisation, connectivity, and efficiency of these systems have been observed in older children with reading difficulty, particularly within networks linking occipito-temporal, temporoparietal, and frontal regions. Genetic and hereditary influences are also examined, drawing on evidence related to genes involved in neuronal migration, axonal connectivity, and synaptic regulation. Variability in these biological processes appears to contribute to individual differences in reading development and vulnerability to persistent difficulty. Alongside biological risk, the paper reviews developmental approaches used to support reading improvement in older children. Evidence from behavioural and neuroimaging studies is synthesised to describe how structured and intensive interventions are associated with changes in neural activation patterns, connectivity, and processing efficiency. These findings indicate that reading-related neural systems retain a degree of plasticity beyond early childhood, although the magnitude and stability of intervention-related change vary across individuals. By integrating neurobiological, genetic, and intervention-related evidence, this paper situates reading difficulty within the broader context of neurodevelopmental diversity and highlights the relevance of biologically informed approaches to intervention in later childhood.

INTRODUCTION

Reading difficulty in older children often persists beyond early literacy teaching and becomes more consequential as academic learning shifts toward independent reading and written work [1–3]. At this stage, reading is no longer a discrete classroom skill; it becomes the primary route through which students access content across subjects. For some children, reading remains slow, inconsistent, and effortful

despite sustained instruction, indicating differences in neurodevelopment rather than delayed learning alone [1–3]. A useful way to frame persistent reading difficulty is to treat it as a developmental outcome shaped by both biology and experience [4,5]. Reading is an acquired cultural skill that relies on the adaptation of neural systems originally developed for spoken language and visual processing [6,7]. This adaptation varies across individuals, and when network organisation or timing differs, reading efficiency may remain limited even with appropriate exposure [6,7].

Genetic and hereditary influences contribute to this variability by shaping processes such as neuronal migration, synaptic regulation, and white-matter connectivity [4,5]. These biological factors interact with instructional quality, language environment, and educational opportunity to influence reading outcomes [4,5]. This interaction helps explain familial clustering of reading difficulty and variability in response to intervention [8,9]. Importantly, persistence does not imply immutability. Neurodevelopment continues across late childhood and adolescence, and reading-related networks retain some plasticity [10]. This provides a rationale for developmentally informed interventions in older children and for examining whether behavioural improvement is accompanied by measurable biological change.

NEUROBIOLOGICAL BASIS OF READING AND LANGUAGE PROCESSING

Reading depends on coordinated activity across brain systems supporting visual recognition, phonological analysis, and language integration [11]. In most individuals, these functions are primarily supported by left-hemisphere networks. Frontal regions, including the inferior frontal gyrus, contribute to phonological processing and articulatory planning, while superior temporal areas support analysis of speech sounds and spoken language input [11].

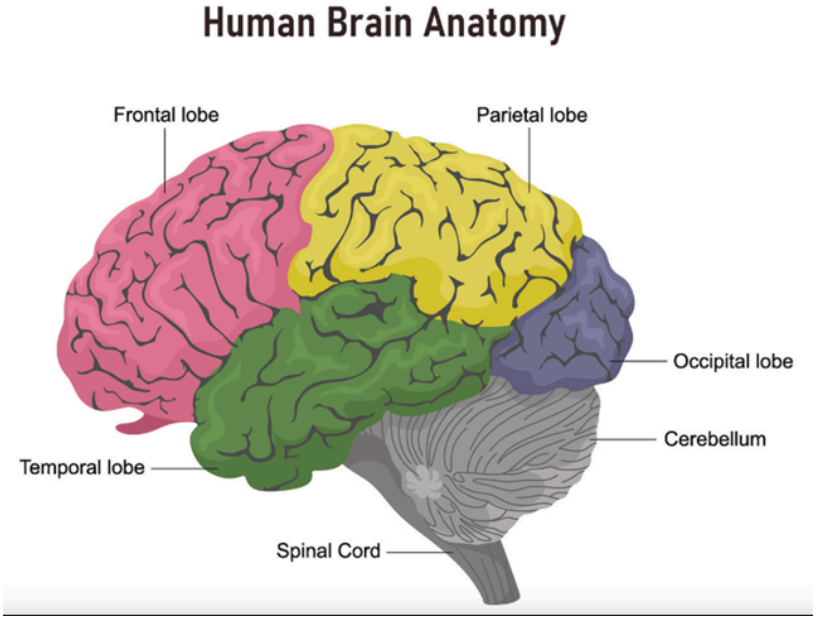

Figure 1. Anatomy of the human brain (Johns Hopkins Medicine, 2025)
Schematic representation of major cortical regions involved in reading and language processing, including frontal, temporoparietal, and occipito-temporal areas. The figure provides anatomical context for the distributed neural networks discussed in relation to phonological processing, visual word recognition, and language integration.

Linking print to speech depends heavily on temporoparietal regions, including the angular and supramarginal gyri, which support phonological decoding and orthography–phonology mapping [12]. Efficient word recognition additionally requires the left occipito-temporal cortex, where visual processing becomes increasingly specialised with reading experience [13,14]. As reading becomes fluent, processing shifts toward greater efficiency within these pathways. Connectivity between these regions is central to reading proficiency. White-matter pathways such as the arcuate fasciculus and superior longitudinal fasciculus support information transfer between visual and language-related systems [15]. Alterations in these connections have been associated with reduced fluency and accuracy [16]. When typical processing is less efficient, increased involvement of right-hemisphere regions may be observed, reflecting compensatory strategies rather than optimal efficiency [17].

STRUCTURAL BRAIN ABNORMALITIES IN READING DIFFICULTY

In skilled readers, written text is processed through a left-hemisphere network linking occipito-temporal, temporoparietal, and frontal regions [18]. This organisation supports rapid word recognition, accurate phonological mapping, and integration into spoken language representations. With proficiency, these processes become increasingly automated, reducing cognitive load during reading. In dyslexia and persistent reading difficulty, consistent differences have been reported within this network. Functional neuroimaging studies commonly show reduced activation and weaker connectivity in left occipito-temporal and temporoparietal regions during reading tasks [19,20]. These differences are associated with slower word recognition and less stable decoding. Increased activation in right-hemisphere regions and frontal areas is frequently interpreted as compensatory rather than efficient processing [21].

Structural differences in hemispheric organisation have also been described. Reduced or absent left–right asymmetry of the planum temporale has been reported in dyslexia [22]. Abnormalities have additionally been observed in frontal and temporoparietal regions involved in phonological processing and auditory language perception [23]. Some evidence also links altered frontal–cerebellar connectivity to slower reading development in specific subgroups [24].

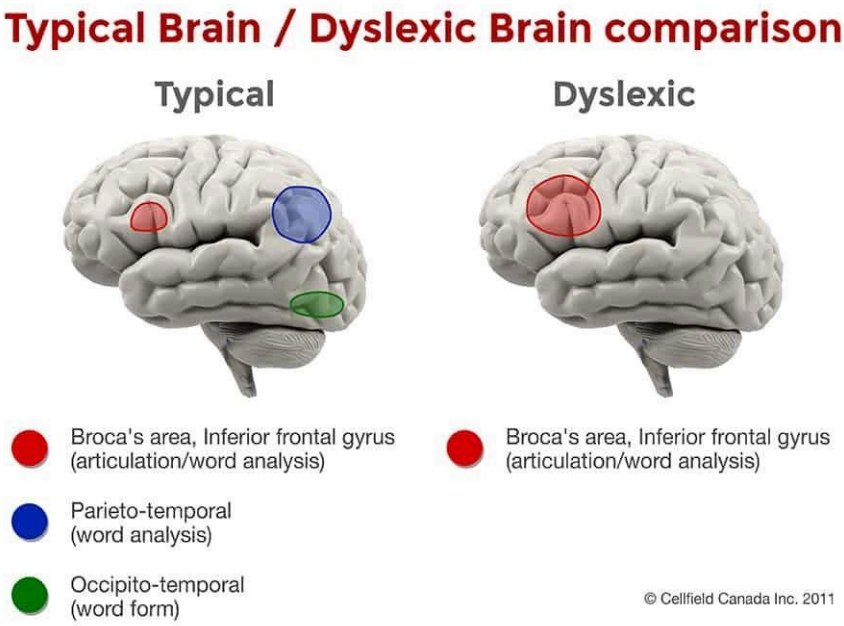

Figure 2. Comparison of the typical and dyslexic brain (Building Better Brains, 2018)
Conceptual comparison of neural activation patterns typically observed in skilled readers and in individuals with dyslexia. The illustration highlights reduced engagement of left-hemisphere reading networks and increased reliance on compensatory regions, consistent with findings from functional neuroimaging studies.

NEUROCHEMICAL AND NEUROPHYSIOLOGICAL FACTORS IN READING

Reading performance also depends on the timing and regulation of neural signalling within language-related networks. Dopaminergic modulation influences attention regulation and processing speed, and variations in dopamine signalling have been linked to reduced attentional stability that may further limit reading fluency [25]. Neurophysiological evidence from EEG studies indicates that children with reading difficulty often show altered activity in frequency bands associated with language processing. Differences in theta and gamma synchronisation have been linked to delayed phonological integration and inefficient word recognition [26]. Event-related potential studies further demonstrate atypical timing of auditory and linguistic processing in dyslexia [27]

Table 1. Summary of neurobiological and genetic factors associated with reading difficulty, including implicated brain regions, cognitive processes, and key genetic influences reported in the literature.

Level	Factor	Primary Function	Reading-related implication
Neurochemical	Glutamate	Excitatory transmission, synaptic plasticity	Supports formation and strengthening of sound–letter associations
Neurochemical	GABA	Inhibitory control, signal regulation	Maintains precision and timing of neural responses during reading
Neuromodulatory	Dopamine	Attention regulation, processing speed	Influences reading fluency and sustained engagement
Neurophysiological	Theta band activity	Phonological processing, language integration	Altered synchronisation linked to delayed sound–letter mapping
Neurophysiological	Gamma band activity	Rapid neural coordination	Reduced synchrony associated with inefficient word recognition

GENETIC AND HEREDITARY FACTORS

Family and twin studies consistently report higher concordance for reading difficulty among monozygotic twins compared with dizygotic twins, indicating a substantial genetic contribution to reading-related outcomes across childhood [28,29]. Molecular genetic studies have identified several genomic regions associated with reading difficulty and dyslexia. Early association studies implicated *DYX1C1* [30] and *DCDC2* [31], genes involved in neuronal migration. Subsequent studies identified associations with *KIAA0319* [32] and *ROBO1* [33], with reported effects on reading-related measures. Genome-wide analyses indicate that no single genetic variant accounts for a large proportion of variance in reading ability. Instead, multiple loci exert small effects, consistent with a polygenic architecture shared with broader language and neurodevelopmental traits [34]. Observed associations vary across developmental stages and cohorts [35].

EVIDENCE-BASED APPROACHES TO IMPROVE READING DISABILITIES

Intervention studies in older children with reading difficulty primarily focus on structured approaches targeting phonological processing, decoding accuracy, and reading fluency. Intensive remedial instruction has been shown to produce measurable gains in word recognition and reading speed compared with standard classroom instruction [36]. Systematic phonics-based programmes demonstrate consistent benefits across alphabetic languages [37].

Older children who do not respond adequately to early instruction may benefit from interventions delivered with increased intensity and duration, although outcomes vary across individuals [38]. Approaches incorporating guided oral reading and repeated reading practice have been associated with improvements in fluency and accuracy [39]. Multicomponent interventions combining phonological training with vocabulary and comprehension strategies yield heterogeneous response patterns [40]. Across intervention research, variability in response is a consistent finding [41].

BIOLOGICAL IMPACT OF INTERVENTION OUTCOMES

Neuroimaging studies have examined whether behavioural improvements following reading intervention are accompanied by changes in brain activity and connectivity. Functional MRI studies report altered activation patterns within reading-related networks following structured instruction [18]. Longitudinal studies further indicate altered functional connectivity between frontal, temporoparietal, and occipito-temporal regions [19]. Diffusion tensor imaging (DTI) assesses white-matter microstructural properties by modelling water diffusion in tissue. DTI studies provide complementary evidence at the level of white-matter organisation, with some cohorts showing increased fractional anisotropy in reading-related tracts following intervention [15]. Electrophysiological methods such as EEG capture millisecond-level brain responses, and event-related potentials (ERPs) reflect time-locked neural processing during language tasks. Electrophysiological studies report intervention-related changes in neural timing, including alterations in event-related potentials linked to phonological processing [27].

FUTURE DIRECTIONS AND CONCLUSION

Studies examining reading difficulty in older children consistently highlight variation across genetic, neural, and developmental domains. Existing evidence indicates that these factors do not combine in a uniform manner across individuals, and that reading-related outcomes reflect multiple developmental pathways rather than a single profile. Across intervention and neuroimaging research, patterns of neural change show substantial variability. Differences are evident in the location, magnitude, and timing of changes associated with reading improvement, as well as in the extent to which behavioural progress corresponds with measurable biological alterations. Variation in age, instructional exposure, and baseline reading characteristics appears to shape these patterns across individuals. From a developmental perspective, responses to reading intervention differ across stages of childhood.

Earlier intervention is often associated with more rapid changes in core reading skills, whereas improvement in later childhood tends to unfold more gradually and may rely on sustained instructional input and cumulative practice. In older children, gains in word recognition and fluency can still be achieved, but outcomes are more heterogeneous and less predictable than those observed during the early stages of reading acquisition. This variability underscores the importance of accounting for individual developmental profiles when designing and evaluating intervention approaches.

Neurobiological findings further suggest that reading improvement in later childhood may depend more on the reorganisation and strengthened coordination of existing neural networks than on the establishment of entirely new processing pathways. In this context, behavioural progress does not necessarily imply a return to typical neural activation patterns, but may instead reflect the development of alternative or compensatory processing strategies.

Taken together, these findings situate reading difficulty within a broader framework of neurodevelopmental diversity. Genetic influences, neural organisation, and experience-related change jointly contribute to observed reading profiles in older children. Recognising this complexity supports the use of sustained, developmentally informed intervention strategies and cautions against assuming uniform mechanisms of change across different ages or neurodevelopmental trajectories. Future work integrating longitudinal, genetic, and intervention studies will be essential for refining biologically informed approaches to reading support across development.

REFERENCES

1. Lyon GR, Shaywitz SE, Shaywitz BA. A definition of dyslexia. *Ann Dyslexia*. 2003;53:1–14.
2. Snowling MJ, Hulme C. Annual research review: The nature and classification of reading disorders. *J Child Psychol Psychiatry*. 2012;53(6):593–607.
3. Pennington BF. From single to multiple deficit models of developmental disorders. *Cognition*. 2006;101(2):385–413.
4. Bishop DVM, Snowling MJ. Developmental dyslexia and specific language impairment. *Psychol Bull*. 2004;130(6):858–886.
5. Plomin R, DeFries JC, Knopik VS, Neiderhiser JM. Top 10 replicated findings from behavioral genetics. *Perspect Psychol Sci*. 2016;11(1):3–23.
6. Dehaene S. *Reading in the Brain: The New Science of How We Read*. New York: Viking; 2009.
7. Dehaene S, Cohen L. Cultural recycling of cortical maps. *Neuron*. 2007;56(2):384–398.
8. Olson RK, Keenan JM, Byrne B, et al. Genetic and environmental influences on reading and language ability. *Sci Stud Read*. 2011;15(1):1–24.
9. Harlaar N, Spinath FM, Dale PS, Plomin R. Genetic influences on early word recognition. *J Child Psychol Psychiatry*. 2005;46(4):373–384.
10. Price CJ. A review of PET and fMRI studies of reading. *Neuroimage*. 2012;62(2):816–847.
11. Pugh KR, Mencl WE, Jenner AR, et al. Neurobiological studies of reading disability. *J Commun Disord*. 2000;33(6):479–492.
12. Boets B, Op de Beeck HP, Vandermosten M, et al. Intact but less accessible phonetic representations in adults with dyslexia. *Science*. 2013;342:1251–1254.
13. Shaywitz BA, Shaywitz SE, Pugh KR, et al. Disruption of posterior brain systems for reading in children with developmental dyslexia. *Biol Psychiatry*. 2002;52(2):101–110.
14. McCandliss BD, Cohen L, Dehaene S. The visual word form area: Expertise for reading in the fusiform gyrus. *Trends Cogn Sci*. 2003;7(7):293–299.

15. Dehaene S, Pegado F, Braga LW, et al. How learning to read changes the cortical networks for vision and language. *Science*. 2010;330:1359–1364.
16. Vandermosten M, Boets B, Wouters J, Ghesquière P. A qualitative and quantitative review of diffusion tensor imaging studies in reading and dyslexia. *Neurosci Biobehav Rev*. 2012;36(6):1532–1552.
17. Maisog JM, Einbinder ER, Flowers DL, Turkeltaub PE, Eden GF. A meta-analysis of functional neuroimaging studies of dyslexia. *Ann N Y Acad Sci*. 2008;1145:237–259.
18. Richlan F, Kronbichler M, Wimmer H. Functional abnormalities in the dyslexic brain: A quantitative meta-analysis of neuroimaging studies. *Hum Brain Mapp*. 2009;30(10):3299–3308.
19. Eden GF, Jones KM, Cappell K, et al. Neural changes following remediation in adult developmental dyslexia. *Neuron*. 2004;44(3):411–422.
20. Galaburda AM, Kemper TL. Cytoarchitectonic abnormalities in developmental dyslexia: A case study. *Ann Neurol*. 1979;6(2):94–100.
21. Eckert MA, Leonard CM, Richards TL, et al. Anatomical correlates of dyslexia: Frontal and cerebellar findings. *Cereb Cortex*. 2003;13(7):767–775.
22. Pugh KR, Frost SJ, Sandak R, et al. Effects of stimulus difficulty and repetition on printed word identification: An fMRI comparison of nonimpaired and reading-disabled adolescent cohorts. *J Cogn Neurosci*. 2008;20(7):1146–1160.
23. Diamond A. Attention-deficit disorder (attention-deficit/hyperactivity disorder without hyperactivity): A neurobiologically and behaviorally distinct disorder. *Dev Psychopathol*. 2005;17(3):807–825.
24. Lehongre K, Ramus F, Villiermet N, Schwartz D, Giraud AL. Altered low-gamma sampling in auditory cortex accounts for the three main facets of dyslexia. *Neuron*. 2011;72(6):1080–1090.
25. Kujala T, Lovio R, Lepistö T, et al. Auditory event-related potentials and cognitive function in dyslexia. *Clin Neurophysiol*. 2006;117(10):2335–2346.
26. Taipale M, Kaminen N, Nopola-Hemmi J, et al. A candidate gene for developmental dyslexia encodes a nuclear tetratricopeptide repeat domain protein. *Proc Natl Acad Sci U S A*. 2003;100(20):11553–11558.
27. Meng H, Smith SD, Hager K, et al. DCDC2 is associated with reading disability and modulates neuronal migration and ciliary function. *Proc Natl Acad Sci U S A*. 2005;102(47):17053–17058.
28. Paracchini S, Steer CD, Buckingham LL, et al. Association of the KIAA0319 dyslexia susceptibility gene with reading skills in the general population. *Am J Hum Genet*. 2008;83(6):759–768.
29. Hannula-Jouppi K, Kaminen-Ahola N, Taipale M, et al. The axon guidance receptor gene ROBO1 is a candidate gene for developmental dyslexia. *PLoS Genet*. 2005;1(4):e50.
30. Gialluisi A, Andlauer TFM, Mirza-Schreiber N, et al. Genome-wide association study reveals new insights into the genetic architecture of dyslexia. *Mol Psychiatry*. 2021;26(7):3004–3017.
31. Peterson RL, Pennington BF. Developmental dyslexia. *Lancet*. 2012;379(9830):1997–2007.
32. Torgesen JK, Alexander AW, Wagner RK, et al. Intensive remedial instruction for children with severe reading disabilities: Immediate and long-term outcomes. *J Learn Disabil*. 2001;34(1):33–58.
33. Ehri LC, Nunes SR, Stahl SA, Willows DM. Systematic phonics instruction helps students learn to read: Evidence from the National Reading Panel's meta-analysis. *Rev Educ Res*. 2001;71(3):393–447.

34. Lovett MW, Steinbach KA, Frijters JC. Remediating reading disability: A randomized comparison of two instructional approaches. *J Res Read*. 2000;23(3):231–251.
35. Therrien WJ. Fluency and comprehension gains as a result of repeated reading: A meta-analysis. *Remedial Spec Educ*. 2004;25(4):252–261.
36. Snowling MJ, Hulme C. Evidence-based interventions for reading and language difficulties: Creating a virtuous circle. *J Child Psychol Psychiatry*. 2011;52(1):3–13.
37. Fletcher JM, Lyon GR, Fuchs LS, Barnes MA. *Learning Disabilities: From Identification to Intervention*. New York: Guilford Press; 2007.
38. Richards TL, Berninger VW. fMRI evidence of intervention-related brain changes in reading. *J Neurolinguistics*. 2008;21(4):294–304.
39. Keller TA, Just MA. Altering cortical connectivity: Remediation-induced changes in the brain's reading network. *Neuron*. 2009;64(5):624–631.
40. Koyama MS, Di Martino A, Zuo XN, et al. Resting-state functional connectivity and reading ability in children and adults. *Neuroimage*. 2011;56(4):2133–2145.
41. Simos PG, Fletcher JM, Sarkari S, et al. Intensive instruction affects brain activation in children with reading disabilities. *J Learn Disabil*. 2007;40(1):37–48.