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# Dyslexia: Bridging the Gap between Hearing and Reading

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## Abstract

Recent work with dyslexic subjects provides the first empirical evidence linking changes in the brain networks subserving phonological processing to deficits in the matching of speech sounds to their appropriate visual representations.

Although most children rapidly develop a strong facility to read the printed and written word, a surprisingly large number fail to acquire good reading skills, even after intensive instruction. When these reading difficulties are seen in the presence of normal or above-normal intelligence, and when there are measurable deficits in phonological processing — the ability to store, retrieve and manipulate speech sounds — the child (or adult) is typically diagnosed with dyslexia, a term first coined in the late 19$^{th}$ century. The most common form of dyslexia is seen in a developmental context as children fail to meet certain benchmark measures of 'normal' reading ability. Although there appear to be cultural and orthography-related differences in its prevalence, some estimates suggest that the incidence of developmental dyslexia may be as high as 10% in the general population [1]. Not surprisingly given this high prevalence, the monetary and societal impacts of reading disabilities are staggering. The work by Blau *et al*. [2] reported in this issue of *Current Biology* provides important new insights into the neural bases of developmental dyslexia, by showing changes in brain activation patterns in dyslexic readers that are associated with the matching of speech sounds with their appropriate visual representations (letters). Such letter-speech matching must be both rapid and accurate for the emergence of fluent reading abilities.

Although its diagnosis is still considered to be controversial in some domains, there is a growing consensus that dyslexia has a neurobiological basis, with strong evidence that there is a genetic component to the disability [3]. Numerous theories abound as to the physiological processes and neural systems that are affected in dyslexia, with several of the more prominent models focusing on alterations in rapid auditory processing [4-6], disturbances in the magnocellular visual pathway [7,8], and cerebellar dysfunction [9]. As alluded to above, however, the best-established changes (and model) are centered on deficits in phonological encoding and decoding and the networks that support these processes [10-13]. But despite the presence of a strong linkage between disrupted phonological abilities and poor reading skills in dyslexia, there has remained a fundamental gap in our understanding of how problems in encoding speech sounds ultimately translate into reading difficulties. A key step in this process must be the rapid and accurate matching of the

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component speech sounds (phonemes) with their appropriate written representations (graphemes). Despite the intuitive nature of this multisensory transformation process, there is little empirical evidence that relates across these domains and specifically bridges speech processing and reading.

Advances in non-invasive neuroimaging methods, particularly functional magnetic resonance imaging (fMRI), have made this problem more tractable by allowing a view into the neural correlates of reading and phonological processes[1,14-17]. With fMRI, changes in the blood oxygenation level dependent (BOLD) signal, an indirect measure of neural activity, can be measured while the participant is presented with certain stimuli and/or engaged in a specific task. Differences in the BOLD signal can then be compared between two groups of participants, for example typical readers and dyslexic readers, while they are confronted with identical stimuli or performing the same task, with the BOLD differences seen between the populations being attributable to differential neural processes within a given brain area or network of brain areas.

Blau *et al*. [2] used fMRI in an effort to identify the critical neural nodes impacted in dyslexic readers, and specifically focused on the multisensory matching process between visual letters and speech sounds. Participants were presented with either letters on a computer monitor (visual stimuli alone), speech sounds through headphones (auditory stimuli alone), or the simultaneous occurrence of the letters and speech sounds (multisensory stimuli), and sat passively during the procedure with their focus directed toward these stimuli. Critically, the multisensory letter-speech pairings could be either congruent, reflecting the normal matching of letters and sounds, or incongruent, allowing a contrast to be made between the BOLD signal for these normal and abnormal associations.

Previous fMRI work had shown that, in typical readers, congruent letter-speech pairings result in greater activation in both auditory cortex as well as in surrounding regions of the superior temporal sulcus and gyrus (STS/STG), multisensory zones believed to play an important role in the letter-speech matching process [18]. In extending this work to dyslexic readers, Blau *et al*. [2] found several key differences in brain activation patterns from fluent readers. First, the experiment revealed there to be significant group differences for regions of the superior temporal gyrus (STG) in response to both auditory and congruent auditory-visual stimuli. Second, and most dramatically, dyslexic readers showed little difference in their STG responses to congruent and incongruent pairings, suggesting a specific deficit in letter-speech integration. Thus, whereas typical readers show a significant suppression of STG activity during incongruent pairings, dyslexic readers fail to show a similar suppression (Figure 1). Such suppression may represent a neural mechanism for preventing the binding of unwanted and inappropriate associations. Finally, in linking the changes in auditory responses to the letter-speech matching process, strong correlations were found between the responses in STG to speech sounds and the magnitude of both the congruency effect and the response suppression, strongly suggesting that the multisensory integration that constitutes the letter-speech matching process is strongly dependent on the responses to speech sounds seen in this region.

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Poor auditory encoding of sound may ultimately result in inefficient and/or inaccurate letter-speech mappings, as the neural ‘signature’ identifying specific speech sounds may be compromised and ambiguous. Recent work suggests that these alterations in the multisensory mapping process that is so critical for reading may even be seen for non-linguistic stimuli. Using simple visual and auditory stimuli — flashes of light and tone pips — dyslexic readers were found to differ dramatically from normal readers in their performance on a multisensory temporal order judgment task [19]. These differences were interpreted to be due to an enlarged temporal ‘window’ within which the visual and auditory stimuli were bound into a unitary construct.

Taken together, these recent studies are providing important insights into the neurobiological bases of specific reading disabilities, and are converging on a multisensory model that better links auditory processing deficits with the visual functions that mediate reading. This knowledge provides a better conceptual framework for understanding reading disabilities, and holds great promise for the development of more effective remediation strategies for the treatment of those suffering from these often debilitating disabilities.

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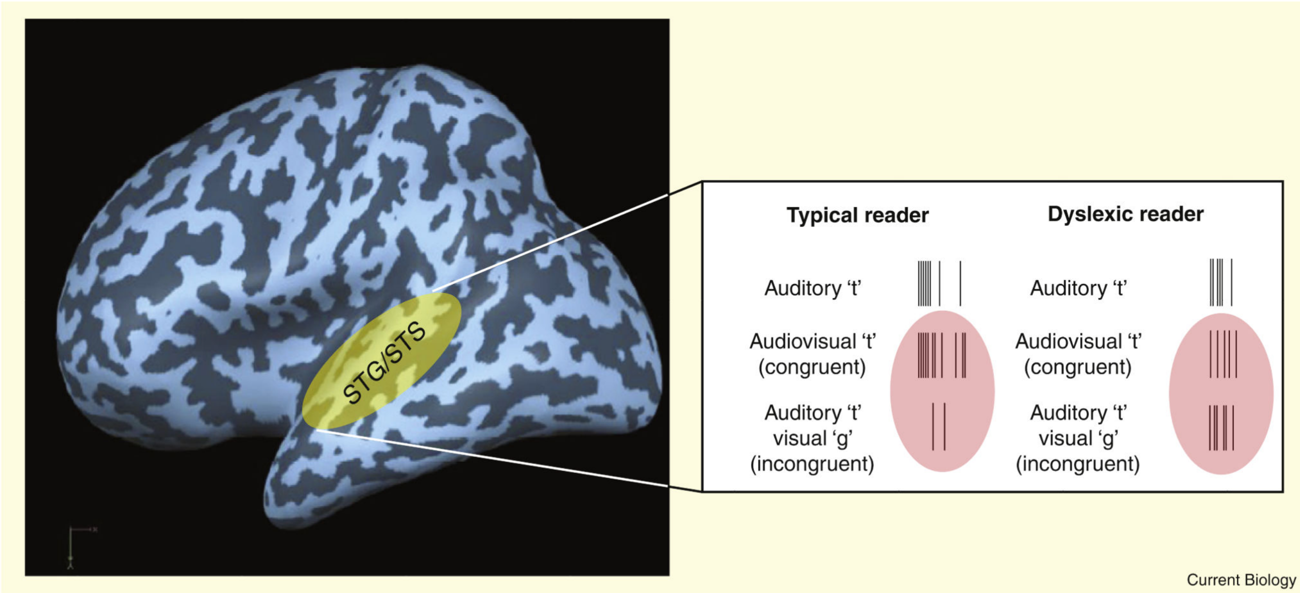


**Figure 1.**

In the superior temporal gyrus and sulcus (STG/STS), the processing of the multisensory combination of auditory speech sounds and visual letters is different between typical and dyslexic readers. The brain template on the left shows the relative location of the STG/STS. The line drawing on the right shows the proposed neural processing differences between typical and dyslexic readers. The vertical lines are meant to represent the patterns of action potentials seen in a representative neuron in this brain region in response to an auditory speech sound alone (auditory 't'), the congruent presentation of an auditory speech sound and its visual correlate (audiovisual 't') and an incongruent audiovisual pair (auditory 't' + visual 'g'). Note the slightly diminished response in the dyslexic readers compared with typical readers to the auditory speech sound alone, but more dramatically, the lack of the normal suppression seen in response to the incongruent audiovisual presentation (red shading).