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Atypical lateralization of phonological working memory in developmental dyslexia

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ABSTRACT

Developmental dyslexia is a neurological condition characterized by unexpected low reading performance in people with normal intelligence and typical schooling. One prominent theory posits that dyslexic children fail to establish left-hemispheric dominance of visual representations and visual-phonological/meaning integration of printed words and thus exhibit an atypical lateralization of lexical processing. Behavioral, electrophysiological, histological, and morphological imaging studies examining this hemispheric asymmetry have generated conflicting evidence; however, it remains possible that dyslexics have impaired functional lateralization of language processes without a structural correlate. Here, using functional magnetic resonance imaging (fMRI) and a phonological task with working memory, we found distinct hemispheric asymmetry differences between dyslexic and normal children in brain regions subserving the storage and manipulation of phonological information in phonological working memory.

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Further, the degree of leftward asymmetry correlates positively with reading performance. Thus, the language impairments in dyslexic children appear related to a reduced dominance of the left hemisphere in phonological language functions, which offers clues into the biological dysfunction and possible remediation of developmental dyslexia.

1. Introduction

Reading is the process of extracting meaning from written symbols that represent speech. It is a crucial skill for children to master, but unfortunately there are a considerable proportion of people who suffer from developmental dyslexia, which manifests as unexpected low reading performance despite normal intelligence and typical schooling (Eden & Moats, 2002; Gabrieli, 2009; Goswami, 2006; Horwitz, Rumsey, & Donohue, 1998; Peterson & Pennington, 2012; Price & Mechelli, 2005; Schlaggar & McCandliss, 2007; S. E. Shaywitz, 1998). The prevalence estimates of dyslexia in English population range from 5% to 17% (Gabrieli, 2009). It is widely recognized as a neurological disorder with dysfunction of the left-hemisphere language network (Eden & Moats, 2002; Gabrieli, 2009; Goswami, 2006; Horwitz et al., 1998; Paulesu et al., 2001; Peterson & Pennington, 2012; Price & Mechelli, 2005; Schlaggar & McCandliss, 2007; S. E. Shaywitz, 1998; Temple et al., 2000). Despite intensive research after it was first reported more than a century ago (Hinshelwood, 1895; Morgan, 1896), the core deficits of dyslexia are still hotly debated.

In the 1920s, Samuel Orton proposed an atypical lateralization theory of dyslexia (Orton, 1925, 1937). According to this idea, learning to read requires children to develop left-hemispheric dominance of visual representations and visual-phonological/meaning integration of printed words. Further, dyslexic children fail to suppress the right-hemisphere representation to establish appropriate hemisphere dominance, leading to improper word identification. A series of post-mortem studies of dyslexics by Geschwind and Galaburda et al. revealed a symmetrical structure in the planum temporale (Galaburda & Kemper, 1979; Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985; Geschwind & Galaburda, 1985; Humphreys, Kaufmann, & Galaburda, 1990), a region important for phonological encoding and speech perception, whereas most normal brains showed marked leftward asymmetry in this region (Geschwind & Levitsky, 1968; Toga & Thompson, 2003). However, many other approaches, such as behavioral, electrophysiological, and morphological imaging, examining hemispheric asymmetry in dyslexics have generated inconsistent evidence (e.g., Green et al., 1999; Habib, 2000; Heiervang et al., 2000; Heim, Eulitz, & Elbert, 2003; Hynd, Semrud-Clikeman, Lorys, Novey, & Eliopulos, 1990; Leonard, Eckert, Given, Virginia, & Eden, 2006). For example, with morphological MRI, some studies failed to find any difference of cortical symmetry between dyslexic and normal subjects (Green et al., 1999), and some even found an exaggerated pattern of leftward cerebral asymmetry in dyslexics (Leonard et al., 2006). Therefore, the question of whether and how dyslexics differ from normal subjects in brain lateralization is still unsolved.

Even if the morphological structure of language cortex in dyslexics is normal, it is still possible that dyslexics have an abnormal lateralization of functionally defined areas. In the present study, we used fMRI to compare the patterns of hemispheric lateralization in dyslexic and control children when they performed a phonological working memory task in an n-back paradigm. Phonological working memory involves the temporary storage and manipulation of phonological information (Baddeley, 2003b). It has been well-established that phonological working memory makes a unique contribution to learning of spoken and written languages (Baddeley, 2003a; Chee, Soon, Lee, & Pallier, 2004; Gathercole & Baddeley, 1993; Leong, Tse, Loh, & Hau, 2008; Mann & Liberman, 1984) and that children with dyslexia exhibit deficits in phonological working memory (de Jong, 1998; Gathercole,