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Research report

Spatiotemporal reorganization of the reading network in adult dyslexia

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ABSTRACT

Developmental dyslexia is characterized by impairments in reading fluency and spelling that persist into adulthood. Here, we hypothesized that high-achieving adult dyslexics (i.e., university students with a history of dyslexia) manage to cope with these deficits by relying to a greater extent on morphological information than do non-impaired adult readers. We used magnetoencephalography (MEG) in a primed lexical decision task, in which we contrasted orthographic, morphological and semantic processing. Behavioral results confirmed that adult dyslexics did indeed rely to a greater extent on the semantic properties of morphemes than controls. In line with this, MEG results showed early morphological effects (100–200 msec) in a frontal network, which reflected the contribution of semantic processing. The same effects occurred much later in controls (~400 msec). In contrast, controls showed early orthographic priming effects in posterior left inferior temporal gyrus (LITG) at around 130 msec, which were not seen in dyslexics. In the LITG, dyslexics showed only late activation of semantic and orthographic information. The present results suggest a spatiotemporal reorganization of the reading network, in which morphological information located in frontal regions is activated earlier in high-achieving adults dyslexics than controls.

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1. Introduction

Developmental dyslexia is a severe disorder characterized by poor word decoding, low levels of reading fluency, and poor spelling performance (Boets et al., 2013; Demonet, Taylor, & Chaix, 2004; Norton, Beach, & Gabrieli, 2014; Shaywitz & Shaywitz, 2005). It is a long-lasting deficit that persists into adulthood (Gabrieli, 2009). It has been reported that approximately 3.2% of the dyslexics in the UK manage to undertake university studies despite having dyslexia (Warmington, Stothard, & Snowling, 2013). University students with dyslexia are an ideal population to investigate how the reading network had adapted, both spatially and temporally, to compensate for reading deficits of adults with dyslexia. Despite their well-documented impairments in basic reading skills (i.e., poor decoding, reduced reading fluency), they seem to have coped with these deficits in such a way that reading comprehension is not (or less) affected (Deacon, Cook, & Parrila, 2012).

It has been suggested that one of these compensatory mechanisms is reliance on contextual information and semantics (Cavalli, Casalis, El Ahmadi, Zira, Poracchia-George, & Colé, 2016; Snowling, 2000; Stanovich, 1980). However, existing brain imaging studies do not fully support a special role for semantic processing as a compensatory mechanism in adults with dyslexia. First, while previous fMRI studies consistently found an under-activation of ventral occipito-temporal cortex in charge of orthographic processing (for meta-analyses see Paulesu, Danelli, & Berlingeri, 2014; Richlan, 2012; Richlan, Kronbichler, & Wimmer, 2011), only few studies found an over-activation of frontal areas that could potentially be associated with semantic processing (Brunswick, McCrory, Price, Frith, & Frith, 1999; Salmelin, Service, Kiesilä, Uutela, & Salonen, 1996; Shaywitz et al., 1998). Yet, the over-activation in frontal areas, such as the left inferior frontal gyrus (LIFG), has typically been interpreted in terms of an articulatory compensatory mechanism or increased effort (Richlan et al., 2011). Second, the few neuroimaging studies that specifically investigated semantic processing in dyslexia typically found weaker activation in the left middle and superior temporal cortex in dyslexics than controls (Helenius, Salmelin, Service, & Connolly, 1999). Finally, previous studies found no evidence for faster activation of semantics in EEG or MEG. For example, Helenius et al. (1999) showed that the onset of the N400m in the left superior temporal cortex began about 100 msec later in adults with dyslexia than controls. Similarly, Rüsseler, Becker, Johannes, and Münte (2007) found a delayed N400 in a semantic judgment task for adults with dyslexia. Taken together, at present, there is little evidence for a greater involvement of semantic areas or more efficient (faster) semantic processing in adults with dyslexia.

One interesting proposal is that adults with dyslexia might not rely on semantics *per se* but on morphemes, which are the smallest units of meaning (*work-er*, *depart-ure*) and provide a direct link between form and meaning. Indeed, morphologically related words share form and meaning (*work, worker, working*…), which significantly reduces the arbitrariness of the mapping between form and meaning (e.g., knowing that a word starts with the letter *w* does not tell us anything about its meaning). Indeed, some evidence from university students with dyslexia suggests that some oral language skills, such as vocabulary and morphological knowledge, might function as protective factors in dyslexia (for a review, see Haft, Myers, & Hoeft, 2016). In line with this hypothesis, Martin, Frauenfelder, and Colé (2013) showed that morphological knowledge is relatively preserved in university students with dyslexia, whereas phonological processing is clearly impaired (see also Law, Wouters, & Ghesquière, 2015). Recently, a study showed that the dissociation between good morphological and poor phonological skills was highly predictive of reading skills in university students with dyslexia (Cavalli, Duncan, Elbro, El Ahmadi, & Colé, 2017), which was taken to suggest that adults with dyslexia may capitalize on the semantic dimension of morphology to compensate for the well-documented phonological impairments. In addition, Elbro and Arnbak (1996) found that dyslexics tend to use a reading strategy based on morphemes rather than graphemes and phonemes. Interestingly, children with dyslexia seem to show morphological priming that is mainly due to morpho-semantic processing, whereas morphological priming in controls seems to come from morpho-orthographic processing (Quémart & Casalis, 2013).

Research on skilled adult readers has shown that morphological processing has a specific neural signature that cannot be reduced to the joint activation of form and meaning (Beyersmann, Iakimova, Ziegler, & Colé, 2014; Rastle & Davis, 2008). Morphology-specific effects over and above form and meaning have been found along the ventral stream and in a vastly distributed network that includes left inferior and superior temporal gyri, LIFG and left orbitofrontal gyrus (Cavalli, Colé, Badier, Zielinski, Chanoine, & Ziegler, 2016; Fruchter & Marantz, 2015; Whiting, Shtyrov, & Marslen-Wilson, 2015). In a recent MEG study using a primed lexical decision task, Cavalli et al. (2016) found evidence for a semantically driven morphological priming effect as early as 250 msec (i.e., M250) in left superior temporal gyrus (LSTG). Both orthographic and semantic contributions to morphological facilitation were found around 350 msec (i.e., M350) along the ventral stream and in LIFG. Evidence for recombination of morphemes and semantic unification were found in orbitofrontal cortex around 450–500 msec (see also Fruchter & Marantz, 2015).

The goal of the present study was to investigate the neural underpinnings of morphological processing in adults with dyslexia and the differences in the processing of morphological information between adults with and without dyslexia in a primed-lexical decision task. More precisely, we were interested in finding out whether high-achieving adult dyslexics rely to a greater extent on morphological processing than normal readers. We hypothesized that successful compensation (or adaptation) in university students with dyslexia is achieved through a spatiotemporal reorganization of the reading network, in which morphological information primarily processed in frontal regions is activated earlier and more strongly in this population than in controls.

To investigate the spatiotemporal dynamics of morphological processing, we recorded MEG in a primed-lexical decision task in French university students with and without dyslexia. We compared the event-related fields (ERFs) elicited by word pairs that were morphologically related, such as *ourson – OURS [bear cub-bear]*, orthographically related, *oursin – OURS [urchin-bear]*, semantically related *peluche – OURS*