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Sluggish dorsally-driven inhibition of return during orthographic processing in adults with dyslexia

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ABSTRACT

Dyslexia (D) is a neurodevelopmental reading disorder characterized by phonological and orthographic deficits. Before phonological decoding, reading requires a specialized orthographic system for parallel letter processing that assigns letter identities to different spatial locations. The magnocellular-dorsal (MD) stream rapidly process the spatial location of visual stimuli controlling visuo-spatial attention. To investigate the visuo-spatial attention efficiency during orthographic processing, inhibition of return (IOR) was measured in adults with and without D in a lexical decision task. IOR is the delay in responding to stimuli displayed in a cued location after a long cue-target interval. Only adults with D did not showed IOR effect during letter-string recognition, despite the typical left-hemisphere specialization for word identification. A specific deficit in coherent-dot-motion perception confirmed an MD-stream disorder in adults with D. Our results suggest that adults with D might develop an efficient visual word form area, but a dorsal-attentional dysfunction impairs their reading fluency.

1. Introduction

Dyslexia (D) represents the most common heritable neurodevelopmental disorder and is characterized by severe difficulties in learning to read, despite normal intelligence, absence of neurological deficits and adequate educational opportunities (Peterson & Pennington, 2015). Difficulties in learning to read are ascribed mainly to an impairment in phonological awareness (see Gabrieli, 2009; Peterson & Pennington, 2015; for reviews), which refers to the ability to perceive and manipulate the sounds of spoken words (Mattingly, 1972) and involves discriminating speech sounds and explicitly acting upon them (Castles & Coltheart, 2004).

However, recent data show that also visual factors involved in the orthographic processing could be independent predictors of reading abilities (e.g., Boets, Vandermosten, Cornelissen, Wouters, & Ghesquière, 2011; Carroll, Solity, & Shapiro, 2016; Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Franceschini et al., 2013; Gori, Molteni, & Facoetti, 2016; Gori, Seitz, Ronconi, Franceschini, & Facoetti, 2016; Zorzi et al., 2012; see Grainger, Dufau, & Ziegler, 2016; Vidyasagar & Pammer, 2010 for recent reviews). As reported by Grainger et al. (2016, p. 171): "processing of orthographic information begins with scale-invariant gaze-centered letter detectors that conjunctively encode letter identity and letter location. Visual acuity, crowding, and spatial attention conjointly determine activity in these gaze-centered letter detectors".

The visual system is structurally and functionally subdivided into the "what" or "perception" parvocellular-ventral (PV), and "where" or "action" magnocellular-dorsal (MD) main channels (Merigan & Maunsell, 1993; Mishkin & Ungerleider, 1982). The faster MD-stream fulfill a first stimulus-driven analysis of the visual field and drives the localization processing. Subsequently, by top down and feedback mechanisms, the coarse pattern can be used to select the PV pathway-driven information (Ahissar & Hochstein, 2004; Vidyasagar, 1999). During a reading task, the coarse information about letter pattern identity needs fast feedback from the MD stream. The MD feedback allows to focus on a restricted number of locations in order to identify the target composition or for a letter by letter (Pelli, Farell, & Moore, 2003; Stein, 2014; Vidyasagar, 1999; Vidyasagar & Pammer, 2010). Several studies showed that an MD stream deficit is associated to D (Gori, Molteni, et al., 2016; Stein & Walsh, 1997). Training the MD-stream directly (Franceschini et al., 2013; Gori, Molteni, et al., 2016; Lawton, 2016) and indirectly (Olulade, Napoliello, & Eden, 2013; but see Joo, Donnelly, & Yeatman, 2017) improves reading skills. Also an electric neuromodulation (i.e., the transcranial direct current stimulation) of V5-MT area (included in the MD stream) has been shown to be associated with an improvement in reading abilities (Heth & Lavidor,

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2015). Transient suppression of activity in MT+ area by repetitive transcranial magnetic stimulation, significantly decreased performance in pseudowords naming, without any changes in phonological skills (Liederman et al., 2003).

The MD stream may play a fundamental role for attentional orienting functions, initially activating the alerting system, and then driving with a spatial letters coding (Cornelissen et al., 1998; Vidyasagar & Pammer, 2010). The MD stream terminates mainly in the posterior parietal cortex (Merigan & Maunsell, 1993; Mishkin & Ungerleider, 1982), which is the cortical region controlling spatial attention in humans (see Corbetta & Shulman, 2002, 2011 for reviews). The role of MD stream on attentional and reading abilities has been extensively studied (Gori & Facoetti, 2014, 2015; Gori, Molteni, et al., 2016). Performance in coherent dot motion detection, which resulted in a very reliable proxy of the MD stream, is related to letter feature position encoding, independently from phonological awareness abilities (Cornelissen et al., 1998).

Recent data demonstrated that also visuo-spatial attention abilities are independent predictors of future reading abilities (e.g., Carroll et al., 2016; Ferretti, Mazzotti, & Brizzolara, 2008; Franceschini et al., 2017; Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Gori, Seitz, et al., 2016; Plaza & Cohen, 2007). Attentional orienting is the shifting mechanism regulating the spotlight of attention upon a specific visual area. During new word and pseudoword decoding, the attentional mechanisms scan sequentially the letter string which fall into the attentional spotlight, exactly like during a visual search task. Information are subsequently processed in the specific temporal sequence yielding the letter spatial order (Boros et al., 2016; Bullier, 2001; Vidyasagar & Pammer, 2010). Accordingly, graphemes are then mapped to theirs corresponding speech sounds.

Visual attentional orienting resulted impaired in people with D (e.g., Bosse, Tainturier, & Valdois, 2007; Brannan & Williams, 1987; Buchholz & Aimola, 2005, 2007; Buchholz & McKone, 2004; Carroll et al., 2016; Cestnick & Coltheart, 1999; Ding et al., 2016; Facoetti, Corradi, Ruffino, Gori, & Zorzi, 2010; Facoetti, Lorusso, Cattaneo, Galli, & Molteni, 2005; Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Facoetti, Ruffino, Peru, Paganoni, & Chelazzi, 2008; Facoetti, Trussardi, et al., 2010; Facoetti, Turatto, Lorusso, & Mascetti, 2001; Facoetti et al., 2006; Ferretti et al., 2008; Franceschini et al., 2012; Hari & Renvall, 2001; Iles, Walsh, & Richardson, 2000; Roach & Hogben, 2007; Ruffino, Gori, Boccardi, Molteni, & Facoetti, 2014; Ruffino et al., 2010; Valdois, Grard, Vanault, & Dugas, 1995; Vidyasagar & Pammer, 1999; Visser, Boden, & Giaschi, 2004; Williams, Brannan, & Lartigue, 1987; Hari et al., 1999; Hari & Renvall, 2001; see for reviews see Boden & Giaschi, 2007; Franceschini et al., 2015, 2016; Gori & Facoetti, 2014, 2015; Gori, Molteni, et al., 2016; Gori, Seitz, et al., 2016; Hari & Renvall, 2001; Stein, 2014; Valdois, Bosse, & Tainturier, 2004; Vidyasagar, 1999; Vidyasagar & Pammer, 2010). This deficit has been largely described in individuals with D characterized by poor phonological decoding skills (e.g., Buchholz & McKone, 2004; Cestnick & Coltheart, 1999; Facoetti, Corradi, et al., 2010; Facoetti, Trussardi, et al., 2010; Facoetti et al., 2006; Gori, Cecchini, Bigoni, Molteni, & Facoetti, 2014; Jones, Branigan, & Kelly, 2008; Roach & Hogben, 2007; Ruffino et al., 2010, 2014). Recently, Boros et al. (2016) reported differences between children with D and age-matched normal readers not only in the activation of the word-specialized occipito-temporal areas of the left hemisphere (i.e. the visual word form area, VWFA), but also in the middle occipital gyrus, an area of the brain engaged in visuospatial processing and necessary for ordering the symbols in unfamiliar visual strings.

Important evidence about difficulties in rapid orienting of attention in D has been shown using covert orienting of visual attention task (Posner, 1980). In this task, a brief cue in the periphery of a central fixation point could indicate the location of successive appearance of a target. The appearance of the target at the same location of the cue (valid condition), within a short time interval, produces a facilitation in target detection compared to the condition in which the appearance of the target is in different locations of the cue (invalid condition; Posner, 1980; Posner, Nissen, & Ogden, 1978). Children with D and pre-readers at risk for D showed impaired functioning in this task because of their slower attentional orienting compared to normal readers (e.g., Buchholz & Aimola, 2008; Facoetti, Trussardi, et al., 2010; Facoetti et al., 2000, 2006; Franceschini et al., 2012). Moreover, attentional treatments of D with tachistoscope or action video games, significantly change attentional orienting mechanisms (Facoetti, Lorusso, Paganoni, Umiltà, & Mascetti, 2003; Lorusso, Facoetti, Paganoni, Pezzani, & Molteni, 2006; Franceschini et al., 2013, in press; Gori, Molteni, et al., 2016; Gori, Seitz, et al., 2016, see Franceschini et al., 2015 for a review).

An overturning between valid and invalid location detection is typically observed by long cue-target interval in the original Posner paradigm (Posner, 1980). In this case, response time to valid condition becomes slower when compared to invalid condition. This effect is known as inhibition of return (IOR). IOR is referred to the inhibition acting as a bias against the relocation of the attentional spotlight to previously attended area (see Klein, 2000; Wang & Klein, 2010 for review). The IOR effect has been originally described in detection tasks at relatively short cue-target interval (about 200–300 ms; Klein, 2000; Lupiez, Klein, & Bartolomeo, 2006 for reviews).

Previous studies have shown that the IOR was not present in children with D during a spatial cueing detection task in alphabetic and logographic languages (Ding et al., 2016; Facoetti, Lorusso, Paganoni, Umiltà, & Mascetti, 2003). Further studies described the IOR effect also in discrimination tasks at longer cue-target interval (about 1000–1500 ms; Chica, Lupianez, & Bartolomeo, 2006; Handy, Jha, & Mangun, 1999; Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Pratt, 1995; Pratt & Abrams, 1999; Pratt, Kingstone, & Khoe, 1997; Vivas & Fuentes, 2001). Importantly, complex tasks such as lexical access is also affected by the IOR effect (Chasteen & Pratt, 1999). Typical adult readers – during a lexical decision task – are slower in identifying words and pseudowords in valid compared to invalid cue condition (Chasteen & Pratt, 1999). This study opens up the question of whether individuals with D would perform differently from typically developed adults in the IOR during a lexical decision task.

Here, in two groups of adults, with and without D, we measured the IOR effect of visuo-spatial attention during a lexical decision task. The letter-string was presented in the upper and lower visual field as originally reported by Chasteen and Pratt (1999). Moreover, in order to estimate a possible difference between the two groups in the efficiency of the VWFA (e.g., Boros et al., 2016; Dehaene, Cohen, Morais, & Kolinsky, 2015), we presented the stimuli also in the left and right visual field. Words presented in the right visual field – directly connected to the VWFA (Dehaene et al., 2002) – should be more accurately and rapidly recognized in comparison to words displayed in the other visual field locations.

In this lexical decision task, we predict that: (i) a main effect of the group could indicate a general disorder of lexical access in our sample of adults with D; (ii) in the word identification, a group by visual field location interaction could indicate a different VWFA efficiency between the two groups, probably due to a different reading experience (Dehaene et al., 2015). In contrast, a difference between groups in the lower and upper visual fields should be irrelevant since the difference in reading experience should not produce effects in the vertical direction. However, lower versus upper visual field is disproportionately represented in the MD stream versus the PV stream (e.g., Previc, 1990). Thus, a deficit in letter-string processing for lower, but not for upper visual field, in adults with D should confirm an MD stream functioning disorder in D; (iii) a group by cue position interaction should indicate a different IOR mechanism in the two groups. Interestingly, some studies in individuals with D found an effect of the visual attention and the MD stream functioning mainly during pseudoword reading (e.g., Facoetti, Trussardi, et al., 2010; Gori et al., 2014; Ruffino et al., 2014; Witton