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Visual Spatial Attention and Speech Segmentation are both Impaired in Preschoolers at Familial Risk for Developmental Dyslexia

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Phonological skills are foundational of reading acquisition and impaired phonological processing is widely assumed to characterize dyslexic individuals. However, reading by phonological decoding also requires rapid selection of sublexical orthographic units through serial attentional orienting, and recent studies have shown that visual spatial attention is impaired in dyslexic children. Our study investigated these different neurocognitive dysfunctions, before reading acquisition, in a sample of preschoolers including children with ($N = 20$) and without ($N = 67$) familial risk for developmental dyslexia. Children were tested on phonological skills, rapid automatized naming, and visual spatial attention. At-risk children presented deficits in both visual spatial attention and syllabic segmentation at the group level. Moreover, the combination of visual spatial attention and syllabic segmentation scores was more reliable than either single measure for the identification of at-risk children. These findings suggest that both visuo-attentional and perisylvian-auditory dysfunctions might adversely affect reading acquisition, and may offer a new approach for early identification and remediation of developmental dyslexia.

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INTRODUCTION

Developmental dyslexia (DD) is a neurobiological disorder (Habib, 2000 for a review) characterized by a difficulty in reading acquisition despite adequate intelligence, conventional education and motivation (American Psychiatric Association, 1994). It is widely believed that impaired phonological processing characterizes individuals with DD (see Ramus, 2003; Shaywitz & Shaywitz, 2005; Vellutino, Fletcher, Snowling, & Scanlon, 2004 for reviews). Indeed, children and adults with DD show poor phonological awareness, slow lexical retrieval and poor phonological short-term memory. These phonological deficits would interfere with one of the most critical skills for successful reading acquisition, that is, phonological decoding (e.g. Ziegler, Perry, Wyatt, Ladner, & Schülte-Korne, 2003; Ziegler & Goswami, 2005). Phonological decoding is based on letter–sound conversion and it allows children to make the connection between novel letter strings and words that are already stored in their phonological (spoken word) lexicon (Share, 1995). Efficient phonological decoding requires accurate representations at the phoneme level (e.g. Harm & Seidenberg, 1999; Perry, Ziegler, & Zorzi, 2007).

Many studies have sought to fractionate the impaired phonological skills into lower-level deficits, with special reference to auditory processing (see Goswami, 2003; Hari & Renvall, 2001; Tallal, 2004; Wright, Bowen, & Zecker, 2000 for reviews). Auditory deficits would impair speech sound perception, which, in turn, would affect grapheme-to-phoneme mapping and phonological short-term memory (Ramus, 2003). For example, children with DD show speech perception deficits when stimuli are presented in noise (e.g. Geiger *et al.*, 2008; Ziegler, Pech-George, George, & Lorenzi, 2009). Speech-in-noise perception deficits persisted when dyslexics' performance was compared with that of much younger children matched for reading level. Goswami *et al.* (2002) reported that children with DD are relatively insensitive to the rise times of amplitude envelope onsets in acoustic signals compared with younger normally reading children matched for reading level. The ability to detect this acoustic feature provides a non-speech-specific mechanism for segmenting syllable onsets and rimes: a crucial precursor to the development of phoneme segmentation skills (Goswami *et al.*, 2002).

However, since phonological decoding requires the precise mapping from orthographic to phonological representations, reading acquisition might be affected not only by a dysfunction of the perisylvian auditory-phonological system, but also by a dysfunction of the visual-orthographic system (e.g. the visual word form area in the left occipito-temporal cortex; McCandliss, Cohen, & Dehaene, 2003). Accordingly, many studies have shown that DD children are impaired in low-level visual and/or attentional processing tasks (e.g. Bosse, Tainturier, & Valdois, 2007; Cornelissen, Richardson, Mason, Fowler, & Stein, 1995; Facoetti *et al.*, 2010; Hari, Renvall, & Tanskanen, 2001; Hawelka, Huber, & Wimmer, 2008; Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009; Sperling, Lu, Manis, & Seidenberg, 2005).

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Visual spatial attention is particularly important for orthographic processing. Letter strings must be segmented into their constituent graphemes (i.e. graphemic parsing) before phonological assembly. This requires rapid and accurate attentional shifts over the letter string (see the computational models of Ans, Carbonnel, & Valdois, 1998; Perry *et al.*, 2007; Whitney & Cornelissen, 2005). Attentional orienting improves visual perception by intensifying the signal inside the focus of attention as well as diminishing the effect of noise outside the focus of attention (Reynolds & Heeger, 2009). Notably, when letters are spatially close, letter identification accuracy is reduced (Bouma, 1970) because of massive competition for object recognition (see Pelli, 2008 for a review). However, almost no competition occurs if attention is rapidly engaged onto the object (e.g. Facoetti, 2001; Van der Lubbe & Keuss, 2001; see Enns & Di Lollo, 2000 for a review).

A deficit of visual attentional orienting has been repeatedly described in DD (see Hari & Renvall, 2001; Valdois, Bosse, & Tainturier, 2004; Vidyasagar & Pammer, 2010 for reviews) and more specifically in dyslexics with poor phonological decoding skills (e.g. Buchholz & McKone, 2004; Cestnick & Coltheart, 1999; Facoetti *et al.*, 2006, 2010; Facoetti, Ruffino, Peru, Paganoni, & Chelazzi, 2008; Jones, Branigan, & Kelly, 2008; Kinsey, Rose, Hansen, Richardson, & Stein, 2004; Roach & Hogben, 2007; Ruffino *et al.*, under revision). However, visual attentional deficits have been sometimes discounted in terms of consequence (rather than cause) of the reading disorder (e.g. Goswami, 2003; Ramus, 2003). It is therefore crucial to demonstrate that visual attentional deficits can be found *before* reading acquisition. Bosse and Valdois (2009), in a cross-sectional study on typically developing children, have shown that visual attention contributes to phonological decoding skills, independently from auditory-phonological processing, even in first graders. Moreover, recent longitudinal studies have suggested that magnocellular-dorsal stream sensitivity and attentional processing, in addition to phonological awareness, is an important predictor of early reading abilities (e.g. Boets, Wouters, van Wieringen, De Smedt, & Ghesquière, 2008; Ferretti, Mazzotti, & Brizzolara, 2008; Kevan & Pammer, 2009; Plaza & Cohen, 2006).

The aim of the present study was to investigate both phonological processing and visual spatial attention before reading acquisition, and to assess their putative dysfunction in preschoolers at familial risk for DD. About half of the reading deficits can be attributed to genetic influences (Gayán & Olson, 2001) and DD is known to frequently run in families (Fisher, 1905; Hallgren, 1950; Thomas, 1905). Note that familial transmission is necessary but not sufficient evidence for a genetic etiology because family members typically share both genes and their environment (DeFries, 1985). What is important for our purposes, however, is that children with a dyslexic parent present a high risk to develop reading difficulties. The hypothesis that impaired orienting of spatial attention is a core deficit in DD (Facoetti *et al.*, 2010) leads to the prediction that at least some of the at-risk pre-readers should manifest this dysfunction. An impairment of the magnocellular-dorsal stream in pre-readers at risk for DD has been previously described by Kevan and Pammer (2008), who found that both coherent dot motion and spatial frequency doubling thresholds were higher in at-risk children in comparison to unselected pre-readers. However, their study did not explicitly investigate orienting of spatial attention and it did not consider other neurocognitive functions. Our study investigated phonological

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skills (i.e. syllabic recognition, segmentation and blending) and visual-to-phonological mapping (i.e. Rapid Automatized Naming, RAN; e.g. Denckla & Rudel, 1976; Lervag & Hulme, 2009), in addition to visual spatial attention, to provide a more comprehensive assessment of the component skills that are foundational to reading acquisition.

METHOD

Participants

A total of 87 (36 female and 51 male) five-year-old children, attending the last year of kindergarten, were included in the present study. In the Italian school system, formal reading instruction starts at the first grade. Consequently, Italian preschoolers are also pre-readers. Sixty-seven children were classified as pre-readers without familial risk for DD (No Risk group), whereas the remaining 20 children were classified at risk for DD (At-Risk group). Children were assigned to the two groups on a basis of their parents' score on the 'Adult Dyslexia Check-list' (Vinegrad, 1994). All children were native Italian speakers without any documented history of brain damage, hearing or visual deficits. The IQ level was estimated through the standard scores in Similarities and Cube Design subtests of the WPPSI scale (Wechsler, 1973). The difference between No Risk and At-Risk group was not statistically significant in chronological age ($t_{(85)} = -1.59$, $p = 0.12$, Cohen's $d = 0.34$) as well as in IQ level (Similarities: $t_{(85)} = 0.29$, $p = 0.78$, Cohen's $d = 0.06$ and Block Design: $t_{(85)} = 0.22$, $p = 0.83$, Cohen's $d = 0.05$). Finally, we used a letter identification task (four frequent letters: 'A', 'E', 'B' and 'O' presented four times) to assess children's pre-reading level of letter knowledge. Performance of the two groups was not statistically different in this task ($t_{(85)} = 0.26$, $p = 0.79$, Cohen's $d = 0.06$), indicating similar knowledge of letters (see Table 1 for details).

Tasks, Stimuli and Procedures

Visual Spatial Attention Task

Automatic orienting of visual attention was measured using a variant of Posner's (1980) task that involved lateralized visual targets preceded by uninformative spatial cues. Participants were individually tested in a dimly lit and quiet room, seated 42 cm away from a 15-inch monitor. A head-chin rest was used to stabilize

Table 1. Mean (*M*) and standard error (SE) of age, Similarities and Block design (Wechsler, 1973), letters identification in pre-readers without (No Risk) and with familial risk for developmental dyslexia (At-Risk)

	No Risk ($N = 67$)		At-Risk ($N = 20$)	
	M	SE	*M*	SE
Age (years)	5.67	0.05	5.85	0.1
Similarities (standard scores)	11.06	0.35	10.85	0.64
Block design (standard scores)	10.15	0.44	10.35	0.8
Letters identification (accuracy rate)	0.66	0.05	0.68	0.09

the head; fixation was binocular. A small cross (0.2 deg) in the centre of the screen was used for fixation. Two horizontal black bars (6 deg $\times$ 0.3 deg) were presented peripherally (horizontal eccentricity from the centre: 12 deg), one for each side, 4 deg below fixation. The peripheral cue consisted of the thickening of one black bar (0.6 deg). The target was an ellipse rotated by 30, 60, 300 or 330°, measuring 8×4 deg and presented at 12 deg of eccentricity. The target was flanked by two lateral masks composed of four overlapping targets. The masks were used to render the task more difficult, thus avoiding a potential ceiling effect in the accuracy scores. The distance between target centre and flanking mask centre was 5 deg. Stimuli were black and had luminance of 0.6 cd/m^2. The background was white and its luminance was 119 cd/m^2. Fixation was required during the trial. Eye movements were monitored by a mirror and trials with detected eye movement were deleted. Each trial started with the onset of the fixation and the two black bars, and 500 ms later, the cue appeared for 50 ms. After a further 50 ms (i.e. stimulus onset asynchrony = 100 ms), the target was displayed for 180 ms. The cue was non-predictive of target location. On valid trials (50%), the target was presented over the black bar indicated by the cue, whereas on invalid trials (50%) the target appeared over the opposite black bar. At the end of the trial, participants' task was to identify the target by choosing between the four possible target stimuli (accuracy rate = 0.25 corresponded to chance level) displayed on the screen until response (see Figure 1 panel A). Each participant was instructed to use all time necessary to identify the target accurately. Only accuracy rates were measured. Responses were given by manually pointing to the target on the screen and then recorded by the experimenter by pressing the corresponding key on the computer keyboard. No feedback was provided. The experimental session consisted of 36 trials (18 valid and 18 invalid trials).

Peripheral Target Identification Task

The procedure was the same as in the previous experiment, the only difference being the following: (i) the cue was not present and (ii) the target was not flanked by the two lateral masks (see Figure 1 panel B). The aim of this task was to

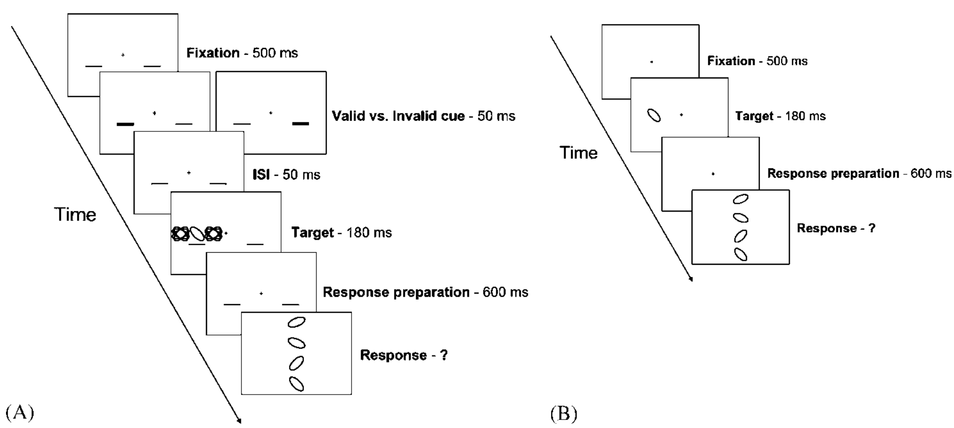

Figure 1. (A) Schematic representation of the stimulus sequence for the visual spatial attention task. (B) Schematic representation of the stimulus sequence for the peripheral target identification task.

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provide a baseline to compare peripheral target identification accuracy in the two groups.

Phonological Tasks

Phonological skills at the syllabic level were tested by using three tasks included in the Italian 'Phonological Awareness Battery' (Marotta, Ronchetti, Trasciani, & Vicari, 2004): (i) *Syllabic recognition,* measuring the ability to identify if two similar spoken words were composed by the same or different syllables (15 word pairs; e.g. 'pane' and 'cane' = different); (ii) *Syllabic segmentation*, measuring the ability to parse a spoken word in its constituent syllables (15 words; e.g. 'rana' = 'ra' and 'na') and (iii) *Syllabic blending*, measuring the ability to blend segmented syllables into a word (15 words; e.g. 'fi', 'o' and 're' = 'fiore').

Visual-to-phonological Mapping Task

Cross-modal mapping from visual stimuli to the correspondent spoken words (i.e. search for and access to phonological lexicon from visual input) was measured by using a RAN task, in which the visual items were 16 filled coloured circles. The participants' task was to name as fast as possible the familiar colours filling the circles. The dependent variable was the total time (in seconds) for naming the visual items.

RESULTS

Groups Analyses

Visual Spatial Attention

Mean accuracy rates (i.e. proportion of targets correctly identified) was submitted to a mixed analysis of variance (ANOVA) with 2×2 design in which the within-subject factor was Cue condition (Valid and Invalid) and the between-subject factor was Group (No Risk and At-Risk).

The main effects of Cue condition and Group were not significant (both $Fs < 1$, partial $\eta^2 = 0.01$). Crucially, the Cue condition $\times$ Group interaction was significant, $F(1, 85) = 5.05$, $p = 0.023$, partial $\eta^2 = 0.6$ (see Figure 2 panel A). Pre-reader children without familial risk for DD showed efficient automatic orienting of visual attention, because target identification was more accurate when the target appeared at the valid location (Valid = 0.43 and Invalid = 0.33, $t(66) = 3.23$, $p = 0.002$, Cohen's $d = 0.79$). In contrast, the performance of at-risk children was not influenced by Cue condition (Valid = 0.36 and Invalid = 0.40, $t(19) = 0.79$, $p = 0.44$, Cohen's $d = 0.36$), thus showing inefficient automatic orienting of visual attention. Notably, the critical two-way interaction was significant [$F(1, 81) = 6.02$, $p = 0.016$, partial $\eta^2 = 0.68$] even when chronological age, IQ and letter identification scores were included as covariates in the ANOVA. Thus, the inefficient automatic orienting of visual attention seems a specific feature of pre-reader children at-risk for DD and it cannot be accounted for by differences in age, general cognitive skills or letter knowledge.

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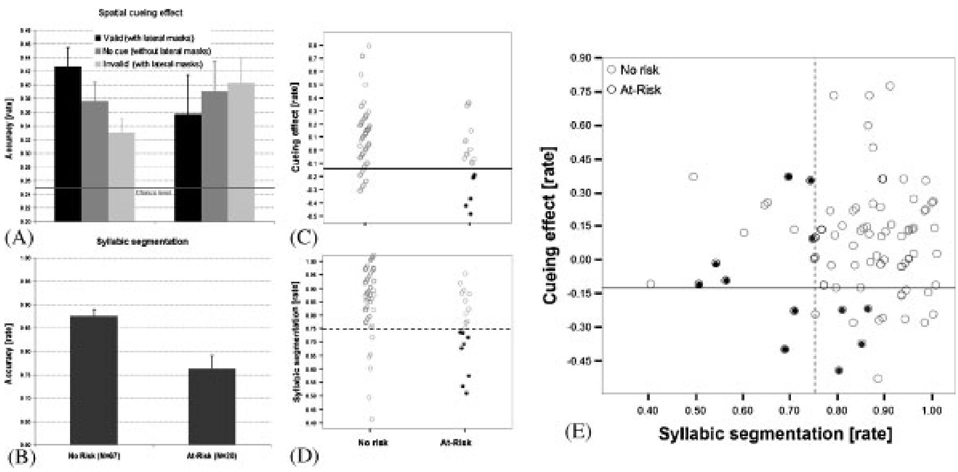

Figure 2. Panel A. Mean target accuracy and standard errors as a function of Group (No Risk and At-Risk) and Cue condition (valid, invalid and no cue). Panel B. Mean syllabic segmentation accuracy and standard error as a function of Group (No Risk and At-Risk). Panel C. Scatter plot showing the individual data in visual spatial attention orienting task: i.e. facilitation of the target identification in valid vs. invalid location. Six out of twenty At-Risk pre-readers (30%) are below 1 SD of the No Risk pre-readers, as they fall below the solid line. Panel D. Scatter plot showing the individual data in syllabic segmentation task. Eight out of twenty At-Risk pre-readers (40%) are below 1 SD of the No Risk pre-readers, as they fall below the dashed line. Panel E. Scatter plot showing the individual data in visual spatial attention orienting as well as in syllabic segmentation task. Twelve out of twenty At-Risk pre-readers are below 1 SD of the No Risk pre-readers, as they fall below the solid line (visual spatial cueing) or to the left of the dashed line (syllabic segmentation). To note that only one At-Risk pre-reader child is clearly unimpaired in both visual spatial attention orienting and syllabic segmentation indexes.

Peripheral Target Identification

Peripheral target identification (accuracy rate) was analysed with a univariate ANOVA where Group (No Risk and At-Risk) was the between-subject factor. The effect of Group was not significant (No Risk group = 0.38 and At-Risk group = 0.39, $F < 1$, partial $\eta^2 < 0.01$). This result indicates that the two groups did not significantly differ in the perceptual baseline task (see Figure 2 panel A and Table 2).

Phonological Skills

Accuracy rates for the three phonological tasks (i.e. syllabic recognition, segmentation and blending) were submitted to a Multivariate ANOVA where the Group (No Risk and At-Risk) was the between-subject factor. The effect of Group was significant [$F(1, 83) = 6.02$, $p = 0.001$, partial $\eta^2 = 0.95$]. However, univariate tests showed that the two groups differed only in the syllabic segmentation task [$F(1, 83) = 13.69$, $p < 0.01$, partial $\eta^2 = 0.95$]. The mean accuracy rate in at-risk children was 0.76, whereas in pre-readers without risk it was 0.87 (see Figure 2 panel B and Table 2).

Visual-to-phonological Mapping

The speed of visual-to-phonological mapping (RAN in seconds) was submitted to a univariate ANOVA with Group (No Risk and At-Risk) as between-subject factor. The effect of Group was not significant (No Risk group = 18.55 and

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Table 2. Mean (*M*) and standard error (SE) of syllabic recognition, rapid automatized naming, syllabic blending, syllabic segmentation, peripheral target recognition (without masks) and spatial cueing effect in pre-readers without (No Risk) and with familial risk for developmental dyslexia (At-Risk)

	No Risk ($N = 67$)		At-Risk ($N = 20$)		Comparison	
	M	SE	*M*	SE	*T*(85)	*P*
Syllabic recognition (accuracy rate)	0.82	0.02	0.87	0.02	−1.61	0.11
Rapid automatized naming (seconds)	18.55	0.98	18.89	1.14	−1.18	0.86
Syllabic blending (accuracy rate)	0.87	0.01	0.88	0.02	−0.64	0.52
Syllabic segmentation (accuracy rate)	0.87	0.01	0.76	0.03	3.70	**0.001**
Peripheral target recognition (accuracy rate)	0.38	0.03	0.39	0.06	−0.25	0.80
Spatial cueing effect (accuracy rate)	0.10	0.03	−0.04	0.06	2.25	**0.02**

Note: *P* values <0.05 are shown in bold font.

At-Risk group = 18.89 seconds, $F < 1$, partial $\eta^2 < 0.01$), indicating that the two groups did not significantly differ in cross-modal mapping of a visual stimulus to the correspondent spoken word (see Table 2).

Individual Data

Visual Spatial Attention in Pre-readers at Risk for Developmental Dyslexia

Although pre-reader children in the At-Risk group showed an inefficient automatic orienting of visual attention at the group level, it is important to establish the reliability of this abnormal pattern at individual level. The cueing effect (i.e. target accuracy in valid–invalid condition) was used as index of the orienting efficiency. Positive values indicate that attention is efficiently oriented to the cued location. Six out of twenty pre-reader children At-Risk (30%) were at least 1 SD below the mean of No Risk pre-readers (see Figure 2 panel C).

Syllabic Segmentation in pre-readers at Risk for DD

Syllabic segmentation accuracy was used as index of speech-sound segmentation efficiency. Eight out of twenty pre-reader children At-Risk (40%) were at least 1 SD below the mean of No Risk pre-readers (see Figure 2 panel D).

Identification of At-risk Children Using Visual Spatial Attention and Syllabic Segmentation Scores

One of the most important aims of predictive studies on future reading difficulties is to increase the precision of at risk children identification. We therefore assessed the possibility of identifying at-risk children on the basis of the performance in both visual spatial attention and syllabic segmentation tasks. Twelve out of twenty At-Risk pre-reader children (60%) were at least 1 SD below the mean of No Risk pre-readers in at least one task (see Figure 2 panel E). Moreover, to quantify the reliability of these two combined neurocognitive impairments, we computed the odds ratios between hits and false alarms. The odds ratio is the ratio of the odds of an event occurring in one group to the odds of it occurring in another group. The results show that for 1 At-Risk pre-reader

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falling below 1 SD for either tasks, only 0.19 of No Risk children fall below that limit (95% confidence interval from 0.07 to 0.56). Moreover, for 1 At-Risk pre-reader falling above 1 SD for either tasks, 5.2 No Risk children fall above that limit (95% confidence interval from 1.79 to 15.06).

DISCUSSION

Pre-reading children at risk for DD showed the expected deficit in phonological processing compared with children without risk, although in our sample the difference was significant only in the syllabic segmentation task. This result is in agreement with the typically observed speech-sound segmentation deficit shown in longitudinal studies of reading acquisition (see Bowey, 2005 for a review). Phonological processing deficits can hinder reading acquisition because the development of spelling-to-sound mappings (i.e. phonological decoding) requires accurate sublexical representations (Harm & Seidenberg, 1999; Perry *et al.*, 2007; Ziegler & Goswami, 2005). Indeed, several authors have argued that impaired auditory-phonological processing is the core deficit in DD (e.g. Goswami, 2003; Ramus, 2003; Tallal, 2004).

However, at risk pre-readers showed also a deficit of visual spatial attention in comparison to children without risk. The issue of whether magnocellular-dorsal and attentional deficits are causally linked to reading disorders in dyslexic children has been hotly disputed (e.g. Goswami, 2003; Ramus, 2003; but see Vidyasagar & Pammer, 2010). In particular, it might be argued that magnocellular-dorsal and attentional deficits are a consequence, rather than a cause, of the reading difficulties that characterize DD. An important step towards demonstrating that impaired spatial attention is a core deficit in DD was provided by our previous study on dyslexic children (Facoetti *et al.*, 2010), because dyslexic children showed abnormal deployment of spatial attention even in comparison to much younger, typically developing children matched for reading level. The present study goes one step further because it demonstrates that visual spatial attention can be impaired even before children learn to read.

The defective automatic orienting of visual attention observed in at-risk pre-readers is consistent with other neuropsychological studies on children with DD (see Hari & Renvall, 2001; Valdois *et al.*, 2004; Vidyasagar & Pammer, 2010 for reviews). More specifically, a deficit of visual attentional orienting has been repeatedly described in DD with poor phonological decoding skills (e.g. Buchholz & McKone, 2004; Cestnick & Coltheart, 1999; Facoetti *et al.*, 2006, 2008, 2010; Jones *et al.*, 2008; Kinsey *et al.*, 2004; Roach & Hogben, 2007; Ruffino *et al.*, under revision). The lack of cueing effect at a short cue-target SOA (i.e. 100 ms) observed in the present study is predicted by the 'sluggish attentional shifting' theory (see Hari & Renvall, 2001 for a review) and is consistent with the finding that dyslexic children show a delayed time course in attention orienting (Facoetti *et al.*, 2010). As attentional orienting improves visual perception by intensifying the signal inside the focus of attention as well as diminishing the effect of noise outside the focus of attention (Reynolds & Heeger, 2009), sluggish attention implies higher interference of spatio-temporal proximity between letters. In turn, this can have a detrimental effect on orthographic processing and in particular on the segmentation of letter strings into their constituent graphemes. The involvement of a serial reading

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mechanism based on visual attentional orienting is assumed by several computational models (Ans *et al.*, 1998; Perry *et al.*, 2007; Whitney & Cornelissen, 2005). For example, in the CDP+model of reading aloud (Perry *et al.*, 2007; Perry, Ziegler, & Zorzi, 2010; Zorzi, 2010), spatial attention is explicitly linked to graphemic parsing in the phonological assembly route.

At-risk pre-reader children were significantly less sensitive to the peripheral transient and uninformative cue compared with the group without familial risk for DD. This attentional deficit could be specific to the magnocellular-dorsal stream because it is mainly involved in the processing of peripheral and transient stimuli (see Boden & Giaschi, 2007; Hari & Renvall, 2001; Laycock & Crewther, 2008; Stein & Walsh, 1997; Vidyasagar & Pammer, 2010 for reviews). Notably, at-risk children demonstrated no deficit in the identification of peripheral targets when the attentional orienting mechanism was not involved. These results are consistent with recent predictive and longitudinal studies that suggest a specific role of magnocellular-dorsal as well as visual spatial attentional systems during the development of early reading abilities (e.g. Boets *et al.*, 2008; Ferretti *et al.*, 2008; Kevan & Pammer, 2008, 2009; Plaza & Cohen, 2006).

At the neurobiological level, the role of visual attentional processes in phonological decoding is emphasized by the additional activation of the corresponding brain regions when participants read long non-words (e.g. Valdois *et al.*, 2006). Accordingly, neuroimaging studies of both typical and atypical reading development have consistently implicated regions that are known to subserve the orienting of visual attention (see Corbetta & Shulman, 2002 for a review of the functional anatomy of attention). For example, several studies employing phonological decoding tasks have shown deficient task-related activation in areas surrounding the bilateral temporo-parietal junction (TPJ) in dyslexics (see Eden & Zeffiro, 1998 for a review). While the left TPJ has been linked to auditory-phonological processing (Pugh *et al.*, 2000, for a review), the right TPJ is a crucial component of the network subserving automatic orienting of attention (Corbetta & Shulman, 2002). Notably, developmental changes in right TPJ activation have been linked to reading acquisition in normally developing children (Turkeltaub, Gareau, Flowers, Zeffiro & Eden, 2003) and some studies have observed a right TPJ deficiency in dyslexics (e.g. Hoeft *et al.*, 2006; Grünling *et al.*, 2004).

One of the most important aims of predictive studies on future reading difficulties is to increase the precision of at-risk children identification, because these children could be treated with preventive remediation programs before learning to read (Gabrieli, 2009). Indeed, recent studies demonstrate that reading abilities can be improved by specific pre-reading programs (e.g. Gormley, Philips, & Gayer, 2008), suggesting that preventive programs could reduce the incidence of DD. Training of visual spatial attention in at-risk children could help to reduce the risk of developing a reading disorder. In this regard, it is worth noting that the reading and the language performance of DD children, as well as children with specific language impairment, has been shown to improve following a specific training for spatial attention (e.g. Facoetti, Lorusso, Paganoni, Umiltà & Mascetti, 2003; Geiger, Lettvin & Fanhle, 1994; Stevens, Fanning, Coch, Sanders, & Neville, 2008).

Overall, our results support the prediction that in children at familial risk for DD, visual attentional impairment—in addition to the typically observed speech-sound segmentation deficit—exists prior to the beginning of formal

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reading instruction. These findings are consistent with a multi-factorial hypothesis of DD (e.g. Menghini, *et al.*, 2010; Pernet & Demonet, Anderssn, Paulesu, Demonet, 2009; see Pennington, 2006 for a review), which suggests that not only auditory-phonological deficits but also magnocellular-dorsal and attentional deficits are implicated in DD. Accordingly, the combination of visual spatial attention and syllabic segmentation scores was more reliable than either single measure for the identification of at-risk children. Thus, our findings may also offer a new approach for early identification of DD.

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