ORIENTING OF VISUO-SPATIAL ATTENTION IN DEVELOPMENTAL DYSLEXIA

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ABSTRACT

Growing research evidence has shown that individuals with developmental dyslexia have deficits of visuo-spatial attention. It has been suggested that deficits in the visual magnocellular system cause problems in reading and visuo-spatial attention. The purpose of the present study was to replicate the work of Facoetti and co-authors (2006), concerning the relationship between visuo-spatial attention and nonword reading in dyslexia. They found that children with nonword reading impairment have a right attentional inhibition deficit, which means larger focus in the right visual field. Therefore in the present study, the issue under investigation was whether Finnish adolescents with dyslexia (n = 14) show asymmetrical orienting of visuo-spatial attention compared to their normally reading peers (n = 18). As in the study of Facoetti and co-authors (2006), dyslexia was defined as a deficit of phonological decoding. The orienting of visuo-spatial attention was measured using a spatial cueing task; participants responded with a button press to spatially cued targets presented to the left or to the right of the fixation point. The results of this study revealed that adolescents with dyslexia did not show asymmetrical orienting of visuo-spatial attention. Furthermore, nonword reading impairment was not associated with right attentional inhibition deficit. It was concluded that based on the results of this study, reading difficulties cannot be explained in terms of deficits in the visuo-spatial attention. Moreover, the results are not compatible with the Magnocellular theory of dyslexia. One possible explanation for the results is that deficits of visuo-spatial attention exist only in childhood. In future research, the continuity of visuo-spatial attention deficits should be taken into a consideration by means of longitudinal studies.

Keywords: Developmental dyslexia, Reading, Orienting of attention, Posterior parietal cortex, Visuo-spatial attention, Minineglect syndrome, Magnocellular deficits.

CONTENTS

1. INTRODUCTION

Reading is a complex neurocognitive process requiring the acquisition of different types of skills and knowledge. However, individuals with developmental dyslexia have failed to acquire skills needed for fluent reading despite normal intelligence and teaching. Developmental dyslexia is a common disorder affecting 3 to 10 % of the school-age children in Finland (Korhonen, 2002) and the estimate is approximately the same worldwide in spite of different languages and orthographies. A number of studies have provided evidence of deficits in phonological processing in dyslexia (Bradley & Bryant, 1983; Lundberg, Olofsson, & Wall, 1980; Wagner & Torgesen, 1987), but in the recent years several studies have shown the relationship between deficits of visuo-spatial attention and developmental dyslexia (Brannan & Williams, 1987; Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Facoetti, Turatto, Lorusso, & Mascetti, 2001; Facoetti et al., 2006; Hari, Renvall, & Tanskanen, 2001). The present study investigates orientation of visuo-spatial attention in reading impaired adolescents and their normally reading peers.

The goal of reading is to understand written language by means of interpreting written symbols. According to the ‘Computational Dual Route Cascaded Model’ (DRC-model) of reading by Coltheart, Rastle, Perry, Langdon and Ziegler (2001), there are two main routes for transposing printed words into sounds. In the lexical route (i.e., orthographic procedure), the letters are visually analysed and the word is recognised from the memory, whereas nonlexical grapheme-to-phoneme conversion route (i.e., phonological procedure) translates graphemes into phonemes via spelling-to-sound correspondence rules. Grapheme is a letter or letter sequence that corresponds to a single phoneme or speech sound and grapheme-phoneme correspondence varies across languages (Frost, Katz, & Bentin, 1987). For instance, reading of unfamiliar words or nonwords (e.g. puoto) requires grapheme-to-phoneme mapping, in other words, a fundamental phonological skill. It is widely accepted that phonological skills are important for reading achievement (see Wagner & Torgesen, 1987, for a review).

Two subtypes of developmental dyslexia can be predicted on the basis of DRC-model of reading: surface dyslexia and phonological dyslexia. It is assumed that surface dyslexia derives from an impairment of the lexical route, whereas phonological dyslexia arises from an impairment of the nonlexical route. In fact, the predominant theory of developmental dyslexia is the theory of phonological skills deficit (e.g. Bradley & Bryant 1983; Vellutino, Fletcher, Snowling, & Scanlon, 2004). The phonological theory postulates that persons with dyslexia have a specific impairment in representing, storing and/or recalling speech sounds. Support for phonological theory comes from research evidence showing that persons with dyslexia perform poorly for instance on tasks requiring phonemic awareness, phonological learning and non-word repetition (Brady & Shankweiler, 1991; Fox & Routh, 1980; Pennington et al., 1990)

In addition to phonological deficits, individuals with dyslexia often show additional non-linguistic difficulties, which cannot be easily explained by a phonological deficit. For instance, Dyslexics tend to transpose letters in words (e.g., god for dog), which seems to derive from deficit in the visual processing (Stein and Walsh, 1997). The magnocellular theory of dyslexia (Stein and Walsh, 1997; Stein et al., 2000) suggest that the visual magnocellular system is impaired causing various visual, tactile, motor and auditory (phonological) deficits. The visual magnocellular system is one of the two subsystems responsible for visual perception (Ungerleider and Mishkin, 1982). Magno- and parvocellular pathways originate in the primary visual cortex in the occipital lobe. Magnocellular neurons are sensitive to changing and moving stimuli, whereas parvocellular neurons respond more slowly to low temporal frequencies. In fact, several behavioural (e.g., Lovegrove et al., 1980), neuroimaging (Demb, Boynton, & Heeger, 1998; Eden et al., 1996) and electrophysiological (Livingstone, Rosen, Drislane, & Galaburda, 1991) studies have provided evidence of magnocellular deficits in dyslexia. However, the magnocellular hypothesis of dyslexia has been challenged frequently (e.g., Hill & Raymond, 2002; Skottun, 2000; Skoyles & Skottun, 2004).

The magnocellular input is crucial for parietal lobe functioning (Merigan & Maunsell, 1993). The posterior parietal cortex is involved in peripheral vision, normal eye movement control, and visuo-spatial attention, which are all important for reading (Geiger & Lettvin, 1987; Morris & Rayner, 1991; Olson, Conners, & Rack, 1991; McConcie et al., 1991; Pavlidis, 1991). While reading, the focus of visual attention is changing rapidly and therefore fluent reading of text requires orienting and shifting of attention. For instance, translating consecutive graphemes to phonemes during reading (particularly unfamiliar word or nonword reading) requires rapid shifts of visual attention in left to right fashion.

Visual attention can be oriented in space to different locations either overtly or covertly (Posner, 1980). An overt shift of attention refers to a process of directing eyes or body towards a stimulus and a covert attention shift occurs while the eyes are stationary. Furthermore, according to Posner (1980) there are two forms of attentional orienting: exogenous (attention is externally guided) and endogenous (attention is guided by the goals of the perceiver). A positron emission tomography (PET) study by Corbetta et al. (1993) indicates that parietal regions are required in endogenous and exogenous shifts of attention.

In support of the magnocellular theory, dyslexia has been associated difficulties with a variety of attention task that depend upon parietal cortex functioning. Brannan and Williams (1987) were the first to show that poor readers had problems with focusing of visuo-spatial attention. From this time, a number of studies have documented that individuals with developmental dyslexia have visuo-spatial attention deficits (e.g., Facoetti et al., 2003; Facoetti et al., 2006; Facoetti & Turatto, 2000; Facoetti, Turatto, Lorusso, & Mascetti, 2001). Visuo-spatial attention seems to be more important for nonword reading than normal word reading (Sierrof & Posner, 1988). Nonword reading requires rapid serial left to right shifts of visual attention, which requires the engagement of the magnocellular visual processing system (Cestnick & Coltheart, 1999). Buchholz and Aimola Davies (2006) found that covert visual orienting was connected to phonological ability in adult dyslexics further suggesting an important role for visuo-spatial attention in reading ability.

Furthermore, growing evidence has demonstrated that visuo-spatial attention is oriented asymmetrically in children and adults with dyslexia (e.g., Eden et al. 1996; Facoetti et al., 2000; Facoetti et al., 2006; Hari & Renvall, 2001; Hari et al., 2001). Facoetti and co-authors (2006) studied the relationship between visuo-spatial attention and nonword reading in two groups of children with developmental dyslexia (mean ages 11.4 and 11.3 years). Covert visuo-spatial attention was investigated with a spatial cueing task, also known as Posner paradigm (Posner, 1980). In the present study, same paradigm is used for measuring the orienting of visuo-spatial attention. A covert attention shift occurs while the eyes are stationary and therefore in the paradigm, visual attention was focused using a central fixation point. The participants’ task was to respond a target in the left or right visual field, with a manual button press, following a cue arrow which was peripherally or centrally located. The cue can be valid (target appearing in the cued location) or invalid (target appearing in the uncued location). Reaction times are typically faster and more accurate in valid trials, compared to invalid trials (Posner, 1980), which is called the cue effect.

Facoetti and co-authors (2006) reported that children with impaired nonword reading have asymmetrical attentional windows; attention is more focused in the right visual field. The result also indicates that children with dyslexia lack of attentional inhibition to uncued targets in the right visual field, in other words they do not show cueing effect in the right visual field. The authors suggested that right attentional inhibition (RAI) deficit found in children with dyslexia could affect grapheme-to-phoneme conversion process, because children with dyslexia do not inhibit stimuli in the right visual field. Therefore visuo-spatial attention seems to be important for phonological reading. In fact, in the study of Facoetti et al. RAI deficit was a good predictor of nonword reading accuracy: RAI explained 26 % of unique variance after controlling for individual differences in intelligence and age.

Also, in the study of Facoetti and co-authors (2001), the control of attentional orienting was studied in children (mean age 12.1 years) with dyslexia. They used Posner paradigm (1980) with peripheral and central cues which validly or invalidly cued the target location. According to their results, children with dyslexia showed in the invalid cue condition significantly slower reaction times when the target was in the left visual field than in the right visual field. In other words, compared to normal readers, children with dyslexia did not show the cue effect in the right visual field, but even greater cue effect was found in the left visual field. The authors suggested that asymmetric control of visuo-spatial attention might be related with deficit in the right parietal cortex.

Spatial attention was also examined in the study of Facoetti and Turatto (2000). In their study, visuo-spatial attention was evaluated using a Flanker task in which participants needed to react to a central target flanked by irrelevant distractor. According to their results, children with dyslexia exhibited reduced flanker effect in the left visual field and a strong flanker effect in the right visual field, which is consistent with RAI deficit. More interestingly, in a rehabilitation study by Facoetti and co-authors (2003), the results revealed that children's ability to read improved by the aid of the VHSS program. The program trains visual attentional focusing and therefore the study provided evidence for causal connection between visuo-spatial attention and developmental dyslexia. Despite this evidence, the issue whether visuo-spatial attention is causally connected to dyslexia is under debate (Ramus, 2003).

Hari and co-authors (2001) found similar left-right asymmetry in Finnish adults (mean age 32 years) with dyslexia. In their study, a temporal order judgement (TOJ) task and a line motion illusion task was used to measure orienting of attention. In the TOJ task participants had to decide the order of the stimuli presented to the left and to the right of the fixation point. In the line motion illusion task participants needed to indicate verbally whether the line moved from left to right or vice versa. In both tasks, adults with dyslexia responded more slowly to the stimuli in the left visual field compared to stimuli in the right visual field. The authors proposed that their results support the hypothesis of a left-sided “minineglect”, in other words smaller focus in the left visual field than in the right visual field.

Hari and co-authors (2001) also suggested that left-sided minineglect might reflect right parietal lobe hypofunction, which is derived from magnocellular system deficit. As mentioned earlier, magnocellular input is important for parietal lobe functioning. More support for the minineglect hypothesis comes from the fact that usually hemispatial neglect syndrome occurs after a posterior parietal lobe damage or lesion. Patients with neglect may fail to attend to stimuli that appear on the opposite side of space of the lesion. Moreover, compared to left hemisphere, lesions to right hemisphere are causing more severe neglect (Bartolomeo & Chokron, 2004; Driver & Vuilleumier, 2001). In addition, hemispatial neglect affects the phonological reading route (Ladavas, Shallice, & Zanella, 1997; Ladavas, Umiltá, & Mapelli, 1997; Sierroff & Posner 1988). Therefore it seems reasonable to assume interaction between reading and attentional processes.

The importance of parietal lobe dysfunction in dyslexia was also documented in the study of Hari and Renvall (2001). They suggested that dyslexic children suffer from sluggish attentional shifting (SAS) due to a right parietal lobe dysfunction. According to their study, the attention cannot be easily disengaged in dyslexics and therefore SAS serves as pathophysiological link between magnocellular deficit and dyslexia.

However, there is some evidence which contradicts the theory of right parietal lobe dysfunction in Dyslexia. For instance, in a study by Hawelka, Huber and Wimmer (2006), a string prosessing task was used to measure visual processing. In the task, stimulus strings (five digits or consonants) were presented briefly on a monitor screen. After stimulus presentation, the string was masked and participants needed to report the digits. Their results showed that German adults with dyslexia exhibited an advantage for the first and final positions of the letter strings, which is inconsistent with left mini-neglect hypothesis.

Moreover, in the recent study by Judge, Caravolas and Knox (2007), British adults with dyslexia (mean age 20.8 years) did not show any visual field asymmetry. In their study, Judge and co-authors used a simple cueing task and a saccadic version of the same task. The paradigm was the same as that of Facoetti and Molteni (2001) used previously. In the cueing task, a target appeared 3°, 6° or 9° to the left or right of the fixation square. Participants were required to respond to the onset of the target with a button press. Their results showed that adults with dyslexia did not respond more slowly to the targets at the left visual field than did controls. The second task of their study was identical to the cueing task, with the exception that participants had to move their eyes to the position where they believed the target had appeared. The results of the saccadic version of the cueing task revealed that the Dyslexic group was as accurate as the control group. Moreover, correlation analyses showed that phoneme awareness was not associated with visual attention in adult dyslexics. Instead, their results supported the phonological theory of dyslexia, because phonological processing skills were correlated with word reading in both groups. The authors suggested that there might be a possibility that distribution of attention is asymmetrical in persons with dyslexia only in childhood.

The main purpose of the present study was to replicate Facoetti's et al. (2006) study described above. The study of Facoetti and co-authors was selected for replication, because the issue of visuo-spatial attention and its connections to phonological processing have received little attention in Finland. Moreover, Facoetti's et al. study was conducted in Italy and Italian language, as well as Finnish language, has orthographically regular writing system. In other words, both languages have strong grapheme-to-phoneme correspondence. Therefore the aim of this study is to see if also Finnish adolescents with dyslexia show asymmetrical orienting of visuo-spatial attention compared to their normally reading peers. A secondary aim was to investigate possible association between visuo-spatial attention and reading performance.

Based on the results from studies presented above (Facoetti et al., 2001; Facoetti et al, 2006; Hari et al., 2001), three primary hypotheses were set. First, it was hypothesized that adolescents with developmental dyslexia show smaller focus in the left visual field than in the right visual field in the spatial cueing task (Hypothesis 1). In other words reaction times for targets in the left visual field should be slower than those in the right visual field. Second, it was hypothesized that reaction times are faster in valid than in invalid trials (Hypothesis 2). The reason for this is that reaction times in the valid cue condition are usually faster than in the invalid cue condition (e.g., Posner, 1980). Third, it was hypothesized that adolescents with dyslexia show a right attentional inhibition deficit (hypothesis 3), which means that the cue effect should be absent when the target appears in the right visual field. Finally, it was hypothesized that orienting of visuo-spatial attention correlates positively to nonword reading accuracy in persons with dyslexia (Hypothesis 4). The reason for choosing nonword reading accuracy instead of nonword reading speed was that Facoetti and co-authors (2006) found that nonword reading accuracy correlated RAI-measure.

2. METHODS

2.1. Participants

A total of 32 adolescents from Jyväskylä's vocational and high schools participated in this study. The sample consisted of 14 adolescents (8 males and 6 females) with developmental dyslexia and 18 normally reading adolescents (7 males and 11 females), ranging in age from 15 to 22 years (group with dyslexia: *M* = 17.38 years, control group: *M* = 17.50 years). Some of the participants were selected from the special education groups on basis of poor reading performance and the rest were recruited via on advertisement placed on the walls of the schools. Data collection started in May 2006 and finished in April 2007.

Testing took place in one session lasting approximately 1.5 hours. All participants were tested individually and they were given a test battery including reading tests, spatial cueing task and also five other computer-based tasks, which are not reported in this study. Moreover, two subtests of Wechsler Adult Intelligence Scale – revised (WAIS-R; Wechsler, 1992) were administered to all of the participants.

The participating persons signed an informed consent form. The parents of the under aged persons had to give signed consent for the participation of their children. All participants were given a movie ticket for their participation.

2.2. Measures

2.2.1. Reading

Reading performance was assessed by three subtests from an individual test battery on reading and spelling skills for adolescents and adults (Nevala, Kairaluoma, Ahonen, Aro, & Holopainen, 2006). The first test was reading words aloud. In this task participants were asked to read aloud a list of 20 Finnish words as quickly and accurately as possible. In the second test, participants had to read aloud a list of 20 nonwords. The third test was text reading, in which participants read aloud a text concerning the topic “How to protect from the cold weather” for three minutes.

The participants’ reading performance was scored for fluency and accuracy in relation to the performance of the normative data (Nevala et al., 2006). Also Z-scores of the reading performance measures were computed for each participant, based on means and standard deviations of the normative data (N=208). Subjects were classified as dyslexic if either their nonword reading accuracy was 1.5 standard deviations below the age-standardized norm or their nonword reading speed was 1.5 standard deviations above the norm, which means longer time taken to nonword reading.

Compared to Facoetti’s et al. study, in which children with (DDN-) or without (DDN+) nonword reading impairment, only one dyslexic group was formed on the basis of reading performance. The reason for this was a small sample size in the present study. In addition, Facoetti and co-authors (2006) found that only children with impaired nonword reading showed a lack of attentional inhibition. Thus in this study, only dyslexics with nonword reading impairment were assigned to the dyslexic group. Therefore dyslexia was defined as a deficit of phonological decoding, the most appropriate test for which is nonword reading (Olson, Rack, & Snowling, 1992).

2.2.2. General intelligence

General intelligence was estimated using two subtests of the WAIS-R (Wechsler, 1992). Verbal intelligence was measured by Vocabulary subtest and Block Design was used to measure performance intelligence. Following Facoetti et al., the selection criterion for both groups was verbal and performance Intelligence Quotient (IQ) greater or equal to 85.

2.2.3. Apparatus and stimuli

Visuo-spatial attention was measured using a spatial cueing paradigm, which is similar to the paradigm used by Facoetti et al. (2006). Stimuli, which appeared black against a white background, were presented on a 15 inch flat-screen monitor using E-prime (version 1.1) software. Response times were collected automatically within the E-prime software. Participants were seated in the front of a monitor and the distance between eye and screen was approximately 40 cm. Compared to Facoetti et al. (2006) study, a headrest was not used, because of practical issues. However, the participants were told not to move their head during the experiment.

Each trial began with appearance of the fixation point at the centre of the screen followed by a warning tone. After 500 ms, two circles displayed peripherally to the left and to the right of the fixation point. 500 ms later a spatial cue (an arrow) appeared either in the centre or in the periphery. The purpose of the cue was to orient attention to the left or to the right. After 300 ms, the target (a dot) appeared inside one of the two circles. On valid trials, the target appeared in the cued location, whereas on invalid trials, the target appeared in the uncued location. The target was shown for 50 ms. The maximum time allowed for responding was 1500 ms from the appearance of the target. The sequence of events in trials is illustrated in Figure 1.

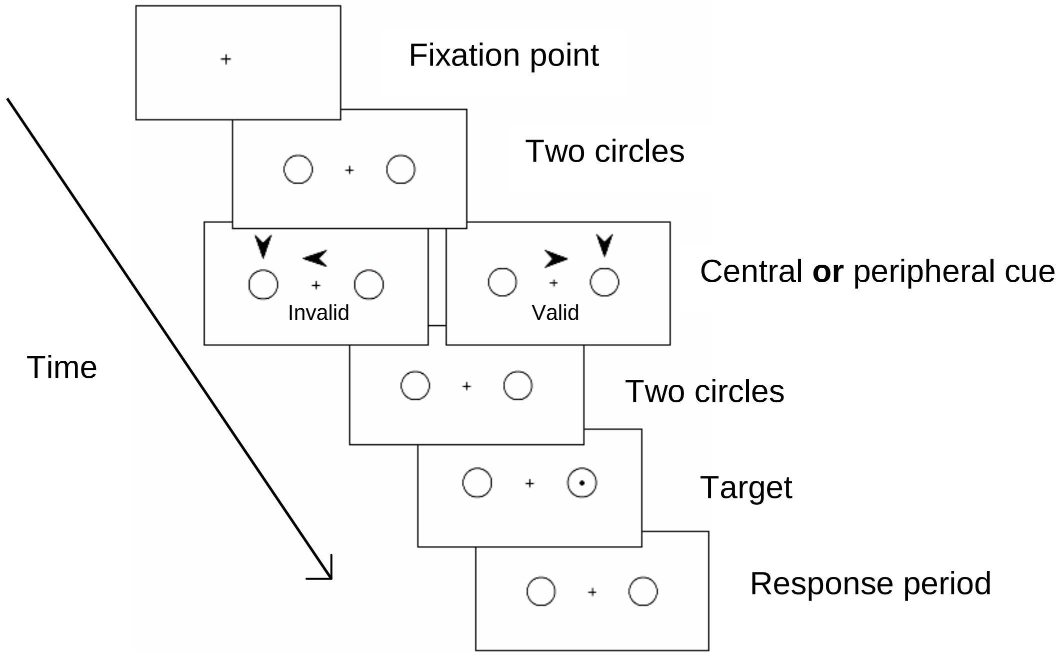

FIGURE 1. Illustration of the spatial cueing paradigm.

2.2.4. Procedure

Participants were instructed to press the spacebar on the computer keyboard when they see the target stimulus. The participants were reminded to keep their eyes on the fixation point. They were also told to respond to the target as quickly as they can.

Participants did not have to press the button in catch trials, when the target was not presented. All participants went also trough a practice task of 12 trials to make sure they understood given instructions.

The experimental session consisted of 208 trials, which were divided into two blocks (104 trials) on the basis of spatial cue location (central or peripheral). The order of central and peripheral blocks was counterbalanced across subjects. Both blocks consisted of 64 valid (target appearing in the cued location) trials, 16 invalid trials (target appearing in the uncued location) and 24 catch trials.

2.3. Statistical analysis

Independent samples t-tests were used to see if groups differed in age, verbal or performance IQ or in reading tests (in z-scores). Response time and accuracy data from the spatial cueing task were analysed using a mixed design Analysis of Variance (ANOVA) in SPSS version 14.0. Mean reaction times (RTs) of the spatial cueing task were analysed with a four-way analysis of variance (ANOVA) in which the between subjects factor was group (controls and dyslexics) and three within-subjects were cue location (central and peripheral), cue condition (valid and invalid) and target location (left and right visual field). Incorrect responses were excluded from the analysis.

Pearson correlations were computed in order to explore connections between RAI (right attentional inhibition), LAI (left attentional inhibition), age, verbal IQ, performance IQ and standard scores in the reading tests. RAI- and LAI-measures were indexed by the difference in reaction times between invalid and valid cue condition for targets either in the left or right visual field. For example RAI-measure was computed by subtracting mean reaction times of right invalid cue condition from right valid cue condition.

3. RESULTS

3.1. Psychometric assessment

Table 1 shows descriptive data of the two groups. Independent samples t-test revealed that the groups did not differ in age, verbal IQ or performance IQ. The groups were defined on the basis of nonword reading performance. Therefore in addition to nonword reading performance, groups differed statistically, in all reading measures, except word reading accuracy.

TABLE 1. Means and standard deviations of age, verbal and performance IQ and reading tests for readers with dyslexia and skilled readers.

	Dyslexics (n = 14)		*Controls (n = 18)*		*Comparison*	
Measure	*M*	*SD*	*M*	*SD*	*t-score*	*p-value*
Age	17.38	1.19	17.50	2.04	0.34	.73
WAIS-R						
Verbal IQ	94.62	4.77	97.78	7.32	1.73	.09
Performance IQ	110.38	14.21	110.28	12.66	0.13	.89
Word reading						
speed	3.10	2.93	-0.561	1.35	-3.95	<.001
accuracy	-0.67	1.99	-0.02	0.80	1.29	.20
Nonword reading						
speed	2.60	2.45	-0.15	1.01	-3.86	<.001
accuracy	-1.36	1.33	0.45	0.55	4.92	<.001
Text reading						
speed	-1.52	1.23	0.12	1.34	3.47	<.002
accuracy	-0.82	1.02	0.48	0.38	4.17	<.009

Note: IQ: Age in years; Intelligence Quotient, WAIS-R; reading test results in Z-scores, positive Z-scores in word and nonword reading speed indicate slower reading speed.

3.2. Spatial cueing task

The rate of false alarms on catch trials (when the target did not appear) was 1.5 %. Subject's response to the target was considered as an outlier if reaction time was faster than 150 ms or more than 2.5 standard deviations above the mean reaction time of total sample. Outliers (2.49 % of the trials) were removed from the data before computing individual means for each cue condition, cue and target location. The means and standard deviations of the spatial cueing task are shown in Table 2.

TABLE 2. Mean reaction times (milliseconds) for targets in the left and right visual field.

Group	*Left visual field*		*Right visual field*	
	M	SD	M	SD
Controls	343.92	41.73	343.81	40.87
Dyslexics	366.90	41.40	358.00	44.18

In order to investigate whether groups differ in orienting of visuo-spatial attention, reaction time data were analysed using a four-way (group × cue condition × cue location × target location) mixed design analysis of variance (ANOVA). This analysis revealed no main effect of group [F (1,30) = 1,56, p = .217], indicating that overall reaction times did not differ between groups in spatial cueing task. Then, it was examined whether reaction times of the spatial cueing task differ across groups according to target location. The Group × Target location interaction was not significant [F (1,34) = 2.00, p = .166], indicating that reaction times did not differ between groups according to left or right target location. Reaction times as a function of a group and target location are depicted in Figure 2.

Moreover, there was no main effect of cue location (central or peripheral) [F (1,30) = 2,78, p =.106] or target location (left or right) [F (1,30) = 3,09, p = .089]. There was a significant target location x cue location interaction [F (1,30) = 5,10, p = .031]. Reaction times were slower in both groups when peripherally cued target appeared in the left than in the right.

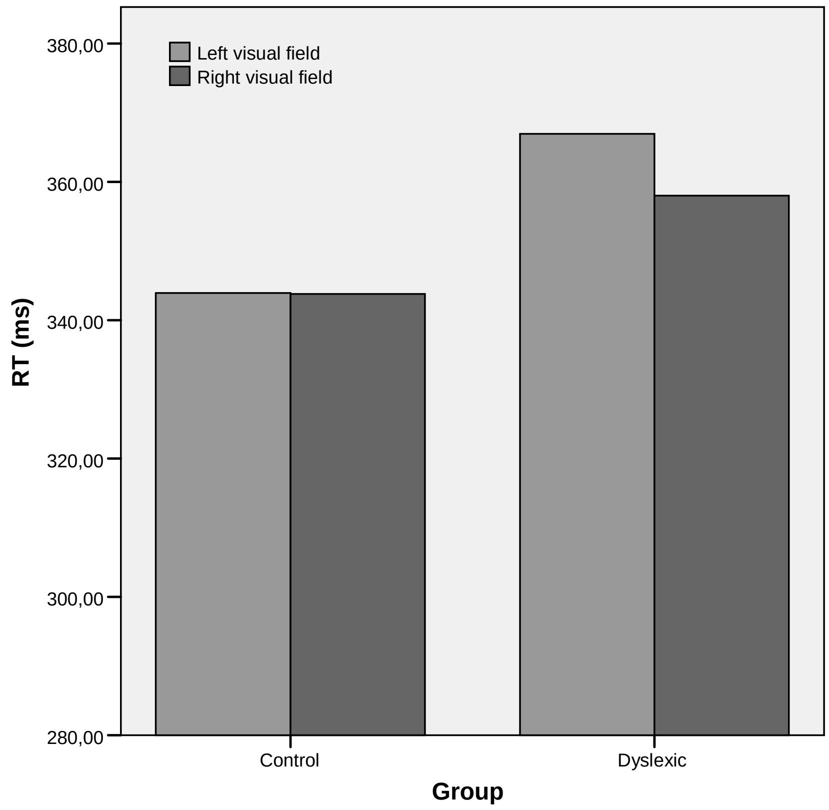

FIGURE 2. Reaction times as a function of group and target location.

Next, the effect of the cue was investigated. There was a significant main effect of cue condition [F (1,30) = 24.97, p <.001]. Subjects in both groups responded faster to validly cued targets (341 ms) than invalidly cued targets (360 ms).

It was also investigated whether the cue effect varies across groups according to target location. The interaction between Cue condition, Target location and Group was not significant [F (1,30) = 1.50, p = .229]. Therefore the cue effect (i.e., faster reaction times in validly cued targets) for target detection was similar in control group (13 ms in left visual field and 20 ms in right visual field) and group with dyslexia (29 ms in left visual field and 23 ms in right visual field). Reaction times as a function of a group, cue condition and target location are shown in figure 3. To gain a deeper insight into results, individual measures of cueing effect were also calculated. The individual data of the spatial cueing task revealed that only in the small minority of dyslexics (3/14), the cue effect for targets in right visual field was absent.

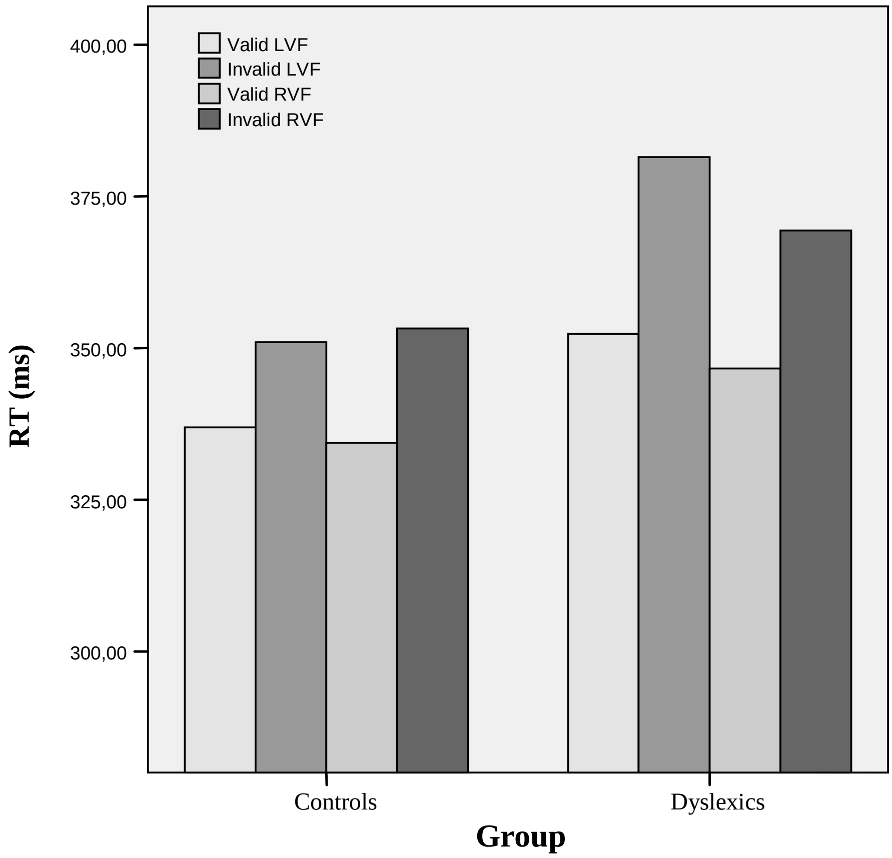

FIGURE 3. Reaction times of the spatial cueing task as a function of a group, cue condition and target location (LVF = left visual field, RVF = right visual field).

The four-way Group × Cue condition × Cue location × Target location interaction was not significant [F (1,30) = 1.79, *p* = .191]. Taken together, the present data revealed no significant interactions with the exception of the target location x cue location interaction.

3.3. Correlations between measures

In order to explore the relationship between measures, bivariate correlations were examined for both groups between RAI (right attentional inhibition), LAI (left attentional inhibition), age, verbal IQ, performance IQ and reading tasks (see Tables 3 & 4). In facoetti's et al. study, word and nonword reading accuracy were the measures of reading, but in the present study, word and nonword reading speed were also included to the analysis.

TABLE 3. Pearson correlations between RAI, LAI, age, verbal and performance IQ, and reading tests in the control group.

Measure	1	2	3	4	5	6	7	8
1. RAI	_							
2. LAI	0.43							
3. Age	-0.39	-0.09						
4. Verbal IQ	-0.36	0.12	0.37					
5. Performance IQ	-0.29	0.05	0.13	0.34				
Word reading								
6. Speed	-0.24	-0.06	-0.49*	-0.25	-0.35			
7. Accuracy	-0.27	-0.28	0.35	0.10	0.40	-0.13		
Nonword reading								
8. Speed	-0.30	-0.07	-0.31	-0.40	-0.31	0.78**	-0.28	
9. Accuracy	0.09	0.02	-0.05	-0.13	-0.11	-0.13	0.24	-0.34

Note: Control group: $n = 18$. RAI = Right attentional inhibition, LAI = left attentional inhibition.
** $p < .01$; * $p < .05$

In the control group, word reading speed was significantly correlated with age ($r = -.49$, $p < .05$), suggesting that faster word reading was associated with higher age. Word reading was also significantly related to nonword reading speed ($r = .78$, $p < .01$).

TABLE 4. Pearson correlations between RAI, LAI, age, verbal and performance IQ, and reading tests in the group with dyslexia.

Measure	1	2	3	4	5	6	7	8
1. RAI	_							
2. LAI	.52	_						
3. Age	.24	.11	-					
4. Verbal IQ	.05	-.20	.27	_				
5. Performance IQ	.42	.06	.08	.45	_			
Word reading								
6. Speed	.30	-.21	.22	.18	.07	_		
7. Accuracy	.07	-.01	-.14	.46	.20	-.39		
Nonword reading								
8. Speed	.54*	-.12	.27	.28	.42	.83**	-.11	_
9. Accuracy	-.20	-.42	.20	.41	.31	.02	.22	-.05

Note: Group with dyslexia: n = 14. RAI = Right attentional inhibition, LAI = left attentional inhibition.
** $p < .01$; * $p < .05$

In the group with dyslexia, word reading speed correlated significantly with nonword reading speed ($r = .83$, $p < .01$). In contrary to expectations, nonword reading accuracy did not correlate positively to RAI-measure. In addition, nonword reading speed was significantly correlated with RAI ($r = .54$, $p < .05$), but not with LAI ($r = -.03$, $p >.92$). However, the relationship between nonword reading speed and RAI was not in the expected direction: the positive correlation is suggesting that faster nonword reading speed was associated with RAI deficit.

4. DISCUSSION

The main goal of this study was to replicate Facoetti's et al. (2006) study of the association between visuo-spatial attention and nonword reading in developmental dyslexia. The present study investigated the orienting of visuo-spatial attention, measured by the covert spatial cueing paradigm, in adolescents with dyslexia and their normally reading peers. Furthermore, the association between reading performance and visuo-spatial attention was examined.

In general, groups did not differ in orienting of attention in the spatial cueing task, in other words, adolescents with dyslexia performed comparably to their normally reading peers. This finding is inconsistent with some of the previous studies (e.g., Facoetti et al., 2001; Facoetti et al., 2006), but supports the results of Judge and co-authors (2007), whose group with dyslexia did not show visual field asymmetry. Contrary to expectations (Hypothesis 1), no significant visual field asymmetry was found in adolescents with dyslexia. Thus Hypothesis 1 was not supported and the null hypothesis was accepted. These results can be taken to suggest that Finnish adolescents with Nonword reading dyslexia do not have impaired orientation of visuo-spatial attention measured by spatial cueing task. The result contradicts the hypothesis of left-sided minineglect put forward first by Hari and Koivikko (1999), who suggest a smaller focus of attention in the left visual field than in the right visual field in dyslexia. Moreover, it contradicts the findings of Facoetti and co-authors (2006) who found that Italian children (mean age 11.4 years) with impaired nonword reading showed an asymmetrical attentional window, which is more extended to the right side.

One interpretation of this discrepant result might be that asymmetrical orienting of attention only occurs in children with developmental dyslexia, but not in adolescents with dyslexia. Judge and co-authors (2007), who studied British adults with dyslexia, also argued that there might not be continuity of visual and/or attention problems from childhood to adulthood. Only longitudinal studies can answer this question about the continuity of visuo-spatial problems.

However, Hari and coauthors (2001) found that Finnish adults with dyslexia showed a left-sided minineglect, which means smaller focus in the left visual field, leaving open the question of why left-sided minineglect was found in Hari and co-authors' adults, but not in the present cohort of teenagers? One possible explanation is that, in the study of Hari and co-authors, temporal order judgement and line motion illusion task were used to measure orienting of attention, but in the present study, the spatial cueing task was used. The existence of left-sided deficits could therefore be task-dependent. In addition, Hari and co-authors emphasized the mildness of the observed left-minineglect: adults with dyslexia processed stimuli in the left visual field only 15 ms slower than normal readers. Therefore it is important to explore the question, how clinically significant are left-sided deficits in dyslexia?

In keeping with previous findings (e.g., Posner, 1980; Facoetti et al., 2006), participants in both groups responded faster to validly cued targets than invalidly cued targets. Thus Hypothesis 2 can be accepted. The reason for this is the cue effect: valid cues facilitate attentional processing and therefore reaction times are faster. In contrast, invalid cues produce slower reaction times, because it takes more time to disengage attention from the cued location (Posner & Raichle, 1997).

The results of the present study do not support Hypothesis 3, and thus the null hypothesis was accepted: adolescents with dyslexia did not show the right attentional inhibition (RAI) deficit. This is inconsistent with the previous findings (Facoetti et al., 2001; Facoetti et al., 2006), which suggest that children with dyslexia do not show a cueing effect in the right visual field. Facoetti and co-authors (2001) suggested that in nonword reading in Dyslexic children, the right hemisphere of the brain does not inhibit the cue presented in the left visual field and therefore the cue effect is absent for targets in the right visual field. Therefore, an inability to suppress distracting stimuli in the right visual field should affect reading performance (Facoetti & Turatto, 2000).

The lack of right attentional inhibition is suggested to derive from the impairment of the right parietal lobe functions caused by magnocellular deficit (Facoetti & Turatto, 2000). As discussed above, magnocellular input is important for parietal lobe functioning (Merigan & Maunsell, 1993). Therefore the results of the present study do not support the theory of right parietal lobe dysfunction in dyslexia. Moreover, the findings of the present study do not provide support for the magnocellular theory of dyslexia (Stein & Walsh, 1997), because the group with dyslexia did not show asymmetrical orientation of visuo-spatial attention, a process which should depend on the magnocellular projections into the parietal lobes.

The reason for discrepancy between results of the present study and Facoetti's and co-authors study is unclear. One reason could be that in the present study, a headrest was not used as it was in Facoetti's et al. (2006) study, so small head movements might have been occurred, thus altering the level of focused attention in participants. In addition, unlike in the present study, in the study of Facoetti and co-authors (2006) eye movements of the participants were recorded and discarded if the movement was larger than 1°. This was not done in the present study due to lack of eye tracking equipment. However, Judge and co-authors (2007), who did not find any visual field asymmetry in adults with dyslexia, proposed that the results were similar whether eye movements were executed or not. In spite of these limitations of the present study, it can be said that the paradigm used in the present study was robust in that it revealed classical cueing effects (i.e. reaction times were slower for invalidly cued targets). However, it is possible that the reduced controls relative to Facoetti's study resulted in the paradigm only revealing the strongest effects, and missing out more subtle differences.

The result of the present study also showed that nonword reading accuracy was not significantly associated with the RAI-measure in the Dyslexic group. This finding was contradictory to Hypothesis 4 and it also contradicts the result of Facoetti and co-authors (2006), who found that relationship between visuo-spatial attention and nonword reading accuracy. Moreover, in the present study, a significant relationship was found between nonword reading speed and RAI, but it was in the unexpected direction: slow nonword reading speed was associated with even stronger cue effect. In other words, reaction times to invalidly cued targets are slower than to validly cued targets.

However, word reading speed was correlated with nonword reading speed in both groups, indicating the relationship between reading speed in both measures. In other reading measures, the directions of correlations were in expected directions, but correlations did not reach the limit of significance, maybe due to a small sample size. In this sense, the results from the correlation analysis do not give support to the view that visuo-spatial attention is causally connected to reading performance (Buchholz & Aimola Davies, 2006; Facoetti et al., 2006).

When considering generalization of the results, it should be kept in mind that present study has at least four limitations. First, the sample size of the present study is quite small and therefore it is to draw straight forward conclusions from the results. Also, it is hard to find significant results using such a subtle test with a small sample size. However, Facoetti and co-authors (2006) used even smaller sample size (10 dyslexic children and 12 normally reading children) than in the present study. Thus, it can be assumed that if asymmetrical orienting of visuo-spatial attention is prevalent deficit in Finnish adolescents with dyslexia, it would have been occurred in the results of the present study.

The second limitation is that it was not clarified if participants had also some other developmental disorders (e.g., attention deficit/hyperactivity disorder, ADHD), which can affect their performance in the spatial cueing task. The third limitation of the study is that a headrest was not used during the spatial cueing task, which might have affected the results by causing small variation to the distance between eyes and monitor. Finally, in the present study, eye-movements were not recorded and therefore if eye movements have occurred, those might have masked possibly existing deficit of visuo-spatial attention.

The findings of the present study produced questions in which future studies are needed to answer. The search to find the underlying cause of dyslexia is ongoing, and in future studies the role of visuo-spatial attention deficit in dyslexia should be investigated more carefully by means of reliable methods. Also the issue whether visuo-spatial attention deficits exist specifically in children with dyslexia, rather than teens or adults, should be taken into a consideration in future research. Therefore continuity of visuo-spatial attention deficits in persons with dyslexia should be explored by the means of longitudinal study.

More importantly, if the deficit in visuo-spatial attention is a specific mark of dyslexia, it would be important to create working rehabilitation method for such deficit. One possible method is the VHSS program, which is designed to improve visual attention focusing. Interestingly, it has been found that children’s ability to read improved by the aid of the VHSS program (Facoetti et al., 2003).

To conclude, the results obtained from the present study indicate that Finnish adolescents with dyslexia did not show asymmetrical orienting of visuo-spatial attention. In this sense, the results differed from the results of Facoetti and co-authors (2006), but the cause of the discrepant results are unclear. In larger scale, the results do not give support for the hypothesis of left-sided minineglect, which is assumed to derive from the deficit in the magnocellular system. Taken together, the findings of the present study propose that deficits of the visuo-spatial attentional do not explain the existence of reading disorders in Finnish adolescents. Obviously an important issue for future research is to gain deeper insight about the role of visuo-spatial attention deficit found in dyslexia using neuroimaging methods.

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