Research report

The role of visuospatial attention in developmental dyslexia: evidence from a rehabilitation study

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Abstract

Shifting of visual attention induced by peripheral cues was studied in 24 children with specific reading disorder (SRD) or dyslexia and was compared with that of 19 normal readers by means of a covert orienting paradigm. This paradigm presents participants with valid, neutral and invalid spatial cues preceding the presentation of a target stimulus. As compared to normal readers, in SRD children the inhibition effect (i.e. the difference between neutral and invalid cues) was absent. The 24 SRD children were divided into two groups matched for age, IQ and reading ability to study the efficacy of two different rehabilitation procedures. We assessed the effects on reading accuracy and speed over a 4-month treatment with visual hemisphere specific stimulation (VHSS; J. Learn Disabil. 25 (1992) 102) vs. traditional speech training. The VHSS program trains participants to perform rapid endogenous attentional orienting by presenting briefly flashed words in the peripheral visual field. We found that children treated with VHSS showed significant changes in their attentional inhibition process, as indicated by increased costs for ‘reorienting’ the attentional focus. As this treatment program also proved to be highly efficient in improving the children’s reading abilities, the possible causal relationship between reading and inhibition mechanisms of visuospatial attention was discussed.

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Keywords: Dyslexia; Spatial attention; Orienting; Inhibition process; Rehabilitation

1. Introduction

Developmental dyslexia is defined as a specific reading disorder despite normal intelligence and teaching, in the absence of any manifest sensory deficit [1].

Learning to read requires appropriate visual and phonological skills. To read an unknown word or non-word, a sequence of visual symbols must be recognized and transformed into a sequence of sounds via the phonological route. For a familiar word to be read correctly via the lexical route, it must be isolated from the others in the text [16]. In either case what is crucial ability is selecting the relevant information while excluding the irrelevant one [40].

Although several studies have provided evidence for a phonological deficit in developmental dyslexia (e.g. [6,44]), dyslexic children also show visual perceptual deficits: they tend to displace letters within a word and invert them, causing words to appear distorted, overlapping and moving. These deficits cannot be attributed to a purely phonological dysfunction. Rather, they signal a defective processing of visual information.

Some authors propose the Magnocellular (M) system as the neural basis underlying such deficit [53]. The information processed by the M system ends in the parietal posterior cortex (PPC), which is an important multi-modal...
selective spatial attention area [20]. The M stream seems to be crucial for the extraction of the spatial relationships of the individual items. The ventral stream neurones that perform the visual discrimination between letters cannot possibly order letters of a word without the spotlighting aid of the dorsal stream. "The M system may thus be necessary for the smooth flow of attentional focus that helps the identification of individual letters or words" ([55] p. 71). Also, the automatisation deficit hypothesis [43] is compatible with the M system deficit, but suggests that abnormal spatial and temporal processing may arise in the output from the cerebellum, rather than in the M system input alone.

The mechanism by which information coming from a particular area of the visual field receives privileged processing is defined as selective spatial attention [12]. Spatial attention has been described as a spotlight [46], a filter channel [40], a specific way of distributing processing resources [21], or a zoom lens [23].

Selective spatial attention is crucial for appropriate serial visual search [10,56,36], for extraction of the spatial relationships of the individual items [33] and for our ability to read effectively [7].

Studies suggest that spatial attention comprises two different processes: orienting and focusing [11]. Orienting shifts the attentional focus in the visual field [46], whereas focusing changes the size of the attentional focus [39].

In dyslexic children there is evidence of both an impaired orienting of attention [7,26,27] and an impaired attentional focusing [48,49,25,26].

Orienting of attention is typically investigated by means of a covert orienting paradigm, in which attention is shifted from one point to another in the visual field without any eye movements. The method consists in presenting a spatial cue followed by the target. The cue either alerts the participant to the correct location of the target (valid cue), the incorrect location of the target (invalid cue), or provides no information as to the location of the target (neutral cue). This results in quicker reaction times (RTs) for valid cues, slower RTs for invalid cues and intermediate RTs for neutral cues [46]. The RT difference between neutral cue and valid cue is called attentional 'benefit', while the RT difference between invalid cue and neutral cue is called attentional 'cost'. Accordingly, orienting of attention is generally defined as the cognitive operation that allows the selection of a particular area inside which information processing is facilitated.

Yet, there is another mechanism regulating selection of relevant information: It is inhibitory and acts through suppression of the information from the unattended area (e.g. Ref. [9]). Indeed, many recent studies have shown that the focus of visual attention is constructed by inhibitory processes [13,42]. It has also been suggested that the act of shifting attention to one side of the visual field facilitates selection of information in that visual field, meanwhile causing inhibition of information in the contralateral visual field [47,24]. Cohen et al. [15] presented a computational model that accounts for normal attentional orienting effects by interaction and competition of different locations in the visual space using both facilitation and inhibition processes.

Attentional orienting is thought to occur either in an exogenous or endogenous way. A peripheral cue, with a short cue-target delay, would elicit an exogenous-automatic shift of attention regardless of its validity. By contrast, an informative and central cue, and a longer cue target delay allow endogenous-voluntary control of orienting [57].

Brannan and Williams [7] demonstrated that, compared to good readers, poor readers were not able to use rapidly the information provided by a peripheral cue (exogenous capture of attention). In fact, at shorter cue-target delays, poor readers showed no attentional facilitation (benefit) and no attentional inhibition (cost). Jonkman et al. [37] investigated shifting of attention in dyslexic and normally reading children using a paradigm with a central spatial cue and a long cue-target delay (endogenous orienting of attention), but they did not detect any difference between the two groups. Finally, Faccoetti et al. (Ref. [26] see also Ref. [27]) showed that the deficit in spatial orienting of attention found in dyslexic children seems to mainly involve the automatic-exogenous capture.

Despite this evidence, however, there is still a great deal of argument about whether dyslexics’ visuospatial attention disorder actually causes a reading deficit. One way to confirm the role of visuospatial attention would be to demonstrate that, by improving a child’s visuospatial attentional process, his/her ability to read improves. Therefore, the aim of the present study was to verify whether visuospatial attention could be causally related to developmental dyslexia by using a rehabilitation approach. In addition, because dyslexics seem to exhibit a deficit mainly in the exogenous capture of attention [7,26], we used an exogenous orienting paradigm.

The present study is subdivided into three stages. In the first stage, a group of children with specific reading disorder (SRD children) and an age-matched group of normal readers were compared on a covert attention orienting paradigm. In the second stage, the SRD children were divided into two training groups, and received either the visual hemisphere specific stimulation (VHSS: Ref. [4]) or the traditional speech training. In the third stage, the reading and visuospatial attention abilities of SRD children were re-tested, and results of the two training groups were compared to see whether the different types of rehabilitation procedures produced different improvement of reading and visuospatial attention.

2. Stage 1: pre-training

The aim of Stage 1 was to compare the covert shifting of visual attention induced by peripheral cues in children with SRD and in normally reading children.
2.1. Method

2.1.1. Participants

Twenty-four children (age 9.84 years) had been diagnosed as dyslexic between the ages of 7 and 9 years, based on standard exclusion criteria. Their performance in oral reading of a text, words and non-words was 2 standard deviations (S.D.s) below the norm on age-standardized Italian tests. SRD participants were 20 males and four females selected on the basis of: (1) the absence of a spoken language impairment (see Ref. [41]); (2) a full scale IQ greater than 85 as measured by the Wechsler Intelligence Scale for Children-Revised [58]; (3) no known gross behavioral or emotional problems; (4) normal or corrected-to-normal vision and hearing; (5) the absence of attention deficit disorder with hyperactivity (ADHD), as evaluated through DSM diagnostic criteria [1]; and (6) right manual preference [8]. Seven children were categorized as Perceptual-type (P) dyslexics, showing accurate but slow and fragmented reading, seven children were categorized as Linguistic-type (L) dyslexics showing fast but inaccurate reading, and 10 children were categorized as Mixed-type (M) dyslexics showing slow and inaccurate reading according to Bakker’s balance model [4]. Nineteen normal readers (age 9.7 years) were also selected, recommended as normal readers by their teachers. They were at or above the norm on age-standardized Italian reading tests. Normally reading children were of at least average intelligence, as measured by WISC-R sub-tests (Comprehension=11.3 standard score and Block Design=11.8 standard score). All participants’ parents gave informed consent.

2.1.2. Apparatus and procedure

Tests were carried out in a dimly lit room (luminance of 1.5 cd/m²). Participants sat in front of a monitor screen (15 in. and with a background luminance of 0.5 cd/m²), with their head positioned on a headrest so that the eye–screen distance was 40 cm. The fixation point consisted of a cross (1° of visual angle) appearing at the center of the screen. Two circles (2.5°) were presented peripherally (8° of eccentricity), one to the left and one to the right of the fixation point. A vertical arrow (1.5°) shown above the circles was used as cue. A dot (0.5°) in the center of one of the two circles was the target stimulus. Stimuli were white and had a luminance of 24 cd/m². Participants were instructed to keep their eyes fixed on the fixation point throughout the duration of the trial. Eye movements were monitored by means of a video-camera system. Any eye movement larger than 1° was detected by the system and the corresponding trial was discarded but not replaced.

Each trial started with the onset of the fixation point accompanied by a 1000 Hz warning signal tone. After 500 ms, the two circles were displayed peripherally, and 500 ms later the cue was shown for 50 ms. Then, after 300 ms, the target appeared for 50 ms inside one of the two circles. On valid trials, the target was presented inside the circle indicated by the cue, whereas on invalid trials the target appeared in the circle on the side opposite to that indicated by the cue. Finally, on neutral trials, both circles were cued (one arrow on each circle) and the target was presented randomly inside only one of the two circles. At the target onset, participants were instructed to react as quickly as possible by pressing the spacebar on the computer keyboard, and RTs were recorded by the computer. The maximum time allowed to respond was 1500 ms. The inter-trial interval was 1000 ms (Fig. 1). Catch trials, in which the target was not presented and participants did not have to respond, were intermingled with normal trials.

The experimental session consisted of 144 trials divided into two blocks of 72 trials each. Trials were distributed as follows: 32 valid trials (16 for each side), 20 neutral trials (10 for each side), eight invalid trials (four for each side), and 12 catch trials.

2.2. Results

Errors, that is responses on catch trials and misses, were less than 2.5% and were not analyzed. Outliers were excluded from the data sets before the analyses were carried out. They were defined as RTs faster than 150 ms or more than 2.5 S.D.s above the mean. In the present experiment, this resulted in the removal of approximately 3% of all observations. Eye movements occurred in about 2.4% of total trials. Mean correct RTs were analyzed with a two-way analysis of variance (ANOVA) in which the between-subjects factor was group (SRD and normally reading children) and the within-subjects factor was cue condition (valid, neutral and invalid). The group main effect was significant, F(1,41)=4.34, P<0.05; RTs were faster in normal readers (414 ms) than in dyslexics (479 ms). The main effect of cue condition was significant, F(2,82)=21.57, P<0.001; RTs were 416 ms in the valid cue condition, 455 ms in the neutral cue condition, and 468 ms in the invalid cue condition. The cue condition x group interaction was significant, F(2,82)=3.25, P<0.05. In normal readers, the RT difference between neutral (411 ms) and valid (381 ms) cue conditions (i.e. the facilitation effect) was 30 ms. Also, the RT difference between invalid (441 ms) and neutral (411 ms) cue conditions (i.e. the inhibition effect) was 30 ms. In dyslexics the facilitation effect was 57 ms, whereas the inhibition effect was −4 ms. Planned comparisons showed that the facilitation effect was significant in both normal readers and SRD children (Ps<0.05), whereas the inhibition effect was present in normal readers (P<0.05) but not in SRD children (P=0.75) (Fig. 2).

2.3. Discussion

Spatial attention consists of two separate mechanisms: (1) a facilitatory process at the attended location, which enhances processing of selected information; and (2) an inhibitory process at the unattended location, which sup-
presses unselected information. Both work as integrated processes of spatial selection [47,40,12]. Selective spatial attention facilitates activity in neural populations receiving input from stimuli at attended locations, while suppressing neural activity in regions representing unattended locations [52].

Because the inability to filter or ignore irrelevant inputs has been emphasized in reading disability [30,38], it is relevant to distinguish the two processes and focus on the mechanism of suppressing non-attended stimuli.

Our results indicated that the peripheral cue was generally able to elicit an exogenous orienting of attention.

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**Fig. 1.** Schematic representation of the display used in the present study (covert orienting of visual attention).

**Fig. 2.** Mean reaction times (RTs) as a function of groups (normal readers and dyslexics) and cue conditions (neutral and invalid).
However, as compared to normal readers, SRD children were generally slower in responding to target onset. More specifically, and more importantly, they showed no trace of an inhibition process, as attested by the fact that there was no significant RT difference between neutral and invalid cue conditions. In contrast, normal readers showed both facilitation and inhibition effects of attention orienting.

The results of the current experiment partially confirm previous data. Brannan and Williams [7] showed that the facilitation and inhibition effects due to a peripheral cue in good readers were not present in poor readers. They suggested that only rapid shifting of visual attention could be impaired (shorter cue-target delays). However, Facocetti et al. [26], by using a peripheral cue with longer cue-target delays (150 and 250 ms), still did not find any facilitation and inhibition effects in dyslexic children. In a subsequent recent research Facocetti et al. [27], by using the same paradigm as the one used in the present study (informative peripheral cue and 350 ms cue-target delay), found a marked asymmetry in control of visuospatial attention: the cue effect (facilitation effect plus inhibition effect) was absent in the right visual field and present in the left visual field (see also Ref. [34]). However, this study can hardly be compared with the present one because of the absence in the former of the neutral cue condition and because in the latter the visual field factor was not considered.

The experimental paradigm used in this study allows one to differentiate the visuospatial performance of SRD children and normally reading children on the basis of the attentional inhibition mechanism, which is present in normal readers but not in SRD children. Therefore, all subsequent analyses and discussions will mainly focus on the inhibition mechanism of visual attention.

It is interesting to note that, Geiger and Lettvin [30] suggested that the visual processing deficit in SRD children may be caused by their difficulty to filter out distracting peripheral information. Specifically, Geiger and Lettvin [30], using lateral masking experiments, provided evidence that the ‘peripheral background de-emphasis’ (inattentiveness as an active process) was dysfunctional in SRDs. Also, Klein and D’Entremont [38], based on LaBerge and Brown’s theory of attention [40], suggested that it could be the inhibitory mechanism that is different and possibly deficient, in poor readers. Gernsbacker [32] too concluded that poor readers suffer from a general deficit in suppression mechanisms. In sum, both our findings and those of Geiger and Lettvin [30] and Klein and D’Entremont [38] suggest that SRDs and poor readers filter visual information differently from normal and good readers.

3. Stage 2: specific rehabilitation training

The aim of Stage 2 was to divide the SRD children into two matched groups to investigate the effects of VHSS training and a speech treatment program on their reading and spatial attentional abilities.

3.1. Method

3.1.1. Participants

The 24 SRD children were divided into two groups matched for reading ability, age and IQ. Each group was randomly assigned to either the VHSS treatment program (12 children, 10 males and two females; four P-type, three L-type and five M-type), or a speech treatment program (12 children, 10 males and two females; three P-type, four L-type and five M-type). Table 1 shows descriptive data of the two groups.

Speed and accuracy of reading were determined using an Italian test of oral text reading [17]. Variables considered were both speed (time per syllable and Z-score) and accuracy (errors on 200 syllables and Z-score). In the VHSS group the mean speed was 88.7 time per syllable in hundredths of second (Z-score −2.71) and the mean errors were 10.6 on 200 syllables (Z-score −1.99). In the traditional speech training group the mean speed was 83.8 time per syllable (Z-score −2.32) and the mean errors were 8.4 on 200 syllables (Z-score −1.92). There were no significant differences between the two groups in terms of either speed or accuracy (all P’s > 0.05).

3.1.2. The inhibition process in the two training groups

An ANOVA on the attentional inhibition mechanism of the two training groups of SRD children was performed to exclude possible pre-training differences in the inhibition process.

Mean correct RTs were analyzed with a two-way ANOVA in which the between-subjects factor was training-group (VHSS and speech training) and the within-subjects factor was cue condition (neutral and invalid). The training-group main effect was not significant (F < 1); RTs were 494 ms in the speech training group and 500 ms in the VHSS training group. The main effect of cue condition was not significant (F < 1); RTs were 498 ms in the neutral cue condition and 495 ms in the invalid cue condition. Also, the cue condition × training-group interaction was not significant (F < 1), indicating that RTs did not vary be-

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<th>Table 1</th>
<th>Means of age, full IQ and with reading abilities of the two SRD groups in the pre-training stage and attentional inhibition after abilities</th>
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<td>VHSS training</td>
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<tr>
<td>Age</td>
<td>9.85</td>
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<tr>
<td>Full IQ</td>
<td>104</td>
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<tr>
<td>Reading accuracy (errors on 200 syllables)</td>
<td>10.6</td>
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<tr>
<td>Reading speed (time per syllable)</td>
<td>88.71</td>
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<tr>
<td>Attentional inhibition (ms)</td>
<td>0</td>
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tween groups according to the cue condition. The inhibition effect was \(-6\) ms in the speech training group and 0 ms in the VHSS training group. Planned comparisons showed that the inhibition effect was not present in either training group \((P_s > 0.8)\).

### 3.1.3. Apparatus and procedure
Each participant was trained by a specific treatment program for 4 months. Training sessions took place twice a week (32 sessions). Each training session took approximately 45 min.

#### 3.1.3.1. VHSS treatment program
Bakker’s VHSS rests on the assumption that dyslexia depends on an imbalance in the contributions of the two cerebral hemispheres to the process of reading. In the very early stages of learning-to-read, there would be heavy reliance on right-hemisphere processing, devoted to the perceptual features of the words. After the first 12–18 months of schooling, perceptual recognition of letters should become automatic, and the reading process should involve progressively more functions of the linguistic type, mediated by the left hemisphere. Reading at this stage is quicker and relies not only on perceptual analysis but also on anticipations and integrations made on the basis of linguistic knowledge (lexical, syntactic, semantic). According to Bakker’s classification of dyslexia, therefore, children who keep relying too much on right-hemisphere strategies are called ‘P-types’, where P stands for ‘perceptual’. Their reading style is slow and characterized by fragmentation and repetitions, the so-called ‘time-consuming errors’. Dyslexic children who rely predominantly on left-hemisphere processes, although their perceptual analysis is not efficient enough to correctly integrate them, are called ‘L-types’, where L stands for ‘linguistic’. Their reading style is relatively quick and their errors are of the ‘substantive’ type, i.e. substitutions, inversions, omissions, often generating plausible words and generally not correcting the mistakes. Children who are both slow and incorrect are considered as mixed, or ‘M-types’. Intervention in the VHSS approach aims at specifically stimulating the hemisphere which is considered to be insufficiently activated during reading (or both hemispheres subsequently in the case of M-types), by flashing words in the controlateral visual and using different kinds of stimuli (perceptually demanding vs. linguistically complex), according to the type of dyslexia. Other types of intervention in the same program involve different modalities (i.e. tactile HSS) or manipulation of the task according to right- or left-hemisphere strategies (HAS, i.e. hemisphere alluding stimulation).

Children belonging to this group underwent HSS in the left or right visual field. Before each trial began, criteria for time word presentation were set, which varied between 250 and 100 ms. Ocular fixation was monitored asking the child to follow a dot oscillating on the screen from top to bottom and vice versa; the word was laterally presented when the child pressed a button on the mouse indicating that the dot was inside the central target. Strings of letters (words) became increasingly difficult in terms of length and frequency of use.

Subtypes of dyslexic children received specific VHSS, in line with Bakker’s guidelines [4]: left hemisphere stimulation by tachistoscopic presentation of words in the right visual field for P-dyslexics and right hemisphere stimulation for L-dyslexics by tachistoscopic presentation of words in the left visual field. Children with M-dyslexia received stimulation to the right hemisphere first (2 months) and the left hemisphere later (another 2 months).

#### 3.1.3.2. Speech treatment program
The term ‘traditional speech therapy’ refers to a treatment based on the various intervention programs for remediation of dyslexia that do not make use of visual tachistoscopic presentation of verbal stimuli. Tasks vary according to the participant’s age and functional profile. They may focus mainly on some reading sub-processes (phonological processing or awareness, perceptual pre-requisites, etc.), re-education using guided reading tasks or they may be aimed at strengthening compensatory strategies.

### 4. Stage 3: post training tests
The aim of Stage 3 was to re-test the two groups of SRD children after completion of training to establish: (1) whether VHSS training led to a greater improvement in reading ability than the speech treatment program did; and (2) whether there was an improvement in the inhibition process of covert visuospatial attention limited to the group showing selective enhancement of reading skills.

#### 4.1. Method

##### 4.1.1. Participants
All SRD children who had completed the two training programs \((n=24)\).

##### 4.1.2. Apparatus and procedures

##### 4.1.2.1. Reading test
The oral reading test was the same as in Stage 2.

##### 4.1.2.2. Covert orienting of visual attention
Experimental conditions, stimuli, total number of trials, and number of each type of trial were the same as in Stage 1.

#### 4.2. Results

##### 4.2.1. Effects of treatment programs on reading ability
Mean reading speed was analyzed with \(t\)-test for depen-
dent groups between stage 2 (pre-training) and stage 3 (post-training).

In the VHSS training group the mean speed was 88.7 pre-training and 59.2 post-training, $P<0.02$ (Z score: pre-training $-2.71$ and post-training $-1.53$, $P<0.05$). In the speech training group the mean speed was 83.8 pre-training and 75 post-training, $P>0.05$ (Z-score: pre-training $-2.32$ and post-training $-1.74$, $P>0.05$) (Fig. 3).

Mean accuracy was analyzed with $t$-test for dependent groups pre- and post-training.

In the VHSS training group the mean errors were 10.6 pre-training and 4.3 post-training, $P<0.001$ (Z-score: pre-training $-1.99$ and post-training $-0.69$, $P<0.01$). In the speech training group the mean errors were 8.4 pre-training and 11.8 post-training, $P>0.05$ (Z-score: pre-training $-1.92$ and post-training $-2.2$, $P>0.05$) (Fig. 4).

4.2.2. Effects of the treatment programs on the inhibition process of covert visuospatial attention

Mean correct RTs were analyzed with a two-way ANOVA in which the between-subjects factor was training group (VHSS and speech training) and the within-subjects factor was cue condition (neutral and invalid).

The training-group main effect was not significant ($F<1$); RTs were 467 ms in the speech training group and 491 ms in the VHSS training group. The main effect of cue condition was significant, $F(1,22)=10.02$, $P<0.005$; RTs were 460 ms in the neutral cue condition and 498 ms in the invalid cue condition. Also, the cue condition×training group interaction was significant, $F(1,22)=6.25$, $P<0.05$, indicating that RTs varied between groups according to the cue condition. The inhibition effect was 8 ms ($P>0.05$) in speech training group and 68 ms ($P<0.001$) in the VHSS.
training group. Planned comparisons showed that in the neutral cue condition the difference between the two training groups was not significant (6 ms, $P>0.05$), whereas it was significant in the invalid cue condition (54 ms, $P<0.01$) (Fig. 5).

There are no evident differences among Bakker’s subtypes of dyslexia. Due to the little number of subjects in each subgroup, this variable was not entered as a factor into the analyses.

Mean correct RTs of the VHSS group were analyzed with another two-way ANOVA in which the within-subjects factors were cue condition (neutral and invalid) and stage (pre- and post-training). The stage main effect was not significant ($F<1$); RTs were 500 ms in the pre-training stage and 492 ms in the post-training stage. The main effect of cue condition was significant, $F(1,11)=10.32$, $P<0.01$; RTs were 478 ms in the neutral cue condition and 512 ms in the invalid cue condition. The cue condition×training stage interaction was significant too, $F(1,11)=8.77$, $P<0.02$, indicating that RTs varied between stages depending on the cue condition. The inhibition effect was 0 ms in the pre-training stage, and 68 ms ($P<0.05$) in the post-training stage. Planned comparisons showed that in the neutral cue condition the difference between the two training stages was significant (43 ms, $P<0.05$), whereas in the invalid cue condition it was not ($-25$ ms, $P>0.05$).

Mean correct RTs of the speech training group were analyzed with another two-way ANOVA in which the within-subjects factors were cue condition (neutral and invalid) and stage (pre- and post-training). The stage main effect was not significant, $F(1,11)=2.16$, $P=0.17$; RTs were 494 ms in the pre-training stage and 467 ms in the post-training stage. The main effect of cue condition was not significant ($F<1$); RTs were 480 ms in the neutral cue condition and 481 ms in the invalid cue condition. The cue condition×training stage interaction was not significant either ($F<1$), indicating that RTs did not vary between stages depending on the cue condition.

4.3. Discussion

Clearly VHSS training led to a significant improvement in reading speed and accuracy. That supports the effectiveness of the VHSS treatment for improving reading skills in SRD children, as was found in some studies investigating the results of the application of HSS or HAS trainings in either clinical or school settings [5,50]. If compared with traditional speech training, the VHSS program proved to be more effective, at least over the short time interval (4 months) considered in this study (Table 2).

However, in the study by Dryer et al. [22], participants were given either a treatment program that was specifically designed for their particular dyslexia subtype or a program that had been deliberately chosen to be inconsistent with their subtype. Contrary to predictions, participants made gains on all the reading measures, regardless of the type of treatment. Thus, it was suggested that treatment gains are due to nonspecific training effects and not to the specific nature of Bakker’s remedial strategies.

We suggest that practicing to apply the inhibition mechanism in rapid endogenous attentional orienting is one of these nonspecific training effects. In fact, in the pre-training stage the inhibition effect was absent in both SRD groups, whereas in the post-training stage the inhibition effect was present only in the VHSS group. This result suggests that the VHSS treatment trained SRD children’s inhibition mechanism of attentional orienting.

As this treatment program also proved to be highly efficient in improving reading speed and accuracy in SRD children, we assume that there is a possible causal link.
Table 2
Means of reading accuracy (errors on 200 syllables), reading speed (time for syllable) and attention inhibition (invalid–neutral RTs difference) of the two SRD groups (VHSS and speech training) pre- and post-training stages

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<td>Attentional inhibition (ms)</td>
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<td>Invalid–Neutral</td>
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between reading and the inhibition mechanism of visuospatial attention (see also Ref. [30]).

5. Conclusion

Normal readers and SRD children in our study (stage 1) differed in their ability to control the visual spatial region of unattended information or to inhibit information in unattended location outside the attentional focus [30,38,45,25]. In fact, normal readers showed the typical RTs pattern in covert orienting of attention: a facilitation effect at the attended location caused by the enhancement mechanism and an inhibitory effect at the unattended location caused by a suppression mechanism, both working as integrated processes of selective spatial attention [40,12,24]. In contrast, selective spatial attention in SRD children seems to work as a unique enhancement mechanism without the integrated suppression mechanism.

In LaBerge and Brown’s [40] attentional model, the information flow from a selected position increases relative to other locations but, in addition to this enhancement mechanism, there is a filtering mechanism that opens channels so as to allow visual information to pass through. Based on this model (see also Refs. [47,15,24]) our results suggest that the inhibitory mechanism may be specifically dysfunctional in SRD children.

However, the results of stage 1 do not show any causal connection between this attentional inhibition deficit and SRD children’s reading disability. Also, the alternative direction of causal connection, from poor reading to an attentional inhibition deficit, must be considered. Perhaps, the most convincing strategy for choosing between these two alternative directions would be to conduct a rehabilitation study in which the attentional mechanism of SRD children were trained, and their reading and attentional performances were assessed pre- and post-treatment. An alternative approach would be to conduct a longitudinal study in which the attentional skills of pre-reading children were evaluated, and their learning-to-read skill subsequently measured. However, a longitudinal approach does not attribute any specificity to the decoding process, thus assuming that possible attention disorders should be present before children engage in the learning-to-read process. Decoding of a written text requires precise and specific abilities to select and filter visual information, which, in contrast, is not necessary for other cognitive processes.

Results of stage 3 indicate that only the VHSS group showed an post-treatment improvement of both reading and the inhibition mechanism. It is therefore to be concluded that the inhibition mechanism of selective spatial attention could be one of the factors responsible for the improved reading skills of SRD children. Our results thus support the hypothesis of a direct causal relation between attention focusing disorders and developmental dyslexia, and confirm studies by Geiger and Lettvin [30], Klein and D’Entremont [38] and Pepper and Lovegrove [45].

Finally, the present study may allow one to gain interesting insight on the relationship between phonological and visual attentional deficits. Indeed, deficits in children with learning problems often affect also the phonological–auditory system (speech–sound perception), causing difficulties in discriminating phonemes in a complex auditory environment [18]. While this could be due to abnormal magnocells in the medial geniculate nucleus (Ref. [29] see also Ref. [14]), it is also possible that the auditory deficit follows from a visual M disorder. In fact, the VHSS training also increases phonological coding or awareness. Specifically, the VHSS group’s accuracy (number of hits on 20 items) increased both in the elision phonemic test (from 16 to 18.6 errors, \( P<0.05 \)) and in the fusion phonemic test (from 10.5 to 15.8 hits, \( P<0.05 \)) (see also Ref. [31]).

There is evidence that a supra-modal space representation exists in the posterior parietal cortex with convergence of both visual and auditory inputs [28], and there is also evidence of multi-modal cells in the PPC [2]. These findings suggest that the PPC may be involved in attentional selection independent of modality [19]. The ‘multi-modal map’ of spatial locations may be created from synchronized inputs from different modalities and this map would be used for orienting attention in both the visual and auditory worlds. In fact, recent behavioral and brain imaging studies suggest that cross-modal interactions are the rule and not the exception in perception, and that the neural pathways previously thought to be sensory-specific
are modulated by signals from other modalities [51]. Lack of a normal spatial map in the PPC would cause the attentional filtering functions to be disturbed, thus causing both visual and phonological perceptual deficits in SRD children [55]. Direct and recent evidence in SRD for this filtering deficit in the auditory modality was provided by Taub et al. [54] and Asbjørnsen and Bryden [3].

In line with this framework, Hari et al. [34] proposed that the causal link from the M deficit to reading and phonological deficits involved the control of automatic attention. They suggest that the primary cause of various sensory problems, many of which related to impaired processing of stimuli that are presented in rapid succession, could be the sluggish exogenous attentional capture [34]. Accordingly, Hari et al. [35] showed that the dwell time of visual attention is 30% longer in dyslexic adults than in normal-reading subjects.

It should be noted that the results presented in this paper apply to dyslexia in a particularly transparent orthography such as Italian has. Although it seems reasonable to suppose that the neuropsychological basis of dyslexia should be relatively similar for children speaking different languages, it still has to be taken into account that the processes needed for reading Italian words and texts need not be exactly the same needed for reading texts in English or other less transparent languages.

Since in principle Italian could be read by using exclusively grapheme-to-phoneme conversion, while whole-word recognition seems to be less crucial, it might well be that sequential analysis plays a more fundamental role in reading Italian, and is therefore more severely disrupted by attentional deficits [14].

This could also mean that treatment of dyslexia for Italian subjects should be better focused on training components of attention, besides other reading-related skills.

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References


