Tachistoscopic treatment of dyslexia changes the distribution of visual–spatial attention

Maria Luisa Lorussoa,*, Andrea Facoettia,b, Alessio Toraldo,c, Massimo Moltenia

a Unità di Psicologia e Neuropsicologia Cognitiva, IRCCS “E. Medea,” Bosisio Parini, Lecco, Italy
b Dipartimento di Psicologia Generale, Università di Padova, Italy
c International School for Advanced Studies (SISSA), Trieste, Italy

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Abstract

Twelve children with developmental dyslexia underwent a four-month treatment with tachistoscopic presentation of words, according to Bakker’s methodology. One group received standard lateral presentation of words on a PC screen, while the other group received the same stimuli in random lateral position. The spatial distribution of visual attention was measured by means of the Form-Resolving Field (FRF; Geiger, Lettvin, & Zegarra-Moran, 1992), which was administered along with reading tests, before and after treatment. The FRF of children who received random presentation widened at $\pm 12.5^\circ$ on the left side, while the FRF in the group that received standard lateral presentation narrowed at that position. Both groups significantly improved in reading accuracy for both words and nonwords. Some hypotheses are proposed concerning the mechanisms responsible for the changes in the FRF and their correlation with improvements in word and nonword reading. The results of the present study are also compared with data suggesting a left “minineglect” in dyslexia.

Keywords: Dyslexia; Treatment; Peripheral vision; Visual attention

1. Introduction

In the last few decades, renewed attention has been paid to the visual aspects of developmental dyslexia (e.g., Stein & Walsh, 1997). Among the theories that have been proposed, some point to visual–spatial attention as a core requirement for the development of reading ability. For instance, LaBerge and Brown (1989) highlighted the importance of sustained and focused attention, while Sieroff and Posner (1988) emphasized the role of attentional orienting [for a recent review, see Auclair and Sieroff (2002)]. These views have been further confirmed and expanded by more recent studies (Facoetti, Paganoni, & Lorusso, 2000; Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Vidyasagar, 1999). Cestnick and Coltheart (1999) suggested that serial left-to-right allocation of covert attention is necessary to read letter strings such as nonwords, a process involving both magnocellular and parvocellular pathways.

Some authors have further shown that attentional processes differ in dyslexic readers between the two visual hemifields, thus suggesting an asymmetric distribution of attentional resources across the visual field (Facoetti & Molteni, 2001; Facoetti & Turatto, 2000; Facoetti, Turatto, Lorusso, & Mascetti, 2001). Hari and Renvall (2001) as well as Hari, Renvall, and Tanskanen (2001) proposed that a combination of mild left inattention (also called “left minineglect”) and sluggish attentional capture on both sides could explain dyslexics’ difficulties in reading and also in rapid temporal processing.
A related, although not equivalent, interpretation is that proposed by Geiger and collaborators, who suggested that a different distribution of lateral masking in the visual field is the core characteristic of developmental dyslexia (Geiger & Lettvin, 1987). More specifically, it was suggested that lateral masking is reduced in the right visual field, i.e., in the direction of reading (for Hebrew reading subjects, the opposite finding of reduced lateral masking in the left visual field was documented by Geiger, Lettvin, & Zegarra-Moran, 1992). Lateral masking is the process by which a visual stimulus becomes less recognizable when flanked by other visual elements. If lateral masking in the periphery is not effective, visual information from the entire surroundings is simultaneously perceived, which may result in confusion (Geiger & Lettvin, 1987; Geiger et al., 1992). The same phenomenon could be interpreted in terms of a difficulty to focus attentional resources in the center of gaze, i.e., by assuming a diffuse attentional state (e.g., Facoetti, Paganoni, & Lorusso, 2000). The spatial distribution of lateral masking (or visual–spatial attention) was measured by Geiger and colleagues in a task where pairs of horizontally aligned letters—one in the center and another in the periphery—were briefly presented. By plotting the recognition rate of each peripheral letter against its eccentricity a distribution is obtained that Geiger and collaborators named FRF (Form Resolving Field) (Geiger et al., 1992).

Among the intervention programs proposed for the treatment of developmental dyslexia, some address the abilities that are considered to be the prerequisites for learning to read, particularly phonologic awareness (e.g., Hatcher, Hulme, & Ellis, 1994; Wise, Ring, Sessions, & Olson, 1997). Other programs address the reading process as a whole, aiming at a better automatization, through paced/speeded presentation of lexical or sublexical items (Judica, De Luca, Spinelli, & Zoccollotti, 2002; Tressoldi, Lonciari, & Vio, 2000). In spite of this reading-specific focus in rehabilitation, also programs belonging to the latter set have been shown to affect not only reading per se, but its component processes and functions as well. In particular, the computerized tachistoscopic presentation of words according to Bakker’s program of Visual Hemisphere-Specific Stimulation (VHSS) has been found to produce significant effects not only on reading speed and accuracy, but also on visual–spatial attention (Facoetti, Lorusso, Paganoni, Umiltà, & Mascetti, 2003), verbal memory and phonemic awareness (Lorusso, Facoetti, Paganoni, Pezzani, & Molteni, in press). Similar effects are observed when manipulating the position, duration, and predictability of word presentation: comparable improvements in reading were obtained with tachistoscopic central, random-lateral, and nontachistoscopic central presentation, suggesting that nonhemispheric, aspecific factors play a relevant role in treatment (Lorusso, Facoetti, & Molteni, 2004a).

It therefore seems that visual–spatial attentional functions are involved in producing changes in reading abilities. Since the spatial distribution of attention is likely to be reflected in the FRF, it can be assumed that changes in spatial attention parallel changes in the shape of the FRF. The aim of the present study is to further investigate—by means of the FRF—the relationship between reading and visual attention in the treatment of dyslexia.

The experimental predictions can be stated as follows:

(a) treatment-related changes in visual–spatial attention, which have already been found in dyslexia by classical attentional paradigms, will also be detected in the FRF;
(b) the direction or degree of the changes in the FRF will differ according to the characteristics of stimulus presentation during treatment (standard-lateral, random-lateral), involving different spatial-attentional demands;
(c) changes in the FRF will be correlated with improvement in reading words and nonwords.

2. Methods

2.1. Participants

Twelve native Italian dyslexic children, aged between 8 and 14 years, participated in the study. They had been referred to the Cognitive Psychology and Neuropsychology Unit of Scientific Institute “E. Medea,” or to corresponding units of collaborating centers, because of learning difficulties. Assessment and diagnosis were performed at Institute “E. Medea.”

The diagnosis of developmental dyslexia was made according to ICD-10 criteria (WHO, 1992): Full-scale IQ (as assessed by the Wechsler Intelligence Scale for Children-Revised, Italian version, 1986) equal to, or higher than, 85; at least 1 SD below age mean for either accuracy or speed scores in reading a text aloud (MT test for speed and accuracy in reading, Cornoldi, Colpo, & Gruppo MT, 1986); at least one score below 2 SDs on reading and spelling tests (battery for the assessment of Developmental Reading and Spelling Disorders, Sartori, Job, & Tressoldi, 1995).

Moreover, they had neither reports of neurological or psychiatric problems, nor major emotional and social problems. Their language comprehension, assessed through the abridged version of the Token Test (Di Simoni, 1978), was not lower than $z = -2$ with respect to age norms.

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1 Abbreviation used: FRF, Form Resolving Field.

2 In Italian, due to its highly transparent orthography, almost all words can be read via the indirect route, similar to nonwords.
All the children were further classified as P- (perceptual), L- (linguistic), or M- (mixed) type dyslexic on the grounds of their reading speed and type of errors on the text-reading test: slow reading with “time-consuming” errors (fragmentations, repetitions, etc.) for P-types, rapid reading with “substantive” errors (substitutions, omissions etc.) for L-types, slow and inaccurate reading (both kinds of errors) for M-types (see Bakker, 1990, and Lorusso et al., 2004a). Accordingly, 10 children were classified as M-types and two as P-types. No L-types were present in the sample.

To ensure that the participant children, in spite of the small sample size, were representative of the population of children with dyslexia (i.e., that their FRF differed from that of normal readers in the way usually described in the literature), FRF data were also collected from a sample of 23 normally reading children. This group of children was similar to the group of dyslexic children for chronological age and their performance on the text-reading test was in the normal range.

Both dyslexic and normally reading children had normal or trivially corrected-to-normal vision.

2.2. Treatment

All treatment programs were carried out in individual sessions taking place twice a week and lasting 45 min each, over a four months’ period. Treatment took place at the outpatient clinic of Institute “E. Medea” and was carried out by trained speech therapists. The children’s parents and teachers were contacted to ensure that no other specific activity for remediation of the reading difficulty was conducted during the study.

The treatment was a variation of Bakker’s methodology (1990). Bakker based his treatment program on the observation of a different hemispheric involvement in P-, L-, and M-type dyslexia, and developed the idea that selective stimulation of the underactivated hemisphere may induce a functional re-organization of the brain that could lead to a reduction of the reading disorders. Hemispheric stimulation can be carried out directly, by tachistoscopic presentation of words to a visual hemifield or tactile presentation to the left or right hand, and/or indirectly, using specific stimuli and tasks in paper-and-pencil exercises so as to selectively stimulate right-hemisphere perceptual analysis or left-hemisphere linguistic anticipation. The first procedure (direct stimulation) is referred to as hemisphere-specific stimulation (HSS), while the second type of intervention (indirect stimulation) is called hemisphere-alluding stimulation (HAS). Only visual direct stimulation (VHSS) was used in this experiment.

A computerized program (“Flash Word,” Masutto & Fabbro, 1995) was used. In this application, ocular fixation is monitored by asking the child to follow a luminous dot oscillating between the top and the bottom of the screen, at an adjustable speed. The word is flashed only if the child clicks on the mouse at the exact moment that the dot is crossing the central target. Before the beginning of each block of trials, criteria for word presentation were set (font type and presentation times, which varied between 250 and 100 ms). The longest presentation times were used in the first sessions (the initial presentation time was set so as to allow the child to read 60% of the word list correctly) and later, when more complex stimuli were presented for the first time. As the child’s reading performance improved, presentation times were shortened in the following sessions to keep the tasks always challenging. Children belonging to the different subtypes of dyslexia received visual stimulation, in line with suggestions made by Bakker and colleagues (Bakker, 1990; Bakker, Licht, & Kappers, 1995): for P-dyslexics, left-hemisphere stimulation by tachistoscopic presentation of perceptually linear, high-frequency (easy to anticipate) words/short sentences; for L-dyslexics, tachistoscopic presentation of perceptually complex, low-frequency (difficult to anticipate) words/short sentences. Children with M-dyslexia received presentation of L-type materials first (two months), and presentation of P-type materials later (following two months). According to the HSS methodology, L-type materials are flashed in the left visual field, while P-type materials are flashed in the right visual field.

The children’s task was to read the words flashed on the PC monitor; if the child’s response was not correct, the therapist could give feedback on the kind of error, direct the child’s attention to a specific part or feature of the word and repeat the presentation of the word, or go on to the next word. Presentation of the next word was manually paced by the therapist.

The position of the words presented on the computer screen varied across the two experimental groups: group “SL” (six children) received Standard Lateral presentation, according to Bakker’s model (HSS); the words were therefore flashed to either the right or the left of the fixation point, according to the type of dyslexia (and hence the hemisphere to be stimulated); right side for L-types, left side for P-types, and two months of left-side presentation followed by two months of right-side presentation for M-types. Group “R” (six children) received Randomized lateral presentation: the stimuli were randomly flashed to either the left or the right of the fixation point, according to a computer-generated unpredictable sequence.

To avoid introducing confounding variables such as differences in age in the two groups (considering the relatively small sample size), the assignment of children to the different treatment groups was not strictly random, but it was ensured that age was homogeneously distributed across groups (group SL, mean age = 10.7, SD = 2.2; group R, mean age = 10.8, SD = 2.7). As a consequence of this age-matching procedure, only M-types...
were present in the R group, while the SL group included four M-types and two P-types.

The children of both groups were treated by the same speech therapists, who had been specifically trained.

2.3. Testing procedures

All children were tested immediately before and after treatment. Assessment involved reading tests and FRF measurement.

The reading tests administered in the pre- and in the post-test sessions included single word and nonword reading, from the “Batteria per la Valutazione della Dislessia e Disortografia Evolutiva” (Battery for the assessment of Developmental Reading and Spelling Disorders, Sartori et al., 1995). These tests assess speed and accuracy (expressed in number of errors) in reading printed word lists (four lists of 24 words) and nonword lists (three lists of 16 nonwords), and provide grade norms from the second to the last grade of junior high school. They are commonly used in the assessment of reading disabilities in Italy and have satisfactory validity and reliability scores.

The results of these tests are expressed as z scores according to grade norms.

2.4. Procedure for FRF measurement

The procedure and equipment were the same as in Geiger et al. (1992) and Lorusso, Facoetti, Cattaneo, Molteni, and Geiger (2004b). The equipment included three slide projectors, back-projecting onto the same location on a white diffusing screen. The size of the image of the slide on the screen was 48 × 32 cm (subtending 39° × 26° of visual angle from a distance of 70 cm). The first projector carried a slide with a central black fixation point; the second one carried slides with black letters as stimuli; and the third carried a blank “eraser” slide. Stimulus duration was determined individually for each subject (after Geiger et al., 1992), and ranged between 3 and 60 ms. The subjects were asked to gaze at the fixation point on a glass screen. After a verbal warning, a slide was projected replacing the fixation point. The slide showed two letters, one in the center (at fixation point) and another at varying eccentricities to the right or to the left of the fixation point. The eccentricity of the peripheral letter varied from 2.5° to 12.5° from the fixation point, in steps of 2.5° to either side. Twenty stimuli were presented at each eccentricity. Letter height subtended 35 min of visual arc, and letter contrast was 90%.

The subject was requested to name the two letters. After the measurement, the rate of correct identification (expressed as percentage) of the peripheral letter was plotted against its eccentricity. This plot is a graphic representation of the FRF. Negative values are used to indicate eccentricities to the left side of fixation.

3. Results

3.1. Pre-treatment scores: Comparison between children with dyslexia and normal readers

As a first step, the FRFs of the children with dyslexia were compared to those of normally reading children (see Fig. 1). Planned comparisons (t tests) were performed for each eccentricity separately. Correct recognition rates significantly differed between normal and dyslexic readers on the right side at 10° [mean values 37.4 (SE = 3.09) vs. 50 (SE = 5.5), respectively, t(33) = 2.16, p = .038], at 7.5° [52.6 (3.68) vs. 70.8 (3.13), t(33) = 3.26, p = .003] and on the left side at −2.5° [99.6 (43) vs. 95 (1.95), t(12.11) = 2.29, p = .041]. These data confirm the already known “wider FRF” on the right side in dyslexic children as compared to normally reading individuals, and is also compatible with the hypothesis of a “left minineglect” in dyslexic readers.

3.2. Pre-treatment scores: Comparison between group SL and group R

The pre-test performance of the two groups of children with dyslexia was compared for the reading tests and for each of the FRF accuracy scores. No significant difference was found in any of the comparisons (all ps > .05).

3.3. Comparison between pre- and post-treatment scores: FRF accuracy rates

Variations in the FRF were assessed by means of a four-way ANOVA, comparing accuracy rates before and after treatment (factor Time, post-test vs. pre-test) at each Eccentricity (12.5, 10, 7.5, 5, and 2.5°) on each Side (left vs. right) in the two Groups (Standard Lateral vs. Random). There were significant main effects of Eccentricity [F(4, 40) = 167.71, p < .001], due to the usual reduc-

![Fig. 1. FRF in normally reading children and children with dyslexia. Peripheral letter eccentricity is plotted against the percentage of correct recognition.](image)
tion of recognition rates towards the periphery, and an interesting four-way Eccentricity by Side by Group by Time interaction \[ F(4, 40) = 3.23, p = .022 \]. Post hoc tests revealed that this interaction depended on a significant difference between the two groups in change-scores from pre- to post-test (i.e., post-test scores minus pre-test scores) at 12.5°, on the left side only [the Group by Time by Side interaction was significant only at eccentricity 12.5°; \( F(1,10) = 7.81, p = .019 \)]. In particular, the performance of the R group changed from 16.7 (\( SE = 7.15 \)) to 23.3 (\( SE = 6.15 \)) percent correct, while the SL group showed a decrease in the correct recognition rate from 26.7 (\( SE = 4.94 \)) to 13.3 (\( SE = 4.22 \)). These results could be described as the R group having “broadened,” and the SL group having “narrowed” their FRF on the left side, from pre-test to post-test (see Fig. 2A and B).

### 3.4. Comparison between pre- and post-treatment scores: Word and nonword reading

Two-way ANOVAs (factors: Time and Group) were performed on the \( z \) scores obtained by the two groups on tests of word and nonword reading, for both accuracy and speed. The results showed that both groups improved their reading performance after treatment: significant main effects of Time (pre- vs. post-test) on word reading speed \( [F(1,10) = 7.19, p = .023] \), word reading accuracy \( [F(1,10) = 7.88, p = .019] \), and nonword reading accuracy \( [F(1,10) = 38.25, p < .001] \) were found. Time by Group interactions were generally far from significance, although there was a tendency for the SL group to improve more than the R group in nonword reading accuracy \( [F(1,10) = 4.64, p = .057] \).

### 3.5. Relation between reading improvement and FRF change at \(-12.5°\)

The significant dissociation between the two groups in their FRF change in the left periphery after treatment was further investigated by relating it to changes in reading performance. Regression lines were obtained for each group, expressing the relationship between changes in the FRF at \(-12.5°\) and change-scores in word and nonword reading (Fig. 3). For both word and nonword reading, the regression lines had opposite slopes in the two groups. In the SL group, reading improved with increasing narrowing of left FRF. The opposite was true for the R group: reading improved with increasing widening of the left FRF. A General Linear Model analysis was performed with change-scores in reading accuracy (post- minus pre-) as dependent variable, Group as a factor and Change-scores in the FRF at \(-12.5°\) (accuracy, post- minus pre-) as a covariate. In the case of nonword reading, the covariate alone had no significant main effect \( [F(1,8) = .03, p = .86] \), while its interaction with Group was significant \( [F(1,8) = 6.10, p = .039] \). This is compatible with the view of opposite slopes, of approximately the same size, in the two groups. No significant effects were found for word reading accuracy, although the general pattern was similar to that of nonword reading (see Fig. 3).

### 4. Discussion

The prediction that changes in visual–spatial attention after treatment, shown in previous research, would have manifested as changes in the FRF was confirmed. These changes also followed the predicted pattern of specificity according to treatment type. The present results complement and enrich the data showing improvement in attentional inhibition by a classical covert attention orienting paradigm (Faccoetti et al., 2003). They thus support the view of a direct effect of Bakker’s treatment for developmental dyslexia on spatial-attentional functions and visual processing.

The most relevant finding concerns the presence of a differential effect of treatment on visual–spatial attention in the two visual fields. Data concerning asymmetry of
attentional processes in the two hemifields have already been reported in studies that used classical attentional paradigms (Facoetti & Molteni, 2001; Facoetti & Turatto, 2000; Facoetti et al., 2001; Hari et al., 2001), and have been confirmed by further analyses on the data about an increase in inhibition of covert attentional orienting after treatment (Facoetti et al., 2003), showing that the effect of increased inhibition (i.e., narrowing of attentional focus) essentially depends on the right hemifield (Facoetti & Lorusso, in preparation). Other studies have shown that attention in dyslexic readers is more diffuse on the right side, with little or no effect of valid/invalid cueing (Facoetti et al., 2001).

The two treatment groups, SL and R, showed opposite gradients between widening of the FRF in the left periphery and improvement in nonword reading. This pattern could tentatively be explained by hypothesizing that two distinct attentional mechanisms come into play in the treatment of dyslexia with tachistoscopic presentation of words. (i) A first mechanism would involve orienting of attention in a retinocentric reference frame to the side where the word is expected to appear on the screen. This strategy would lead children in the SL group to orient attention to the right of fixation [all of the six children of that group had been shown words only in the right hemifield, either for the entire four-month treatment period (P-types) or for the last two months prior to post-test session (M-types)]. For what concerns the R group, it seems reasonable to assume that the impossibility to anticipate the side where the next word is to be presented determines a “widening” of the attentional field. This might happen because the children learn to widen their attentional focus before the presentation of the word, and/or to rapidly orient attention as soon as the word is presented. (ii) A second mechanism would concern orienting of attention inside a reference frame centered on the word to be read (i.e., an object-centered frame). In this case the reading process would require attention to be (overtly or covertly, as might be necessary with the rapid presentation times of the VHSS treatment) oriented towards the leftmost part of the word so as to start the graphemic parsing. This mechanism would not differ between the two groups.

The retinocentric attentional bias to the right (i) could be responsible for the observed “narrowing” of the attentional field on the left side in the SL group. The R group would instead show an attentional “widening” on the same side because of the strategy of “diffuse” attention induced by the unpredictability of stimulus side during treatment.

For what concerns the right side, a parallel “widening” should be expected in both groups: in the SL group, because of the rightward orienting mechanism (i); in the R group, because of the “diffuse attention” mode. However, this widening on the right side was not observed. Two possible interpretations can be proposed in this respect. It is known that children with dyslexia have a baseline rightward attentional bias (e.g., Facoetti et al., 2001; Geiger & Lettvin, 1999)—they might be close to a physiological “ceiling” and thus be unable to improve their performance any further on that side. Alternatively, the expected widening on the right side might have been counteracted by an opposite (leftward) attentional bias.

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3 The absence of L-types in the present sample did not allow us to test the prediction of a shift to the left in this type of dyslexia. In fact, L-types receive stimulation in the left hemifield during Bakker’s treatment.
i.e., the object-related tendency to orient to the left side of the word as soon as this is presented (ii). The two mechanisms, in this case, would counterbalance each other on the right side. For the SL group, it could be further suggested that the most effective anticipation for the word appearance would be to focus on the right side of the screen, but not too much to the right, so that the word can be scanned as quickly as possible starting from its left side. The positive correlation between broadening of the FRF in the left periphery and improvement in nonword reading accuracy in the R group can thus be interpreted in terms of a larger attentional focus on the left side which allows one to start the serial left-to-right analysis of the word string (see Cestnick & Coltheart, 1999). This also seems to be consistent with Hari et al.’s (2001) observation of a “left minineglect” in dyslexic readers, suggesting a lower density of attentional resources in the left visual hemifield. In the case of children belonging to the R group, specifically, a reduction of this “left minineglect” could result in improvement of nonword reading ability. In the SL group, on the other hand, the direct proportionality between narrowing of the FRF in the left periphery and improvement in reading can be thought of as an indirect effect of the narrowing on the left side: children who were better at restricting their left-sided attentional field could better orient their attention to the right of fixation (where the word was due to appear); therefore, they could profit more from the treatment itself, as they were better able to read the words presented during it.

It can be observed that the often reported narrowing on the right side after treatment (Geiger, Lettvin, & Fahle, 1994; Geiger & Lettvin, 1999; Lorusso et al., 2004b) was not seen in the present sample. However, the treatment used in those studies differs from the one employed in the present research in that the former directly addressed attentional focusing, while tachistoscopic word presentation is more specifically expected to enhance attentional orienting. Moreover, as previous studies on the relationship between the FRF and reading had focused on the right side as the direction of reading in Western languages, possible changes in the left side may have gone unnoticed.

References


4 The FRF of Hebrew-reading dyslexics has been found to be wider on the left side (see Geiger et al., 1992).


