Hemispheric, attentional, and processing speed factors in the treatment of developmental dyslexia

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Accepted 12 February 2004
Available online 13 April 2004

Abstract

Aim of the study is to analyze the contributions of hemispheric, attentional, and processing speed factors to the effects of neuropsychological treatment of developmental dyslexia. Four groups of dyslexic children (M-type dyslexia) were treated over a period of four months. A first group (n = 9) underwent Bakker’s Hemisphere-Specific Stimulation, with presentation of words in the right and left visual field. A second group (n = 7) received the same stimuli randomly in either visual hemifield. A third group (n = 8) received the same words presented centrally at fixation point. A fourth group (n = 6) received central stimuli with fixed presentation time (1500 ms). The children were tested before and after treatment on reading and spelling measures. All groups improved significantly after treatment on all variables. However, the group that was treated with centrally presented stimuli improved more than the other groups in spelling measures. A possible explanation is that rapid, simultaneous presentation to both hemispheres enhances interhemispheric exchange, which could produce an advantage in tasks requiring a high degree of integration between left and right hemispheric functions, such as spelling. The absence of significant differences in reading improvement may point to the role of memory functions or strategic factors characterizing all the treatment programs, possibly outweighing the effect of the other factors.

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1. Introduction

Developmental dyslexia, also defined as specific reading disorder, is one of the most frequent learning disabilities and affects 3–5% of Italian children (Cornoldi, 1991).

It is commonly assumed that the main deficit underlying reading disorders is phonological in nature (Snowling, 2001). However, in the last years, much interest has been devoted to theories that point to deficits in the visual processes mediated by the magnocellular system (Lovegrove, 1991; Stein & Walsh, 1997), to automaticity and cerebellar functioning (Nicolson & Fawcett, 1990), or callosal inter-hemispheric processing (Hynd, Obrzut, & Bowen, 1987).

According to Bakker’s model (Bakker, 1990), the process of reading acquisition is slow at first and requires a detailed analysis of the graphic shape of the letters which make up words. Visuospatial analysis, which characterizes reading acquisition, is mainly subserved by the right hemisphere. Later this perceptual analysis becomes automatic. The left hemisphere, which is responsible for linguistic analysis, would be involved only during a second phase, determining abstraction of meaning through semantic and syntactic clues. Several psychophysiological studies found that this shift from right to left occurs during the first stages of reading acquisition (Bakker, Licht, Kok, & Bouma, 1980; Licht, Bakker, Kok, & Bouma, 1988).

Bakker suggested that some children (P-type dyslexics) fail to make the shift from right to left, thus perseverating in a visuo-perceptual analysis of the written material. Another group of children (L-type dyslexics) makes this shift prematurely, when visual recognition of words has not become sufficiently automatized yet. These children try to process information by means of semantic and syntactic strategies, thus showing an an-
ticipatory reading style. P- and L-type dyslexics can be distinguished on the basis of reading speed and type of errors. Slow reading and time-consuming errors (self-corrections, syllabic reading, fragmentations, stuttering, and repetitions) are peculiar to P-types, whereas relatively fast reading and substantive errors (omissions, substitutions and inversions) are typical of L-types.

Recent studies suggest the existence of a third type of dyslexia, the so-called M-type (mixed type). M-types read rather slowly (Masutto, Bravar, & Fabbro, 1994) and make both time-consuming and substantive errors.

Bakker based his treatment program on the many observations that showed a differential application of hemispheric strategies in P- and L-dyslexia, and developed the idea that selective stimulation of the under-activated hemisphere may determine a functional re-organization of the brain that could lead to a reduction of the reading disorders. Hemispheric stimulation is carried out by presenting words to the left or right hemisphere, which would be addressed both directly (by tachistoscopic presentation to a visual hemifield or tactile stimulation of the left or right hand—hemisphere-alluding stimulation, HSS) and indirectly (by the kind of stimuli and tasks—hemisphere-alluding stimulation, HAS). The main assumption underlying hemispheric stimulation procedures is that of a flexible and changing functional organization of the brain, which can be determined and influenced by the interaction with the environment (Bakker, 1989). The effectiveness of HSS and HAS procedures was investigated in many studies which gave substantially positive results (Bakker, Bouma, & Gardien, 1990; Bakker, Moerland, & Goekoop-Hoefkens, 1981; Goldstein & Obritz, 2001; Robertson, 2000). More recently, controversial data have been presented in the literature as to whether the manipulation of subgroups and treatment type leads to differential results. More specifically, Dryer, Beale, and Lambert (1999) reported a generalized improvement for children treated with type-appropriate and non-appropriate HSS and HAS, and suggested that improvement may be due to unspecific factors and not to hemisphere-specific effects.

Among the possible non-hemispheric factors that could play a significant role in HSS, there are:

(a) Attentional factors, involved in pre-orienting towards a region of the visual space (where the stimulus is expected to appear), and in focusing onto that region (i.e., restricting and concentrating attention within that area). Posner, Snyder, and Davidson (1980) also showed that orienting following a conscious decision is more efficient than automatic orienting of attention produced by a suddenly appearing stimulus. The involvement of attentional factors in reading has been studied by Casco, Tressoldi, and Dellantonio (1998). Furthermore, Facetti, Lorusso, Paganoni, Umiltà, and Mascetti (2002) showed that visual HSS, unlike traditional speech therapy, increases attentional inhibition in dyslexic children.

(b) Amount of general processing resources (speed of information processing), addressed by the decreasing time of presentation of the stimuli (especially in P-type treatment). It is known that, in order to process information at a faster pace, the cognitive system is forced to automatize some components of the reading process (Logan, 1978; Spelke, Hirst, & Neisser, 1976). Since lack of automatization has been referred to as one of the possible causes of reading disorders (Nicolson & Fawcett, 1990), it is crucial to address this point if one wants to study the effects of treatment. It has been shown that automatization is more easily induced when the task is more repetitive and predictable (less resources are needed for task control and organization of activity, Kahaneman, Treisman, & Burkell, 1983; Shiffrin & Schneider, 1977). Deficit of automatization has also been linked to functional or structural cerebellar abnormalities (Finch, Nicolson, & Fawcett, 2002). Although the evidence for the supposed anatomical anomalies is scarce and questionable (Beaton, 2002), the fact that dyslexic children very often show deficits of coordination and of the execution of fine movements is compatible with cerebellar dysfunction, and therefore deserves some attention.

(c) Characteristics of the stimuli (strategic factors). In line with Bakker's indications, the stimulation of a specific cerebral hemisphere is obtained not only through direct flashing of the stimuli into one visual hemifield (contralateral to the target hemisphere), but also through the characteristics of the stimuli themselves. Specifically, stimuli for left-hemisphere stimulation are high-frequency, low-imageability, easily anticipatable, perceptually linear verbal elements (words or short phrases). By contrast, stimuli for right-hemisphere stimulation are low-frequency, high imageability, perceptually complex verbal materials. Although a specific part of Bakker's program (HAS) is exclusively devoted to indirect stimulation of strategies depending on one hemisphere, there are important strategic factors also involved in the reading exercises of HSS.

Our study was designed to compare the effects of: constant lateral (group 1) vs. random lateral (group 2) vs. central (group 3) vs. central-fixed-time (group 4) presentation of visual stimuli, in order to evaluate the specific contributions of attentional pre-orienting, hemispheric factors and increasing speed of processing. Therefore, the experimental hypotheses were:

(1) if hemispheric factors play the main role in producing treatment effects, then the group treated with constant lateral presentation should improve more than the group(s) treated with central presentation;
(2) if pre-orienting factors play a crucial role, then the two (three if the effect is extended to the fixed-time group) groups who received constant presentation of the stimuli, either in the center or in a single hemi-field, should improve more than the group who received random presentation of the stimuli;

(3) if both of the two previous factors play a significant role, then the three groups should improve in the following order: constant lateral (involving both factors) more than central (involving only pre-orienting) and central more than random (involving none of the factors) presentation;

(4) finally, if the crucial factor is increasing speed of processing induced by gradual shortening of presentation time, then groups 1, 2, and 3 should improve more than group 4.

The effectiveness of the four methods was assessed by comparing performance on reading and spelling tests before and after treatment. The strategic components of the program (factor c) were not manipulated but they were kept constant by including only M-types in the experimental groups. In this way, all the children received exactly the same kind of stimuli, and each of them received both types of stimuli (right-hemisphere stimuli first, left-hemisphere stimuli later on).

2. Materials and methods

2.1. Participants

Thirty children with developmental dyslexia, ranging in age between 7 and 14 years, were selected from a sample of children referred to the Scientific Institute “E. Medea” or to the Child Neuropsychiatric unit of Bergamo Hospital for learning difficulties.

The diagnosis of developmental dyslexia was made according to ICD-10 criteria (WHO, 1992). Children were considered as dyslexic if their performances were 2 SDs below age mean in at least one of the tests of reading speed and accuracy and/or writing accuracy (see testing procedure section below), despite a normal IQ (>85) as assessed by the Wechsler Intelligence Scale for Children-Revised (Wechsler, 1974).

The characteristics of the children in the various groups are reported in Table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Descriptive data for the four groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1: Lateral presentation</td>
</tr>
<tr>
<td>Number of participants</td>
<td>9 (8 males, 1 female)</td>
</tr>
<tr>
<td>Mean age (SD)</td>
<td>10.44 (1.81)</td>
</tr>
<tr>
<td>Mean full IQ (SD)</td>
<td>104.11 (7.70)</td>
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</tbody>
</table>

2.2. Classification of dyslexia

All children had been classified as M-dyslexics on the basis of their reading speed and reading errors (time-consuming or substantive errors), according to the following criteria:

(a) more than 60% time-consuming errors but reading speed above 1 SD; or

(b) more than 60% substantive errors but speed below 1 SD; or

(c) presence of an equivalent amount of both kinds of errors (between 50 and 60%).

2.3. Treatment

Treatment was carried out in individual sessions taking place twice a week and lasting 45 min each, over a 4-month period. The sessions took place at the outpatient clinic of the rehabilitation institute “E. Medea” and at the Neuropsychiatric Unit of Bergamo Hospital, and were carried out by trained speech therapists.

For all groups, treatment was carried out by means of a computerized program called “Flash Word” (Masutto & Fabbro, 1995). In the program, ocular fixation is monitored by asking the child to follow a luminous dot oscillating on the screen from top to bottom and vice versa, at an adjustable speed. The word is flashed only if the child clicks on the mouse exactly when the dot is crossing the central target. Before the beginning of each trial, criteria for word presentation were set (font type and presentation time, which varied between 250 and 100 ms). The longest presentation times were used in the first sessions and later, when more complex stimuli were presented for the first time (with the exception of group 4, for whom presentation time was fixed at 1500 ms). The strings of letters became increasingly difficult in terms of word length and complexity of spelling. The children were treated in line with the suggestions made by Bakker et al. (1990) and Bakker, Licht, and Kappers (1995). In the first two months, L-type stimulation was given by tachistoscopic presentation of perceptually complex, low-frequency (difficult to anticipate) words. In the next two months, P-type stimulation was given by tachistoscopic presentation of perceptually linear, high-frequency (easy to anticipate) words. 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 on a specific part or feature of the word and repeat the presentation of the word.

The four experimental groups received exactly the same lists of stimuli in the same sequence, but differed as to the spatial/temporal presentation of the words on the computer screen:

- **Group 1** (nine children): lateral presentation, according to Bakker’s model (HSS). The L-type stimuli (first two months) were presented to the left visual hemifield (in order to stimulate the right hemisphere), and the P-type stimuli (following two months) were presented to the right visual hemifield (in order to stimulate the left hemisphere).
- **Group 2** (seven children): randomized lateral presentation. By means of an option of the computer program, the stimuli was flashed to either the left or the right of the fixation point, without any predictable sequence.
- **Group 3** (eight children): central presentation. All the stimuli were flashed exactly in the center of the computer screen (fixation point).
- **Group 4** (six children): central presentation with fixed time. The stimuli were flashed in the center of the computer screen, with a fixed presentation time of 1500 ms (long enough to allow eye movements for visual scan of the stimulus).

Assignment of children to the different treatment groups was pseudorandom, but it was ensured that age and sex were homogeneously distributed across groups ($P > .05$ at $t$ tests).

Children belonging to the four groups were treated by the same group of speech therapists, who had been specifically trained. The therapists were informed about the aims of the study but there were no reasons to think that they had specific expectations about the results, that could bias the results in any way.

### 2.4. Testing procedures

All children were tested before and after treatment, on a whole battery of reading and spelling tests. These tests are commonly used in the assessment of reading disabilities in Italy; all of them have age norms and satisfactory validity and reliability scores.

The following tests were administered in the pre- and post-test sessions:

1. **Text reading**. “Prove di rapidità e correttezza nella lettura del gruppo MT” (“Test for speed and accuracy in reading, developed by the MT group”) (Cornoldi, Colpo, & Gruppo, 1986), a text reading task meant to assess reading abilities for meaningful material. It provides separate scores for speed and accuracy. Texts are of increasing complexity according to attended grade. Norms are provided for each text. This task was also employed for classification of dyslexia according to Bakker’s model (see previous section).

2. **Single word/nonword reading**. “Batteria per la Valutazione della Dislessia e Disortografia Evolutiva” (Battery for the assessment of Developmental Reading and Spelling Disorders), (Sartori, Job, & Tressoldi, 1995).

   The test assesses speed and accuracy (expressed in number of errors) in reading word lists (4 lists of 24 words) and nonword lists (3 lists of 16 nonwords).

3. **Spelling tests**. “Batteria per la Valutazione della Dislessia e Disortografia Evolutiva” (Battery for the assessment of Developmental Reading and Spelling Disorders), (Sartori et al., 1995). The battery includes three dictation tasks, giving correctness scores in writing words (48), nonwords (24), and sentences (12) for children/adolescents from the second grade to the last grade of junior high school.

### 2.5. Scores

The differential effects of the three kinds of presentation were assessed by comparing performance on the various tests before and after treatment. Raw scores were transformed into $z$ scores, according to age norms. Three global scores were computed:

1. **global accuracy score**, i.e., the average of accuracy scores in text, word, and nonword reading;
2. **global speed score**, i.e., the average of speed scores in text, word and nonword reading;
3. **global spelling score**, i.e., the average of scores in word, nonword and sentence writing from dictation.

### 3. Results

A one-way ANOVA on the pre-treatment global scores showed no significant differences in performance among groups (all $Ps > .05$).

A mixed two-way ANOVA was subsequently performed, with group (1, 2, 3, and 4) as a between factor, and time (pre- vs. post-treatment) as a within factor. The results are shown in Table 2.

All the global scores showed a significant main effect of time, i.e., they significantly improved after treatment.

The interaction time $\times$ group, i.e., the difference in improvement between groups, reached statistical significance only for the global score related to spelling abilities $[F(3, 25) = 3.78, P = .023]$. Post-hoc tests (Newman–Keuls) revealed a significant difference between the two groups who received central presentation of the stimuli, with improvement after tachistoscopic presentation being much higher than improvement after fixed-time presentation. A further analysis (paired $t$-tests) was then carried out on the global spelling variable, in order to compare performances before and after
treatment for each experimental group separately. The results are shown in Table 3.

It can be seen that only the two groups receiving central and lateral random presentation of the stimuli, respectively, significantly improved after treatment on the global spelling measures.

In a final analysis, the effects of the various component tests (i.e., words, nonwords, and text) for each global score were compared. No significant differences were found for any variable (reading speed, accuracy or spelling).

4. Discussion

The comparison of the effectiveness of treatment for developmental dyslexia in four groups differing as to the (temporal and spatial) modalities of presentation of the stimuli revealed a substantially similar degree of improvement in reading ability, irrespectively of conditions. Expected differences in improvement due to the manipulation of hemispheric stimulation, attentional pre-orienting, and required speed of processing were not observed. This may suggest that these factors, though probably contributing to the desired effects, are outweighed by a different, common factor. The hypothesis that the common factor is just an unspecific effect of treatment (a sort of Pygmalion effect) is ruled out by data comparing the effects of visual HSS with those of traditional speech therapy (Lorusso, Facoetti, & Molteni, submitted), and showing a significant advantage of the former over the latter (the children belonging to the first group in the present study were taken from the broader HSS group, that included P-, L-, and M-type dyslexics).

The crucial factor could then tentatively be linked to the stimulation of memory functions, to automatization processes or to the strategic components of the reading tasks. Stimulus presentation, in fact, is rather fast in all groups (although for central, fixed-time presentation it is not tachistoscopic), and thus requires rapid processing of the visual elements, conversion into phonemes and phonemic storing (Short-Term Memory), and assembling (Working Memory). Moreover, verbal (and visual) memory is involved in the process of lexical search for high-frequency words. It can thus be argued that rapid access to, and use of, memory resources is certainly required by the characteristics of stimulus presentation in all experimental conditions. As a matter of fact, improvement in reading abilities has been shown to correlate with improvement in memory functions after visual HSS treatment (Lorusso et al., submitted).

Alternatively (but not necessarily in contrast with the first hypothesis), the relatively rapid presentation of the words could induce a higher degree of automatization (Logan, 1978) of the various components of the reading process, including visual analysis, phonemic assembly, and lexical search. It should be assumed, in this case, that a high pressure on speed of processing is not essential for automatization to occur (considering the similar results obtained with constant presentation time).

Strategic functions, on the other hand, are clearly addressed by the linguistic and perceptual characteristics of the proposed materials. For the stimulation of the right hemisphere, in fact, perceptually complex, low-frequency (difficult to anticipate) words were used; for the left hemisphere, in contrast, perceptually linear, high-frequency (easy to anticipate) words had been selected. The tasks are therefore rather different: careful visual scanning and perceptual analysis are necessary in the case of right hemisphere stimulation; anticipation of words (often on the basis of common characteristics, like prefixes and suffixes, that are repeated in the list) and retrieving of common expressions from LTM (Long-Term Memory) are necessary in the case of left
hemisphere stimulation. It could be observed that the hemispheric factors, which did not prove to be crucial in direct hemisphere-specific stimulation, may still play a fundamental role in the effectiveness of treatment, precisely through the stimulation of specific, hemisphere-related strategies for reading.

It is interesting to note, at this point, that the group who received random lateral presentation of the stimuli could have been disadvantaged by frequent incongruence between the side of presentation (constantly varying) and the kind of presented tasks/materials (addressing the right hemisphere for the first two months and the left hemisphere for the following two months). The results of the study, however, show that this incongruence did not reduce the effectiveness of treatment: the random presentation group, in fact, improved as much as the other groups. This could be explained in two different ways. A first possibility is that the effect of the strategic components is stronger than the (opposite) effect of the presentation to one visual hemifield (it should be remembered that this technique stimulates the targeted hemisphere before, but not necessarily more than, the other hemisphere). An alternative explanation is that the side/material incongruence does not produce any actual interference effect. This might happen because of immediate hemispheric transfer, interhemispheric cooperation, or even mutual cancellation of opposite effects from congruent and incongruent stimuli. In any case, the role of strategic components in the treatment of dyslexia deserves further attention and should be accurately analyzed in controlled experiments (as Lorusso, Facoetti, & Molteni, in preparation, have recently been doing).

The unexpected finding of greater improvement in spelling abilities (writing to dictation) for the group treated with central tachistoscopic presentation of the stimuli also needs to be explained. None of the previously mentioned factors (hemispheric, attentional, and speed-of-processing factors) can account for this selective effect. Moreover, the absence of a similar effect in the group treated with central, fixed-time presentation of the stimuli indicates that the position at which the stimuli are presented is not the crucial factor, and that tachistoscopic presentation is necessary for the effect to manifest itself. A possible explanation is that tachistoscopic presentation of a stimulus appearing at fixation point implies that the stimulus is split into two parts: the first part, to the left of fixation point, is sent to the right hemisphere; and the second part, to the right of fixation point, is sent to the left hemisphere. In order for the word to be identified, the two halves must be put together through interhemispheric integration (via callosal pathways). The data seem to suggest that exercising interhemispheric transfer produces subsequent facilitation in spelling performances, while no advantages are found for reading performances (in which all groups significantly improve). It could be argued, therefore, that callosal transfer is particularly relevant for spelling, while it is not (or to a lesser extent) for reading. Although cognitive neuropsychological models of reading and spelling emphasize the involvement of the left hemisphere in both processes, some studies have shown that the right hemisphere may also give a relevant contribution (e.g., Crossman & Polich, 1988). Moreover, linguistic functions have been shown to be often less lateralized in dyslexic children, who seem to rely more on right-hemispheric processing skills (Pugh et al., 2000). Some authors (e.g., Mather, 2001) even suggested that dyslexia itself originates from processing written language in the right hemisphere. A PET study (Gross-Glenn et al., 1991) showed that dyslexics had a rightward hemispheric asymmetry in activation during whole-word recognition. Italian dyslexics, on the other hand, have been shown to read almost exclusively relying on indirect, grapheme-to-phoneme conversion (i.e., making very limited use of orthographic information) (De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002). In this perspective, it would not be unreasonable to expect that stimulation of callosal connections brings an advantage in dictation tasks, requiring the transfer of verbal auditory information from the left to the right hemisphere for orthographic processing, and then again to the left hemisphere for right hand writing. Indeed, Kershner and Stringer (1991) showed that dyslexic children tend to be less lateralized during writing than during reading. In text writing to dictation, moreover, the need to access contextual information (mainly a right hemisphere function) could be more stringent than in reading, especially in the case of orthographic peculiarities (such as the use of apostrophes in pseudohomophone sentences), that are typically included in Italian spelling tests.

Such hypothesis could also explain the similar improvement in spelling abilities observed in the group who received random lateral presentation of the stimuli. As it was argued before, in fact, this kind of presentation requires callosal transfer of information or a higher degree of interhemispheric cooperation, at least for the processing of stimuli characterized by side/material incongruence.

Several studies documented the presence of deficits of callosal transfer of information in dyslexic children, in the visual (Gross-Glenn & Rothenberg, 1984) and tactile modality (Fabbro et al., 2001). In the latter study, M-types were shown to perform lower than P-types and controls (and comparably to L-types) in a task of tactile callosal transfer. Considering that M-types show difficulties both in direct recognition of words (characterizing L-types’ fast, inaccurate reading) and in grapheme-to-phoneme conversion (characterizing P-types’ slow, fragmented reading) (Van Strien, Bakker, Bouma, & Koops, 1990), it could be argued that interhemispheric
exchange may be particularly relevant for spelling in M-types, since spelling requires integration of orthographic knowledge (stored in the visual lexicon), and phonologic decoding skills. Indeed, the absence of significant differences in improvement between the various spelling tasks (writing words, nonwords and sentences) suggests that treatment affects not only one type of spelling-related skills (e.g., phonemic analysis as required for writing nonwords, or orthographic knowledge as required for words and sentences), but rather the integration of all these subskills for efficient writing to dictation.

As a conclusion, the results of the present study emphasize the concomitant effect of various factors in the treatment of developmental dyslexia. Factors common to various modalities of stimulus presentation could be related to memory functions, automatization and strategic factors. Interhemispheric coordination and integration, on the other hand, seem to play a crucial role in facilitating writing processes during dictation.

Acknowledgments

The research described in this article was supported by MS and CNR Italy, and “Amici della Pediatria” of Bergamo Hospital. Special thanks go to D. Bakker for his helpful suggestions, and to the neuropsychiatrists and speech therapists of the Institute “E. Medea” and of Bergamo Hospital for their precious collaboration in the project.

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