Neuropsychological Treatment of Dyslexia: Does Type of Treatment Matter?

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Abstract
In this study, 123 children with a diagnosis of developmental dyslexia were assigned to different treatment groups, either variations of Bakker’s intervention program based on the balance model or a control, a specific reading training group. Thorough cognitive and neuropsychological assessment allowed determination of the subtype of dyslexia according to the balance model and the neuropsychological profile with respect to reading and spelling abilities, verbal memory, and phonemic awareness. Characteristics of hemisphere-specific stimulation were systematically manipulated in an effort to shed light on the bases and mechanisms of reading improvement. It was shown that the effects of treatment vary according to type of dyslexia and that the different intervention programs have differential effects on reading-related neuropsychological functions. Since opposite effects can be produced by the same type of treatment in different dyslexia subtypes, the results of the study suggest that accurate classification of subtype on the base of reading and reading-related variables is advantageous for an optimal planning of the therapy.

Keywords
developmental dyslexia, intervention, subtype, cerebral hemispheres

Introduction
Developmental dyslexia, also referred to as specific reading disorder, is one of the most frequent learning disabilities, affecting 3% to 5% of Italian children (Lindgren, De Renzi, & Richman, 1985; Stella, 1999).

According to the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) criteria (World Health Organization, 1992), developmental dyslexia is diagnosed in children who fail to develop normal reading skills in spite of normal intelligence, adequate motivation and schooling, and absence of neurological or psychiatric problems. The main diagnostic criterion is that of a reading performance below the population mean (typically, reading scores need to be at least 2 standard deviations below the general population mean), with IQ in the normal range (a usually adopted cutoff is 85).

This heritable disorder (Fisher & De Fries, 2002) usually becomes apparent in the first school years as soon as children learn to read. While reading difficulties are the hint that most often leads to a clinical diagnosis, they probably constitute only the most visible dysfunction of a more composite picture of a defective neurocognitive profile, which is likely to extend across different functions (Habib, 2000). In fact, although phonologic and metaphonologic deficits have been described as one of the most reliable and most distinctive features of dyslexic readers (see Ramus et al., 2003; Vellutino, Fletcher, Snowling, & Scanlon, 2004), several other functions were shown to be specifically impaired in dyslexia, including long-term and short-term verbal memory (Swanson, Xinhua, & Jerman, 2009; Wolf, 1991), working memory (Kibby, Marks, Morgan, & Long, 2004; Schuchardt, Maehler, & Hasselhorn, 2008), visual perception (Geiger & Lettvin, 1999; Jones, Branigan, & Kelly, 2008; Stein, 2001), auditory perception (Stark & Tallal, 1988), automatization and learning functions (Nicolson & Fawcett, 1990), and spatial attention (Facetti,

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Several authors have proposed that different subtypes of dyslexia can be identified. Some classifications reflect the models used in studies of adult dyslexia, subdividing dyslexics according to their performance with different kinds of stimuli, and subsequently classifying dyslexia as surface versus phonological, dysphonetic versus dysidegetic, and so on (e.g., Boder, 1973; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Denckla, 1972; Morton & Patterson, 1980; Seymour, 1998). Other taxonomies apply procedures of statistic clustering in order to identify subgroups characterized by different neuropsychological profiles (Petrauskas & Rourke, 1979; Satz & Morris, 1981; Wolf & Bowers, 1999). Others still refer to distinctive characteristics of reading performance (independent of type of stimuli), considered to be related to specific phases in the learning-to-read process (e.g., Frith, 1985).

According to Bakker’s model of learning to read (Bakker & Licht, 1986), initial reading is predominantly mediated by the right cerebral hemisphere (RH), while mature reading should normally be under primary control of the left cerebral hemisphere (LH). This reasoning fits in a historical line of theorizing that began with Samuel Orton (1937) and that recently was underscored by the findings of Turkeltaub, Gareau, Flowers, Zeffiro, and Eden (2003). Turkeltaub et al. found evidence that learning to read is associated with progressive disengagement of the RH (decreasing reliance on nonlexical form recognition systems for word recognition; extrastriate cortex, inferotemporal cortex) and increased engagement of the LH (inferior frontal regions for nonlexical, phonemic skills and middle temporal regions for lexical word recognition systems). Support for the hypothesis that early reading, differently from advanced reading, is characterized by predominant right hemispheric involvement comes also from event-related potentials (ERP) studies (Licht, Bakker, Kok, & Bouma, 1988, 1992).

It may happen that some young readers somehow “skip” the right hemisphere phase, that is, before visual-spatial analysis of the written material has become automatized, and that they start to use left hemispheric strategies from the onset of learning to read. If this happens, such readers will develop an L- or “guessing” type of dyslexia. Conversely, a P- or “spelling” type of dyslexia is caused by persistent overreliance on early right hemispheric reading strategies.

Bakker thus distinguishes between two types of dyslexic readers: P-types and L-types. P-types are characterized by relatively slow but accurate reading, L-types by relatively fast but inaccurate reading. Some investigators proposed an additional M- (mixed) type of dyslexia, which includes dyslexic children who read both slowly and inaccurately (Masutto, Bravar, & Fabbro, 1994). The validity of Bakker’s classification has been supported by several investigations (Bakker & Licht, 1986; Bakker & Vinke, 1985; Fabbro et al., 2001; Van der Schoot, Licht, Horsley, & Sergeant, 2000, 2002; Van Strien, Bakker, Bouma, & Koops, 1990). Similarities with other classifications of dyslexia may be found, and have been reported in the literature (e.g., between dysidegetic/dysphonetic dyslexia and P- and L-types, or between phonological/surface dyslexia and P- and L-types, respectively), due to the use of analytic versus global reading strategies (Mather, 2001). However, classification according to the balance model retains distinctive characteristics that render overlap with other classifications fairly impossible (for a discussion, see Lorusso, 1994).

So-called hemisphere-specific stimulation (HSS; Bakker, 1990) thus aims at modifying the degree of involvement of specific neuropsychological functions (particularly linguistic vs. visual-spatial analysis) in the reading process, both by selective stimulation of either the left (for P-types) or the right (for L-types) cerebral hemisphere through the visual or tactile sensory channels and by the induction of either anticipatory (P-types) or thorough, visually based deciphering strategies (L-types). Clinical and educational application of HSS, both through the visual (V-HSS) and the tactile sensory channel, has shown positive effects on the reading performance of dyslexic children across languages, characterized by different degrees of orthographic transparency (see Bakker, 2006, for a review). Previous studies also showed that attention, inhibition especially, processing speed, and short-term memory play an intervening role in the effects of V-HSS (Facoetti, Lorusso, Paganoni, Umlità, & Mascetti, 2003; Lorusso, Facoetti, & Molteni, 2004; Lorusso, Facoetti, Paganoni, Pezzani, & Molteni, 2006). However, better identification and understanding of the underlying mechanisms is of crucial importance, as the establishment of their mediating role may be helpful in the choice and set-up of the most effective treatment procedures.

In general, it can be observed that several functions that were shown to be deficient in dyslexia also play a role in its remediation. Whether this should be seen as an indication of their causal role in the etiology of dyslexia or whether they just take part in compensatory processes is still not clear. According to Pugh et al. (2001), compensation of deficits in posterior regions of the LH can occur through enhanced involvement of either anterior regions of the LH or posterior regions of the RH. While a shift to anterior regions of the LH indicates reliance on articulatory recoding, a shift to posterior regions of the RH would indicate reliance on visuo-perceptual strategies for word recognition. In this respect it could be intriguing to look for analogies with P- and L-type characteristics, but some of the conclusions seem to be in conflict with RH and LH predominance, respectively, described for these subtypes. In fact, articulatory recoding in Pugh et al.’s model is based on LH, anterior activation, and therefore should be expected to characterize L-types, yet it seems more similar to P-types’ letter-by-letter reading style. Conversely, whole word recognition, based on RH, posterior areas should characterize P-types’ reading style (because of their reliance on RH functions), but in fact it rather reminds one of L-types’ anticipatory reading.
Another study by the same group (Shaywitz et al., 2003) suggests that compensation through activation of RH functions would result in accuracy improvement and that compensation through LH areas (posterior in this case) would result in more memory-based strategies and more persistent reading problems. One might argue then that the participants showing LH posterior activation remind of Bakker’s L-types, or the more severely impaired M-types, as the result of a failure to activate both “canonical” circuits for compensation, namely, anterior LH and posterior RH.

It seems evident that in spite of the huge progress made by neuroimaging techniques, it is still very difficult to elucidate the microprocesses occurring during the processing of written language. Tallal, Merzenich, Miller, and Jenkins (1998) provide evidence that the LH is specialized in the processing of both verbal and nonverbal stimuli characterized by rapid acoustic change. If correct, one would expect the LH to be the most involved one when using a phonological reading approach. However, when one takes into account the requirements of graphemic parsing (visual sequential scanning of the word; Cestnick & Coltheart, 1999), the role played by the RH (posterior-parietal cortex), controlling visual-spatial attention (Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990), becomes immediately evident. Following Bakker’s suggestions, as also noted by Mather (2001), reading thus requires a steady integration of spatial information (analysis of letter shapes), processed by the RH, and of temporal information (letter recognition and sequencing of letter strings) as processed in the LH. As a consequence, efficient callosal transfer of information seems crucial for proficient reading and its development.

The present investigation aims at finding clues to mechanisms by varying the neuropsychological stimulation procedures in the treatment of dyslexic children, subclassified as P-types, L-types, or M-types. Standard visual HSS provides RH stimulation in L-type dyslexia, LH stimulation in P-type dyslexia, and stimulation of the RH followed by stimulation of the LH in M-type dyslexia. Hemisphere-specific stimulation as designed in this study implies both sending the information to be processed (the words to be read) to a single visual hemifield, and thus to the target hemisphere, and choosing materials and tasks intrinsically requiring processing at either the linguistic (left hemisphere) or visual-perceptual (right hemisphere) level.

Quick presentation of words on the PC screen, usually described as “tachistoscopic” presentation, prevents the eyes from moving along the word during reading (but allows for attention to be preoriented), so that the image of the word appearing into each visual hemifield is projected onto the contralateral hemisphere only. Moreover, the gradual shortening of flashing times requires increasing speed of processing, which might trigger the induction of automatization mechanisms (Logan, 1978; Shiffrin & Schneider, 1977). Stress on automatization and on preorienting of visual attention may be seen as crucial factors in the efficacy of treatment based on the balance model, as is suggested elsewhere (Lorusso et al., 2004), and may offer a bridge to interpretation of data in the frameworks of the magnocellular (Stein, 2001) or the cerebellar (Nicolson & Fawcett, 1990) theories.

Essential in the present study is the systematic manipulation of the flashing procedure, namely, the location and speed of presentation of the verbal stimuli on the computer screen. Tasks and reading materials, by contrast, remained constant and type-appropriate throughout the study.

First, the role of hemisphere-specific stimulation was challenged by inclusion of a group of children who received central presentation of the stimuli, implying the simultaneous stimulation of both cerebral hemispheres. Furthermore, comparing the outcomes of central presentation with and without tachistoscopic flashing times may reveal indications as to the importance of speed of processing and hemispheric integration in the treatment of dyslexia.

Even more challenging is reversing the flashing procedure, namely, stimulating the hemisphere that, according to the balance model, is considered to be overactivated already, instead of the underactivated one. This manipulation has produced controversial results in previous studies (Bakker, 2006; Dryer, Beale, & Lambert, 1999). Should reversed HSS and HSS reveal similar results, it would be evident that the side of brain stimulation is not of great importance in the production of reading improvement. A procedure less deviant from the standard one is stimulating each hemisphere in a random, alternating fashion. In this case, activation is evoked sometimes in the appropriate hemisphere, sometimes in the other. At the same time, however, the type of material and the type of tasks (which are a fixed factor and therefore don’t change) are specifically designed to involve the appropriate hemisphere. This means that about half of the times an incongruence is created between the specific functions subserved by the addressed hemisphere and the type of task and material to be processed. This incongruence is presumably solved by interhemispheric exchange of information. A further characteristic of this type of stimulation is that the unpredictability of the side where the stimuli will be presented decreases the possibility to preorient visual attention toward that side and/or is likely to induce a wider, more diffuse mode of attention (Lorusso, Facoetti, Toraldo, & Molteni, 2005).

A different type of manipulation concerns the exclusive stimulation of the RH, with the assumption that attentional processes, predominantly subserved by the RH (see Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991), are more directly addressed.

In addition to reading accuracy, reading speed, and proficiency in writing to dictation, two possibly interceding factors were explicitly investigated in the present study: phonemic awareness and verbal memory skills (see e.g., Snowling, 2001; Swanson et al., 2009). Since the results of earlier studies suggested that tachistoscopic central stimulation is the most effective treatment for
improving the spelling abilities of M-types (Lorusso et al., 2004), while the comparison of V-HSS with a control treatment in P-, L-, and M-type dyslexic children (not distinguishing among subtypes) showed an advantage of V-HSS for reading accuracy, phonemic awareness, and verbal memory, it was predicted that comparable results would emerge in the present, larger sample of subtyped dyslexic children.

**Method**

**Participant Selection**

For this study, 123 children with developmental dyslexia, ranging in age between 7 and 15 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 by a team of child neuropsychiatrists and psychologists according to 1992 ICD-10 inclusion and exclusion criteria. 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 following testing procedure section), despite a normal IQ (>85) as assessed by the Wechsler Intelligence Scale for Children—Revised (Wechsler, 1986).

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

**Classification of Dyslexia**

All children were classified as P-, L-, or M-dyslexics on the base of their reading speed and reading errors (classified as either “time-consuming,” i.e., slow decoding–based errors, allowing correct identification of the word, or “substantive” errors, i.e., anticipation-based errors, resulting in substitutions of the word or parts of it), according to the following formula (based on Bakker, 1990, and similar to the classification used by Dryer et al., 1999—although the last authors did not take reading speed into account):

- **P-type**, if reading speed is at least 1 SD below age mean (i.e., $z < -1$) and the proportion of time-consuming errors over total errors is ≥60%;
- **L-type**, if reading speed is no more than 1 SD below age mean (i.e., $z \geq -1$) and the proportion of substantive errors over total errors is ≥60%;
- **M-type**: in all other cases (prevalence of time-consuming errors but reading speed above –1 SD; prevalence of substantive errors but speed below –1 SD; presence of an equivalent number of both kinds of errors).

**Cognitive and Neuropsychological Tests**

All children were tested before and after treatment. Assessment involved reading and spelling skills, phonemic awareness, and verbal memory skills. The tests most commonly employed in the assessment of reading disabilities in Italy were used. No reading comprehension assessment was included in the protocol, considering that comprehension is usually a minor problem in the Italian dyslexic population and that the study specifically addressed remediation of decoding difficulties.

The results of the tests, with the exception of phonemic awareness tasks, are expressed as $z$ scores according to age norms.

The following tests were administered in the pre- and posttest sessions.

- **Text reading.** The Prove di rapidità e correttezza nella lettura del gruppo MT (Test of Speed and Accuracy in Reading, developed by the MT Group) (Cornoldi, Colpo, & Gruppo MT, 1986), a text-reading task meant to assess reading abilities for meaningful material, was used. It provides separate scores for speed and accuracy.$^2$ Texts increase in complexity with grade level. Norms are provided for each text. This task was also used for classification of dyslexia according to Bakker’s model (P-, L-, or M-type), based on error type and reading times (see previous section).

- **Single word/nonword reading.** The Batteria per la Valutazione della Dislessia e Disortografia Evolutiva (Battery for the Assessment of Developmental Reading and Spelling

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**Table 1. Descriptive Data for the Five Groups**

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<tr>
<td>Number of participants</td>
<td>13 (12 male, 1 female)</td>
<td>33 (29 male, 4 female)</td>
<td>22 (18 male, 4 female)</td>
<td>18 (15 male, 3 female)</td>
<td>15 (13 male, 2 female)</td>
<td>9 (6 male, 1 female)</td>
<td>13 (8 male, 5 female)</td>
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<tr>
<td>Mean age (SD)</td>
<td>9.69 (1.65)</td>
<td>10.18 (1.86)</td>
<td>10.55 (1.76)</td>
<td>10.78 (2.10)</td>
<td>11.07 (1.44)</td>
<td>11.44 (1.94)</td>
<td>10.62 (1.85)</td>
</tr>
<tr>
<td>Mean full IQ (SD)</td>
<td>105.38 (10.42)</td>
<td>104.35 (13.08)</td>
<td>98.52 (11.55)</td>
<td>97.82 (8.50)</td>
<td>101.54 (8.95)</td>
<td>103.88 (11.27)</td>
<td>100.64 (6.33)</td>
</tr>
<tr>
<td>Type of dyslexia</td>
<td>3 L, 3 P, 7 M</td>
<td>5 L, 15 P, 13 M</td>
<td>5 L, 4 P, 13 M</td>
<td>2 L, 5 P, 11 M</td>
<td>1 L, 7 P, 7 M</td>
<td>2 L, 7 P</td>
<td>13 M</td>
</tr>
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Note: CONTR = control group; V-HSS = standard lateral presentation; RLP = random lateral presentation; CP = central presentation (tachistoscopic); CP-FT = central presentation, fixed time; R-HSS = reversed lateral presentation; RH-stim: stimulation of right hemisphere only.
Persisting 45 minutes each, over a 4-month period, approximately,

Treatment was carried out in individual sessions twice a week,

Treatment Procedures

For all groups except the control group, treatment was carried out by trained speech therapists. All children had been recently diagnosed and had not been treated before.

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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 times, which varied between 250 and 100 milliseconds). The children were treated in line with the suggestions made by Bakker and colleagues (Bakker, 1990; Bakker, Licht, & Kappers, 1995). Thus, L-type stimulation was given by tachistoscopic presentation of perceptually complex, low-frequency (difficult to anticipate) words. 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 to a specific part or feature of the word, and repeat the presentation of the word.

A description of the procedures applied for each treatment group follows:

- Group 1 (33 children): standard lateral presentation, according to Bakker’s model (V-HSS). The L-type stimuli (first 2 months only in the case of M-types) were presented to the left visual hemifield (to stimulate the right hemisphere), and the P-type stimuli (last 2 months in the case of M-types) were presented to the right visual hemifield (to stimulate the left hemisphere).
- Group 2 (18 children): randomized lateral presentation (RLP). By means of an option of the computer program, the stimuli were randomly flashed to either the left or the right of the fixation point.
- Group 3 (22 children): central presentation (CP). All the stimuli were flashed in the center of the computer screen (fixation point), and presentation time was kept below 250 milliseconds.
- Group 4 (15 children): central presentation with fixed time (CPFT). The stimuli were flashed in the center of the computer screen, with a fixed presentation time of 1,500 milliseconds (long enough
to allow eye movements for visual scanning of the stimulus).

- Group 5 (9 children): reversed lateral stimulation (R-HSS). L-types were presented with stimuli in the right visual hemifield (to stimulate the left hemisphere), and P-types were presented with stimuli in the left visual hemifield (to stimulate the right hemisphere). No M-types were included.

- Group 6 (13 children): right-hemisphere-only stimulation (RH-stim). This kind of treatment was used with M-types only (since stimulation of the RH in L-types would have been coincident with standard V-HSS, in P-types with reversed R-HSS). The children were presented with the same materials as the other M-types, but the stimuli were always flashed in the left visual field.

The control treatment (CONTR, 13 children) consisted of an aspecific kind of intervention, often adopted by Italian speech therapists to treat specific reading disorders. The treatment is based on various existing intervention programs for the remediation of dyslexia. Specific tasks focus mainly on training of phonological skills and perceptual prerequisites, re-education by means of guided reading tasks, or strengthening of compensatory strategies. The range of activities that the children would be involved in had been discussed within the whole group of therapists before the beginning of the study. On the whole, the individual control programs, although not identical, addressed basically the same range of functions and could therefore be considered sufficiently homogeneous to be used as a control reading program. To preserve the distinctive features of the treatments, use of tachistoscopic presentation was precluded in the control program.

None of the children were included in any other form of intervention, be it at school or in clinical settings. Following the usual practice in Italy, all children attended mainstream schools and classes.

Children belonging to the six groups were treated by the same team of speech therapists, who had been specifically trained and supervised in the application of the treatments by the first two authors. It should be noted that in the Italian health system, speech therapists are the professionals specialized in the treatment of both oral and written language problems. The therapists were informed about the aims of the study, but there are no reasons to assume that they had specific expectations about the outcomes that could bias the results in one way or another.

Assignment of children to the different treatment groups was pseudorandom, namely, it was ensured that age and sex were homogeneously distributed across groups. At a further check, IQ and pretest reading levels were also shown to be comparable across groups ($p > .05$ at $t$ tests).

### Statistical Analyses

All tests were administered both before and after treatments. Five global scores (in z scores) were computed for pre- and posttests separately:

- a. global accuracy score, namely, the average of accuracy scores in text, word, and nonword reading;
- b. global speed score, namely, the average of speed scores in text, word, and nonword reading;
- c. global spelling score, namely, the average of scores in word, nonword, and sentence writing from dictation;
- d. global phonemic awareness error score, namely, the average of phonemic blending and phonemic elision scores;
- e. global memory score, namely, the average of scores for short-term memory, working memory, long-term memory, and verbal learning.

The standard pretreatment global scores were subtracted from posttreatment global scores to reveal global change scores, indicating improvement or worsening of performance.

The change scores of reading accuracy, reading speed, writing to dictation, phonemic awareness, and memory were each analyzed through univariate analysis of variance. Type of treatment—CONTR, V-HSS, CP, RLP, CPFT, R-HSS (in P- and L-types only), and RH-stim (in M-types only)—was the single independent variable in each analysis. Due to the theoretically (and practically, in terms of treatment procedures) separate status of M-type dyslexia, it was decided to consider the results of the L- and P-dyslexic children separately from those of the M-dyslexic children. A further reason to do so was that M-dyslexic children rather than R-HSS received right hemisphere stimulation (RH-stim), thus making it impossible to have a complete subtype by treatment design.

Even if the different profiles of reading performance in P- and L-types would lead to different expectations as to specific improvements to be found in the two subgroups, it was decided to pool the two groups because of the small number of L-types. Whenever relevant to the interpretation of significant results, nonparametric tests were used to check for differential effects of P- versus L-types.

It should be noted that only differential effects (within subtype groups) will be reported in the results, as general improvements after the various types of treatment were not the focus of the present analysis.

Finally, the involvement of reading-related functions (phonemic awareness and verbal memory) in observed changes of reading and spelling skills was explored through regression analysis.
Results

The results obtained in the various treatment groups are summarized in Table 2.

Planned Comparisons

One of the goals of this study was to highlight the role of some treatment-tied mechanisms that may be crucial in producing improvement of reading and reading-related skills. For this purpose, a number of planned comparisons of global difference scores were performed between types of treatment, either for specific subtypes or for the whole group of dyslexic children (according to each specific hypothesis).

Hemispheric specificity. V-HSS, namely, stimulation of the underactivated hemisphere (the “appropriate” hemisphere according to the balance model) in P- and L-types was compared to R-HSS, namely, stimulation of the overactivated...
hemisphere (the “inappropriate” hemisphere). The results of the \( t \) test on the five global change scores showed significant differences for both reading accuracy, \( t(27) = 2.54, p = .017, \) partial \( \eta^2 = .193 \); (V-HSS: \( M = 1.36, SD = 1.16 \); R-HSS: \( M = 0.27, SD = 0.79 \)), and phonemic awareness errors, \( t(23.082) = -2.49, p = .02, \) partial \( \eta^2 = .143 \); Levene’s test\(^6\) for equality of variance: \( F(14, 6) = 5.36, p = .028 \) (V-HSS: \( M = -2.60, SD = 2.3 \); R-HSS: \( M = -0.83, SD = 1.5 \)).

**One versus two hemispheres.** V-HSS was compared to central stimulation (CP) with tachistoscopic presentation to evaluate the role of single hemisphere versus bihemispheric stimulation. This comparison, in P- and L-types (M-types were excluded as they received stimulation of both hemispheres, but in a sequential fashion), revealed one significant difference in the decrease of global phonemic awareness errors, \( t(27) = -2.43, p = .022, \) partial \( \eta^2 = .179 \), to the advantage of V-HSS (V-HSS: \( M = -2.48, SD = 2.3 \); CP: \( M = -2.28, SD = 2.6 \)). Other global differences were not found significant.

**Speeded versus steady.** Comparison of CP and CPFT, respectively providing tachistoscopic, decreasing versus longer, constant presentation times (1.5 seconds) in the central visual field, across subtypes, yielded a significant difference for improvement in global spelling skills, \( t(35) = 2.10, p = .043, \) partial \( \eta^2 = .122 \), with CP being more effective (CP: \( M = 2.3, SD = 2.0 \); CPFT: \( M = 1.03, SD = 1.4 \)).

**Consistent versus inconsistent (random) hemisphere-specific stimulation.** No significant differences were found comparing V-HSS with RLP, including all subtypes.

**Simultaneous versus alternating stimulation of the two hemispheres.** When comparing RLP with CP, including all subtypes, CP was found to produce nearly significantly higher global spelling improvement than RLP, \( t(38) = 1.95, p = .06, \) partial \( \eta^2 = .091 \) (RLP: \( M = 0.98, SD = 2.2 \); CP: \( M = 2.3, SD = 2.0 \)).

**Hemisphere-appropriate versus RH-only stimulation.** To explore the role of attentional processes, the effects of specific hemisphere stimulation (V-HSS) in M-types were compared with those of stimulation of the right hemisphere only (RH-stim). V-HSS (stimulation of the RH first and the LH later) appeared to produce significantly greater improvement of global phonemic awareness, \( t(14.619) = -2.13, p = .05, \) partial \( \eta^2 = .160 \); Levene’s test of equality of variance: \( F(12, 12) = 11.87, p = .002 \) (V-HSS: \( M = -2.27, SD = 2.3 \); RH-stim: \( M = -0.8, SD = 0.8 \)).

### Evaluation of the Effectiveness of Treatment Programs on Reading and Reading-Related Skills

The analysis of differential effects of the different treatment programs was performed for the group of P- and L-type dyslexic children and the group of M-type dyslexic children separately.

**L- and P-Type Dyslexia.** Type of treatment was found to have a significant effect on improvement in reading accuracy, \( F(5, 58) = 2.54, p = .04, \) partial \( \eta^2 = .19 \). Only V-HSS appeared to deviate significantly from average improvement across types of treatment (\( p = .02 \)). V-HSS differed significantly from R-HSS and from CPFT (in both cases, \( p = .02 \)) but not so from any of the other types of treatment (\( ps > .10 \)). The effects of treatment on the improvement of reading accuracy are graphically presented in Figure 1.

Type of treatment was not found to have any significant effect on reading speed, writing to dictation, and memory (\( ps > .10 \)) but did approach statistical significance for phonemic awareness, \( F(5, 57) = 2.17, p = .07, \) partial \( \eta^2 = .17 \), indicating that V-HSS and CP were (nearly) significantly better (\( p = .01 \)) and worse (\( p = .07 \)) than average improvement across types of treatment and significantly different from each other, \( t(27) = -2.43, p = .02 \) (see Figure 2).

**M-Type Dyslexia.** Type of treatment appeared to significantly affect global spelling improvement, \( F(5, 61) = 2.64, p = .03, \) partial \( \eta^2 = .19 \). CP showed significantly better improvement than average across types of treatment (\( p < .001 \)). The effects of treatment on global spelling abilities are rendered in Figure 3.

Memory was found nearly significantly affected by type of treatment, \( F(5, 56) = 2.29, p = .06, \) partial \( \eta^2 = .18 \). RLP produced significantly worse results than average across types of treatment (\( p < .001 \)).

No significant differences were produced by type of treatment with regard to reading accuracy, reading speed, and phonemic awareness (\( ps > .10 \)).

### Regression Analyses

In exploring the mechanisms possibly implicated in the treatment-induced improvement of reading accuracy and writing to dictation, the association between improvement in phonemic awareness and memory on the one hand and improvement of reading accuracy and writing to dictation on the other was investigated, both across treatments and within the most effective treatments.

**P/L: Across treatments.** The linear regression of global improvement of reading accuracy in P- and L-types on global improvement of phonemic awareness and memory were both found significant: phonemic awareness: \( \beta = -.289, F(1, 53) = 4.24, p = .028 \); memory: \( \beta = .337, F(1, 53) = 6.79, p = .012 \).**

**P/L: Within V-HSS.** Global improvement of reading accuracy did not significantly regress on global improvement in phonemic awareness but did so on global improvement of memory: \( \beta = .525, F(1, 18) = 6.85, p = .017 \).

**M: Across treatments.** Global improvement in global spelling abilities appeared to regress nonsignificantly on global improvement in phonemic awareness and significantly—but
negatively so, $\beta = -0.298, F(1, 54) = 5.27, p = .02$—on global improvement of memory.

**M: Within CP.** Global improvement of spelling abilities was not found to regress significantly on global improvement of phonemic awareness or on global improvement of memory (possibly due to low cell frequency).

### Discussion

It is evident that the treatments produce different results in L- and P-dyslexic versus M-dyslexic children, as accuracy of reading appears to benefit from the V-HSS treatment in L- and P-types and spelling abilities (writing to dictation) from the CP treatment in M-types. This difference suggests that type-specific lateral stimulation (V-HSS) is an appropriate choice to improve reading accuracy in L-/P-dyslexia, but not so to improve spelling abilities in M-dyslexia. Since improvement of writing to dictation in M-dyslexic children was found as a result of central stimulation with short and steadily decreasing presentation times (CP), it may be hypothesized that this type of central stimulation, involving both hemispheres simultaneously, is crucial in the treatment of spelling difficulties. It is known that dyslexic children may have deficits in callosal functions (e.g., Gross-Glenn & Rothenberg, 1984) and interhemispheric connectivity as measured by EEG left-right coherence (Dhar, Been, Minderaa, & Althaus, 2009; Leisman, 2002) or fMRI (Shaywitz et al., 2003). Now, when a word is flashed in the central visual field, half of that word is processed by the RH and the other half by the LH, so that interhemispheric integration is called for, and possibly improved, in order to process the whole word (see Lorusso et al., 2004). This hypothesis finds support in the comparison showing that global spelling improvement was greater in the groups receiving bihemispheric stimulation (CP and CPFT, $M = 1.78, SD = 1.88$) than in those receiving single-hemisphere stimulation (V-HSS, RLP, RH-stim, and R-HSS, $M = 0.98, SD = 1.73; t(1, 107) = -2.231, p = .028$, partial $\eta^2 = .044$). Alternatively, it could be the case that the speeding up of the presentations in the CP condition is a crucial factor in causing improvement of spelling skills in M-dyslexia (Lorusso et al., 2004). As laterality of stimulation and speed of stimulation are confounded in V-HSS, it cannot be precluded that speeded information processing also plays a role in the V-HSS–induced increase...
of reading accuracy in L-/P-children. However, one might wonder why other types of treatment equally requiring accelerated processing of information failed to produce similar results. Thus, if increase of processing speed through shortening of presentation times plays any role in inducing reading improvement, it seemingly does so in interaction with other factors.

On the whole, selectively addressing the right cerebral hemisphere in L-type dyslexic children and the left hemisphere in P-types seems the best choice when it comes to improving accuracy of reading in these children. Indeed, V-HSS was the only treatment producing better than average improvement. Nevertheless, some caution as to the unique effect of V-HSS is in place, given the finding that the effects of neither CP (flashing words in the central visual field) nor RLP (flashing words in the right or left visual field in an alternating fashion) differed significantly from the effect of V-HSS. The most challenging procedure, however (R-HSS)—addressing the hemisphere that seemingly is already strongly, or even overly involved in reading—was definitively found inferior to the standard procedure (V-HSS). This outcome contrasts with the research-based conclusion of Dryer et al. (1999) that standard and reversed hemisphere-specific stimulation produce comparable results.

Improvement in phonemic awareness and memory appeared to go with improvement of reading accuracy within V-HSS, suggesting that these functions play a prominent role (see e.g., Ramus et al., 2003; Snowling, 2001; Swanson et al., 2009).

At this point, it may be relevant to define more precisely the specific effects of V-HSS.

In P- and L-type dyslexic children, this treatment was found to improve both reading accuracy and phonemic awareness. Phonemic awareness is usually associated with left hemisphere functions, especially those of the left inferior frontal gyrus (e.g., Pugh et al., 2001). However, the present data do not support the idea that left hemisphere stimulation is the key factor in improving phonemic skills. At first sight, the role of the left hemisphere for phonemic awareness may seem to be confirmed in M-types by the advantage of V-HSS (stimulating the right hemisphere first and the left hemisphere later on) as compared to RH-only stimulation. Yet, an ad hoc comparison (Mann-Whitney testing was applied considering low cell frequencies) of P- and L-types, separately, in the V-HSS group versus the group receiving reversed stimulation (R-HSS) challenges this assumption. Indeed, V-HSS produces greater improvement than reversed stimulation in both subtypes, significantly so for L-types, who received stimulation of the right hemisphere in V-HSS ($U < .001$; $Z = -1.95, p = .05$; V-HSS: $M = -5.30, SD = 0.91$; R-HSS: $M = -2.0, SD = 0.70$), nonsignificantly yet apparently so for P-types (who received stimulation of the left hemisphere in V-HSS) ($U = 33.0, Z = -1.39, p = .16$; V-HSS: $M = -1.70, DS = 1.82$; R-HSS: $M = -0.50, SD = 1.50$). Interhemispheric exchange of information and callosal functions have also been argued to be crucial for phonological processing (Moore, Brown, Markee, Theberge, & Zvi, 1996). If so, one would predict that a training providing speeded stimulation in the central visual field (CP) would improve phonological processing. Such an improvement, however, did not show up in the present research, and central presentation was even found to have the worst effects on phonemic awareness for P- and L-types.

Somewhat surprising, neither V-HSS nor any other mode of single or dual hemisphere stimulation were found to induce treatment-specific improvement of memory. But memory did improve significantly across treatments, $F(1, 54) = 16.68, p < .001$, which suggests that any of the current neuropsychological treatments is beneficial to memory, and—given the significant association between improvement in reading accuracy and improvement of memory—it is possible that the reading improvement is in part due to memory improvement. Conversely though, it could be that systematic reading exercise—not necessarily through single hemisphere stimulation—gives rise to improvement of memory processing, which in turn might benefit accuracy in reading.

Unexpected and not easy to account for is the significant negative correlation found in M-types between improvement in spelling abilities and improvement in memory: the less improvement in memory, the more improvement in spelling abilities and improvement in memory: the less improvement in memory, the more improvement in writing to dictation, $F(1, 53) = 13.53, p = .001$. A tentative explanation could be that different, conflicting processing modes are called into play, in that writing words and sentences requires access to the orthographic store (whole-word representations), while letter span requires serial processing. Albeit a very speculative explanation, such a conflict might also account for the decrease in global memory scores induced in M-types by random lateral presentation (possibly associated with a more diffuse attentional mode—see Lorusso et al., 2005—not favoring serial processing in letter span). This hypothesis may find partial confirmation in the negative association being essentially due (among the components of global spelling improvement) to sentence writing to dictation, $\beta = -.901, F(1, 5) = 21.44, p = .006$.

Taken together, these results suggest that taking into account individual characteristics and choosing type-appropriate treatment procedures, rather than employing rigid, general procedures based on standard neuropsychological models of brain functioning, are crucial in efforts to enhance phonemic awareness and other reading-related skills.

The difficulty to employ general neuropsychological models in explaining the differences observed between dyslexics and their different responses to remediation is probably due to a variety of factors. One might observe for instance that most neuroimaging studies on developmental dyslexia take
into account word decoding only, while little attention is paid to more sophisticated types of linguistic analysis, involving morpheme and text processing as well, as is suggested by the balance model. As already pointed out by Zaidel (1985), the only truly exclusive function of the left hemisphere is syntactic processing, while reading comprehension (semantic) is based on a complex, as yet unclear interplay between the two hemispheres. There may be a need for a further distinction within the “linguistic” approach to reading, described in Bakker’s model as the extraction of linguistic cues from the text that can help anticipate the word to be read. Now, these cues may differ as to the cerebral hemisphere mainly involved in processing: the left hemisphere for lexical (and morphologic?), phonological, and syntactic cues and the right hemisphere for semantic-pragmatic cues. Moreover, while these factors can probably be isolated in single-word reading, it is not clear how neatly the two kinds of cues can be distinguished during text (and context) processing. Recent studies (Richards et al., 2006), for instance, propose that words are coded according to three kinds of mapping: orthographic, morphological, and phonological, each one represented in a different brain region. According to this model, dyslexia would be caused by reduced connectivity between the left inferior frontal gyrus (substrate of phonological word forms) and the homologue part of the right hemisphere, which seems to be involved in (compensatory processes of) written word learning and in the representation of orthographic forms.

Although the present study produced a number of clear-cut results, some caution is called for. Individual cell frequencies are rather small, and due to low frequencies, L- and P-dyslexic children had to be pooled in one group, which precludes a thorough evaluation of all dyslexia types separately.

Nonetheless, some conclusions seem warranted.

First, the different effects obtained for P-, L-, and M-type dyslexic children suggest that accurate subtyping of dyslexia is a relevant step in designing appropriate, effective treatment programs.

Second, the different effects of the various types of treatment on different components of reading and spelling skills suggest that a clear definition of the main goal to be obtained and the subsequent choice of a specific treatment procedure are recommended.

More precisely, V-HSS seems to be the most effective treatment for the improvement of reading accuracy in P- and L-type dyslexic children. Hemisphere-inappropriate stimulation (R-HSS) was shown to be significantly less effective than hemisphere-appropriate stimulation (V-HSS), thus confirming the role of specific, hemisphere-related strategies in reading accuracy improvement.

Central tachistoscopic presentation (CP), rather than single-hemisphere stimulation, seems to be the most effective treatment for M-dyslexic children if improvement of their spelling abilities is called for. Forcing the two hemispheres to integrate parts of relevant information (as required by central tachistoscopic presentation) thus seems to produce advantage in the process of spelling. However, improvement in phonemic awareness is not induced by this type of treatment.

Finally, treatments that do not involve tachistoscopic, accelerated presentation in general seem to be little effective, suggesting a crucial role of fostering speed of processing and automatization in reading and writing (see also Nicolson & Fawcett, 1990).

So far, the starting hypotheses, based on either the results of previous studies or further theoretical speculations, have been generally confirmed.

Stimulation of the right hemisphere only, as applied in M-dyslexic children, failed to produce particular advantages in the treatment of dyslexia. Nor was any advantage found for right hemisphere stimulation versus left hemisphere stimulation in a further check across treatment groups and dyslexia subtypes (i.e., including both type-appropriate and type-inappropriate treatments: all ps > .15). These findings, more generally, might suggest that even if attention disorders play a crucial role in producing reading difficulties (Casco, Tressoldi, & Dellantonio, 1998; Faccoetti et al., 2005; Faccoetti, Paganoni, & Lorusso, 2000; Hari & Renvall, 2001), and in spite of the evidence showing that V-HSS can improve visual spatial attention in dyslexic children (Faccoetti et al., 2003), a treatment procedure that specifically fosters RH activation does not seem to be an advantageous procedure in M-type dyslexics.

Although the present data give firm indications as to the need of individualizing intervention based on thorough neuropsychological testing, further research is clearly needed to (a) confirm the results on larger samples of subtyped dyslexic children; (b) confirm the validity of the present results, or give possibly different indications for type/treatment interactions in nontransparent orthographies; and (c) add information as to the functional and structural modifications in brain organization (especially referring to interhemispheric organization) following specific intervention programs, for instance through neuroimaging techniques.

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Notes

1. Wechsler’s Wechsler Intelligence Scale for Children–Revised (WISC-R) was used instead of more recent versions because it was the only scale with adequate translation and norms for the Italian population at the time the study.

2. Norms are based on a sample of 292 to 864 (differing among the single texts) children. Validity and reliability scores are reported as adequate (Cornoldi, Colpo, & Gruppo MT, 1986).

3. Norms are based on a sample of 929 children from various parts of the country. Validity and reliability scores for the tests included in this battery are all above .70. Cross-correlation with MT text reading scores is .74.

4. Norms are based on a sample of 1,342 children. Test–retest reliability scores for the tests included in this battery are all above .70. Cross-correlations of the tests used in the present study with WISC-R Digit Span subtest scores are all above .47.

5. Number of children assigned to the different groups varies according to the number of different conditions involved in each treatment, the frequency of the addressed subtypes, and combinations thereof. For instance, in standard lateral presentation (V-HSS), the left hemisphere, the right hemisphere, or both hemispheres (three options) are stimulated according to subtype, whereas in central presentation (CP), central presentation, fixed time (CPFT), or random lateral presentation (RLP), both hemispheres (one option) are always stimulated; stimulation of right hemisphere only (RH-stim) addresses only one specific hemisphere and one (frequent) subtype, and finally, the group receiving reversed lateral presentation (R-HSS) includes two subtypes (but the less frequent ones).

6. Levene’s test values are reported only when indicating significant differences in variances between the two groups: In these cases, adjusted t test results are reported.

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