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# Developmental Dyslexia and Explicit Long-Term Memory

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The reduced verbal long-term memory capacities often reported in dyslexics are generally interpreted as a consequence of their deficit in phonological coding.

The present study was aimed at evaluating whether the learning deficit exhibited by dyslexics was restricted only to the verbal component of the long-term memory abilities or also involved visual-object and visual-spatial domain. A further goal of the present study was to investigate the predictive value of non-verbal long-term memory abilities with respect to word and non-word reading in dyslexic children.

In accordance with these aims, performances of 60 dyslexic children were compared with that of 65 age-matched normal readers on verbal, visual-spatial and visual-object task.

Results documented a generalized impairment of episodic long-term memory capacities in dyslexic children and the results did not vary as a function of children's age.

Furthermore, in addition to verbal measures, also individual differences in non-verbal long-term memory tasks turn out to be good predictors of reading difficulties in dyslexics.

Our findings indicate that the long-term memory deficit in dyslexia is not limited to the dysfunction of phonological components but also involves visual-object and visual-spatial aspect, thus suggesting that dyslexia is associated to multiple cognitive deficits. Copyright © 2010 John Wiley & Sons, Ltd.

**Keywords**: reading; visual long-term memory; spatial long-term memory; non-verbal abilities; learning abilities

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## INTRODUCTION

Developmental dyslexia (DD) is commonly defined as a disability in learning to read, occurring in children with normal intelligence, no sensory or neurological impairment and conventional instruction and socio-economic opportunity (DSM IV). The prevalence of this disorder in the school population varies across countries and languages. It is higher (4–12%) in languages characterized by non transparent orthography, such as English, and lower (3–8%) in those characterized by strict grapheme—phoneme correspondence, such as Italian (Lindgren, De Renzi, & Richman, 1985). In spite of these epidemiological data, many authors believe that DD is a linguistic disorder and, more specifically, the consequence of a phonological disorder. Infact, evidence accumulated over two decades strongly supports this hypothesis (for a review see Dèmonet, Taylor, & Chaix, 2004; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Children with DD usually have great difficulty in analyzing and processing phonological characteristics of spoken words (Snowling, 1987; Snow, Burns, & Griffin, 1998). Thus, for example, dyslexics may be impaired in generating rhymes (Bradley & Bryant, 1983) or in subdividing a word into its single phonemes (Pennington, Van Orden, Smith, Green, & Haith, 1990; Shaywitz *et al*., 1998).

Although it is generally well accepted that DD may be based on a phonological disorder, other hypotheses have also been advanced. Namely, visual processing linked to the transient or magnocellular visual subsystem is often impaired in these individuals (Eden & Zeffiro, 1998; Lovegrove, 1993), as well as auditory processing (Tallal, 1980), attention (Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000), information processing speed (Nicolson & Fawcett, 1995), visual-spatial skills in complex working memory tasks (Smith-Spark, Fisk, Fawcett, & Nicolson, 2003) and implicit learning (Vicari, Marotta, Menghini, Molinari, & Petrosini, 2003; Vicari *et al*., 2005).

As a consequence, it has been suggested that DD may be associated with multiple cognitive disorders (Pennington, 2006).

Both morphological and functional neuroimaging investigations have linked the variety of cognitive dysfunctions observed in people with DD to abnormalities at the level of brain areas subserving these abilities. So, adults with DD show an atypical pattern of activation in the brain regions usually involved in phonological processing (Paulesu *et al*., 1996, 2001). In particular, dyslexic readers only partially activate posterior regions (Wernicke's area, the angular gyrus and striate cortex) and exhibit reduced or absent activation on the left temporo-parietal cortex when performing tasks that demand phonological awareness (Hoeft *et al*., 2007).

Atypical activations in DD are also found in the left prefrontal regions associated with verbal working memory, in some cases related to reading ability rather than DD (Hoeft *et al*., 2007). Moreover, functional magnetic resonance imaging studies devoted to exploring visual processing abilities in individuals with DD revealed little activation in portions of the magnocellular visual system in response to the perception of subtle changes in motion (Eden *et al*., 1996). Irregular brain morphology has also been detected in regions associated with executive functions and in subcortical areas (Galaburda, 1993; Hynd *et al*., 1995; Riccio & Hynd, 1996). Finally, observations made with magnetic resonance spectroscopy (Rae *et al*., 1998), positron emission tomography (Nicolson *et al*., 1999) and



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functional magnetic resonance (Menghini, Hagberg, Caltagirone, Petrosini, & Vicari, 2006) reported cerebellar dysfunction in dyslexic adults, thus suggesting that the cerebellum may be one of the key structures implicated in DD.

In summary, DD appears to involve a widespread neurocognitive system of integrated brain functions and regions. Consequently, the hypothesis of the exclusive phonological defect as determining dyslexia is under critical reconsideration and the study of neuropsychological profiles in dyslexics is increasing.

In line with this theoretical framework, it is of some relevance to investigate long-term memory (LTM) capacities of people with DD. Indeed, as Kipp and Mohr (2008) reported in their recent paper '… It is generally accepted that learning to read requires specific memory functions, which might be selectively damaged' (p. 40). The available literature on LTM capacities of individuals with DD is, however, inconsistent. Indeed, although some studies suggest an impairment of implicit learning in dyslexics (Vicari *et al*., 2003, 2005), others do not support this finding (Kelly, Griffiths, & Frith, 2002; Waber *et al*., 2003). Even more controversial are results on explicit LTM. For example, Bell (1990) found no differences between high school students with and without DD on a visual sequential memory task; conversely Watson and Willows (1995) demonstrated impaired visual sequential memory abilities in a group of dyslexic children. Furthermore, reduced verbal LTM capacities often reported in dyslexics have been interpreted as a consequence of their deficit in phonological coding, thus reconducting the learning impairment to the reduced phonological encoding capacities (Vellutino, Scanlon, & Spearing, 1995).

The present study was aimed at clarifying the nature of the LTM deficit in DD. In particular, we were interested in evaluating whether the deficit exhibited by persons with DD was restricted only to the verbal component or also involved visual-object and visual-spatial domain. Our predictions were the following: First, because of the findings supporting phonological and semantic processing deficits in people with DD, we predict reduced verbal LTM in dyslexics. Second, if the LTM deficit in dyslexics actually results from reduced verbal capacities needed to effectively encode to material to be learned, then no differences in visual and spatial LTM should be observed between dyslexics and normal readers. Should we observe reduced performance scores in the group of dyslexics in the visual-object and visual-spatial tasks too, then the conclusion that LTM deficits in DD is exclusively related to impaired lexical-semantic functionality should be reconsidered.

A second goal of the present study was to investigate the predictive value of non-verbal long-term memory abilities with respect to word and non-word reading in dyslexic children. The possible finding that the reading deficit observed in our group with DD could be at least partially explained by their non-verbal LTM capacities would further weaken the hypothesis of the exclusive phonological defect as determining dyslexia.

## METHODS

### Participants

We examined the performances of two groups of individuals. The first group consisted of 60 children and adolescents with DD (M/F = 33/27; *M* age = 11.4 ± 1.9,



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range = 8.4–17.6). Sixty-five children and adolescents normal readers (NR) formed the second group (M/F = 37/28; *M* age = 11.9 ± 1.8, range = 8.1–15.7).

To take into account developmental changes in the long-term memory domain, we split each of the two groups of participants into two subgroups based on ages. The first subgroups included children in primary school, with a chronological age equal or under 11 years, and were composed of 29 dyslexic children (M/F = 15/14; *M* age = 9.8 ± 0.7, range = 8.4–10.9) and 19 NR (M/F = 8/11; *M* age = 9.85 ± 0.93, range 8.1–10.9). The second subgroups included children in middle and secondary school, with a chronological age equal or above 11 years, and were composed of 31 dyslexic children (M/F = 18/13; *M* age = 12.94 ± 1.32, range 11–17.6) and 46 NR (M/F = 29/17; *M* age = 12.81 ± 1.25, range 11–15.7).

The clinical diagnosis of DD was made on the basis of the DSM-IV recommendations (American Psychiatric Association, 1994). The group with DD included only individuals whose reading speed or accuracy level were at least 2 standard deviations below the mean of their chronological age on the word or non-word reading subtests of the Battery for the Diagnosis of Dyslexia (Sartori, Job, & Tressoldi, 1995). Other criteria for inclusion in the group with DD were the following: normal general intelligence, as documented by a WISC-R (Wechsler, 1986), IQ of no less than 90; performance above the 10th percentile on the Coloured Progressive Matrices (Raven, 1984); normal or corrected to normal visual acuity; no other significant co-morbidity, such as attention deficit or hyperactivity disorder. The control group was matched with children with DD for chronological age, non-verbal intelligence and socio-economic level. The criteria for inclusion in the control sample were the same as those for the group with DD. The only obvious difference was that these individuals should perform in the normal range on the word and non-word subtests of the Battery for the Diagnosis of Dyslexia (Sartori *et al.*, 1995).

The exclusion of children with ADHD in the group with DD and in the control group was decided on the basis of an Italian version of the ADHD rating scale for parents (SDAG) (Cornoldi, Gardinale, Masi, & Pettenò, 1996), as well as a clinical examination. If the score in the ADHD rating scale for parents was above 1.5, children were excluded from the study. For the clinical examination, DSM-IV criteria for ADHD were used. Children with five or more inattentive/hyperactive symptoms were also excluded (children whose levels of symptom approached but did not reach clinical levels).

Children with DD were tested at the *Children's Hospital Bambino Gesú* in Santa Marinella (Rome, Italy). NRs forming the control group were instead individually evaluated at school. Observations were carried out after informed consent had been obtained from all participants and their families, and the study had been approved by the local ethical committee.

## Design and Materials

A test battery was administered to children individually in two testing sessions on separate days, each session lasting approximately one hour and half. In the first session the general intelligence and reading tests were administered. The second session was spent completing the memory tests.



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*General Intelligence Measures*

- Coloured Progressive Matrices CPM (Raven, 1984).
- Wechsler Intelligence Scale for Children, Wisc-R (Wechsler, 1986).

*Reading Assessment*
The speed and accuracy of reading were assessed using The Battery for the Diagnosis of Dyslexia and Dysorthographia (Sartori *et al.*, 1995). Two subtests from the Battery were chosen. In the first subtest, participants had to read aloud 4 lists of 28 concrete and abstract, high or low frequency words (4–8 letters in length). In the second task children had to read 4 lists of 16 legal non-words (5–9 letters in length). The number of errors and the average speed in reading words were computed and considered as a measure of inefficient reading. The ratio between word and non-word reading speed (in seconds) and accuracy rate (number of words and non-words read correctly by the total number of words and non-words read) was also obtained and considered an inefficiency reading index.

*Verbal, Visual-Object and Visual-Spatial Long-Term Memory*
Three tests were used for the assessment of verbal, visual-object and visual-spatial LTM (Vicari, 2007). In the *Word-list Learning Task*, participants are given a list of 15 semantically unrelated words. The list is presented orally by the examiner for three consecutive times and each time the participant is asked to immediately repeat as many items as possible in any order. The total number of words recalled in the three trials gives the performance score.

During the study phase of the *Visual-Object Learning Task*, 15 coloured drawings of common objects (e.g. a tree, a knife, a flower) are shown to the participant. Each figure is presented individually for 5 s. During the test phase, which immediately follows the study phase, 15 pages are presented to the participant in succession. Four different versions of the same object (e.g. 4 trees, 4 knives, 4 flowers) are depicted on each page; only one of the four is the same as the target object in the study phase while the other three are physically different distracters. The participant is asked to indicate the figure, which has been previously studied. The choice to use different representations of the same object as distracters in the recognition phase was aimed at minimizing the adoption of verbal coding and/or retrieval strategy. Study and test phases are presented for three consecutive times and the number of elements correctly recognized in the three trials is scored.

Fifteen figures of common objects are also presented in the study phase of the *Visual-Spatial Learning Task*. In this case, however, the pages are divided into four quadrants and each figure is positioned in one of the quadrants. During the test phase, which follows immediately the study phase, the target stimuli are presented individually and the participant is asked to indicate the position occupied by the figure on an empty page sub-divided into four quadrants. Similar to the other two tasks, the test is repeated three times. The total number of correct recognitions in the three trials is scored.

## Statistical Analysis

Performances on the LTM tasks were analyzed by means of a Multivariate Analysis of Variance (MANOVA) with Group (NR vs DD) as between-subject



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factor and Learning Task (Word-List vs Visual-Spatial vs Visual-Object) and Trial (I vs II vs III) as a within-subject factors. Significance of simple effects and interactions were then qualified by Tukey post hoc tests.

To determine whether, in children with DD, reading abilities were predicted by non-verbal long-term memory abilities, a hierarchical regression analysis with 2 steps was computed. The dependent variable was the inefficiency reading index for the word or for the non-word, and the predictors were performance scores on the Word-List Learning Task (entered at step 1) and performance scores on the Visual-Spatial and Visual-Object Learning Tasks (entered at step 2).

## RESULTS

Table 1 reports mean and standard deviations of performance scores achieved by individuals in the DD and NR groups on the verbal, visual-spatial and visual-object tasks. Eta squared of group difference were also reported.

Results of the MANOVA showed a significant effect of Group ($F_{(1,\ 123)} = 38.44$, $p < 0.001$, $\eta^2 = 0.238$), with NR recalling on the average more items than children with DD ($M = 11.1 \pm 0.97$ and $M = 10.0 \pm 1.08$, respectively), a significant effect of Learning Task ($F_{(2,\ 246)} = 179.79$, $p < 0.001$, $\eta^2 = 0.584$), with scores on the verbal memory task ($M = 8.7 \pm 1.8$) lower than on the visual-object task ($M = 10.6 \pm 1.7$, $p < 0.001$, $\eta^2 = 0.224$) which, in turn, were lower than on the visual-spatial task ($M = 12.4 \pm 1.8$, $p < 0.001$, $\eta^2 = 0.181$). The Trial effect was also significant ($F_{(2,\ 246)} = 1114.2$, $p < 0.001$, $\eta^2 = 0.897$), with scores in Trial I ($M = 8.0 \pm 1.2$) lower than on Trial II ($M = 11.2 \pm 1.4$, $p < 0.001$, $\eta^2 = 0.402$) which, in turn, were lower than on Trial III ($M = 12.4 \pm 1.4$, $p < 0.001$, $\eta^2 = 0.298$). All the interactions resulted statistically significant and, particularly, the triple interaction Group × Learning Task × Trial ($F_{(4,\ 492)} = 2.75$, $p = 0.03$, $\eta^2 = 0.015$) which is shown in Figure 1.

Concerning performances on the Word-List and the Visual-Spatial Learning Tasks, post hoc analyses documented higher performances in the NR than in dyslexics in all three trials (all $p < 0.001$, see Table 1 for the respective $\eta^2$) and both groups increased performance scored over trials (all $p < 0.001$; for Word-list Learning Tasks respectively $\eta^2 = 0.375$ passing from I to II and $\eta^2 = 0.615$ passing from Trials II to III; for Visual-Spatial Learning Tasks respectively $\eta^2 = 0.481$

Table 1. Mean and Standard deviations for verbal, visual-object and visual-spatial memory by groups and trials ($\eta^2$ for each group difference are shown below)

| | Trial | Verbal memory Mean (SD) | Visual-object memory Mean (SD) | Visual-spatial memory Mean (SD) |
|---|---|---|---|---|
| DD | I | 5.6 (1.6) | 7.1 (2.5) | 10.10 (2.3) |
| NR | | 6.8 (1.4) | 6.9 (1.7) | 11.5 (2.3) |
| $\eta^2$ | | 0.125 | 0.001 | 0.084 |
| DD | II | 8.0 (2.2) | 11.5 (2.4) | 12.2 (2.3) |
| NR | | 10.0 (1.9) | 12.2 (1.8) | 13.4 (1.7) |
| $\eta^2$ | | 0.199 | 0.033 | 0.080 |
| DD | III | 9.6 (2.5) | 12.5 (2.1) | 13.1 (1.9) |
| NR | | 11.6 (1.7) | 13.4 (1.4) | 14.1 (1.5) |
| $\eta^2$ | | 0.181 | 0.057 | 0.081 |



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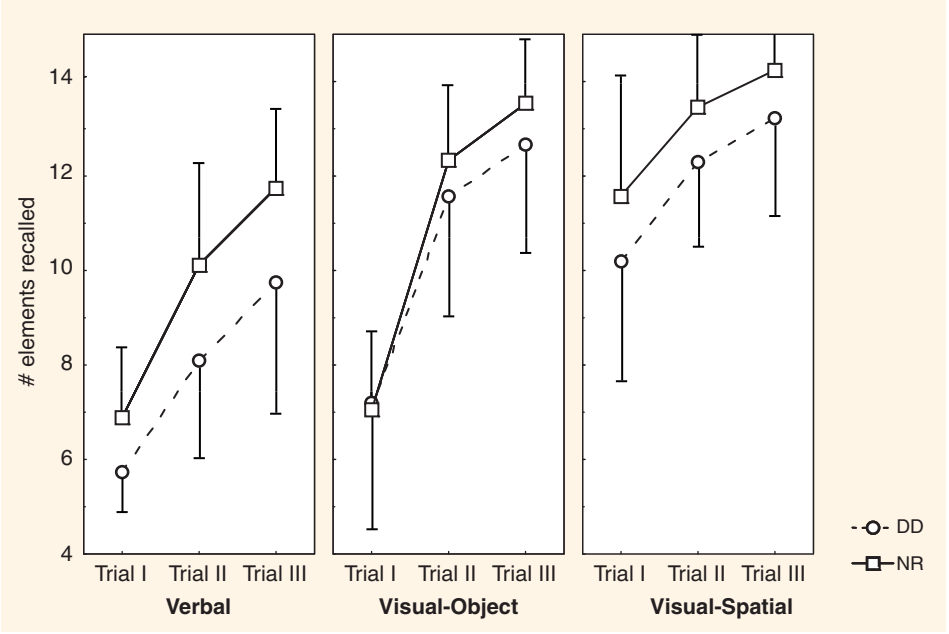


Figure 1. Learning performance over the three trials for verbal, visual-object and visual-spatial tasks obtained by dyslexics and normal readers.

passing from Trials I to II and $\eta^2 = 0.574$ passing from Trials II to III). On the Visual-Object Learning Task, groups did not differ in Trial I ($p > 0.10$, $\eta^2 = 0.001$), but NRs obtained higher scores than dyslexics in Trial II ($p = 0.02$, $\eta^2 = 0.033$) and in Trial III ($p < 0.01$, $\eta^2 = 0.057$). However, both groups improved their performances passing from Trials I to II and from Trials II to III (all $p < 0.001$, respectively $\eta^2 = 0.216$ passing from Trials I to II and $\eta^2 = 0.631$ passing from Trials II to III).

In summary, DD children showed reduced memory abilities in all the three tasks. However, albeit differences between the two groups were consistent across the three trials on the Word-List and Visual-Spatial learning Tasks, on the Visual-Object Learning Task differences between groups emerged in the Trials II and III.

To confirm the learning deficit over the trials in dyslexics, for each task a learning rate has been computed from the difference between the scores of Trials III and I. Results of the MANOVA showed a significant effect of Group ($F_{(1,\ 123)} = 15.50$, $p < 0.001$, $\eta^2 = 0.112$), with higher scores for NR than children with DD ($M = 6.36 \pm 1.2$ and $M = 5.53 \pm 1.08$, respectively), a significant effect of Learning Task ($F_{(2,\ 246)} = 245.75$, $p < 0.001$, $\eta^2 = 0.666$), with a learning rate on the verbal memory task ($M = 9.0 \pm 2.1$) higher than on the visual-object task ($M = 5.9 \pm 2.1$, $p < 0.001$) which, in turn, was higher than on the visual-spatial task ($M = 2.8 \pm 2.0$, $p < 0.001$). Also, the interaction Group $\times$ Learning Task resulted statistically significant ($F_{(2,\ 246)} = 7.96$, $p < 0.001$, $\eta^2 = 0.06$). Post hoc analyses documented that in each group the learning rate obtained on the verbal memory task was higher than on the visual-object task, which, in turn, was higher than on the visual-spatial task (all $p < 0.001$). Groups showed differences on the Word-List and the Visual-Object Learning Tasks (all $p < 0.001$), while on the Visual-Spatial Learning Task, the learning rate of the groups did not differ.



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To take into account developmental changes in the long-term memory domain, we repeated the analyses of performance scores achieved by individuals with DD and NR on the verbal, visual-spatial and visual-object tasks after splitting each of the two groups of participants into two subgroups based on ages and school grade. Performance scores of dyslexics and NR were analyzed by means of a $2 \times 2 \times 3$ mixed ANOVA with Group (NR vs DD) and Age (Younger vs Older) as between-subject factors and Learning Task (Word-List vs Visual-Spatial vs Visual-Object) as within-subject factor. Critically, the Age effect was significant ($F_{(1, 121)} = 35.78$, $p < 0.001$, $\eta^2 = 0.228$), with the younger children ($M = 9.92 \pm 0.9$) scoring consistently lower than the older children ($M = 10.94 \pm 0.87$). The Age × Learning Task interaction was also significant ($F_{(2, 242)} = 4.63$, $p = 0.01$, $\eta^2 = 0.037$). Post hoc analysis did not reveal differences between the two subgroups in the Word-List Learning Task but in the Visual-Spatial Learning Task and in the Visual-Object Learning Task (all $p < 0.001$), with the younger children scoring consistently lower than the older ones. Conversely, the Group × Age ($F_{(1, 121)} = 0.036$), the Trial × Age ($F_{(2, 242)} = 2.62$), the Trial × Age × Learning Task ($F_{(4, 484)} = 0.298$), the Trial × Group × Age ($F_{(2, 242)} = 0.34$), the Trial × Age × Learning Task ($F_{(2, 242)} = 0.72$), the Trial × Age × Group × Learning Task interactions ($F_{(4, 484)} = 0.137$) were not significant.

To determine whether there was some predictive relationship in the DD group between LTM and reading abilities, hierarchical regression analyses with 2 steps was computed. In a first analysis, the inefficiency reading index for words was entered as the dependent variable, while the sum of scores on the three trials of the Word-list Learning Task was entered as independent variable at step 1, and the sum of scores on the three trials of the Visual-Spatial and of the Visual-Object Learning Tasks was entered at step 2. Overall, the regression model accounted for 16.7% of the variance in the word reading inefficiency index. The word-list learning task accounted for 8.1% of variance ($F_{(1, 58)} = 7.05$, $p = 0.03$), while performance on the non-verbal tasks accounted for 12.9% of unique variance in the word reading inefficiency index ($F_{(2, 56)} = 4.5$, $p = 0.01$). An analogous hierarchical regression equation with the inefficiency reading index for non-words as the dependent variable did not reveal any significant effect.

## DISCUSSION

Results of the present study documented a generalized impairment of episodic LTM capacities in dyslexic children. Specifically, we reported reduced verbal as well as visual-spatial and visual-object LTM capacities in a group of children with DD as compared with a group of age-matched normal readers. Differences between dyslexics and NR still persist when data analyses were repeated after splitting each group of participants into two subgroups based on ages. As expected, independently of groups, younger children scored consistently lower than the older ones, thus confirming that learning abilities increase with age. However, the interaction between Age and Learning Tasks resulted significant for the Visual-Spatial Learning Task and for the Visual-Object Learning Task but not for the Word-list Task. As a possible interpretation of this finding, characteristic of the verbal task may be considered. Indeed, the task consisted of a list of 15 semantically unrelated words and it could be that words included in



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the list are not so familiar to the children of the ages considered. Of course, more data should be needed in order to better clarify this result.

Crucially for the aims of our study, children with DD obtained lower score than NR on all the tasks considered independently of ages, thus suggesting a generalized memory impairment of DD at all the ages considered.

Moreover, albeit dyslexics and NR improved their performances throughout the three trial of each task, differences between the two groups were consistent across trials (except for the Trial I of the Visual-Object Learning Task). Similarly, the learning rate of dyslexics was in mean less than that disclosed by normal readers and, in particular, groups showed differences in the learning rate of the Word-List and the Visual-Object Learning Tasks.

If we distinguish between immediate memory, involved particularly in recalling items after Trial I, and learning abilities, considered as the difference between items recalled in Trials III and I, dyslexic children exhibited deficits in both domains. Indeed, children with DD scored significantly lower than NR in Trial I (except for the Visual-Object Learning Task) and exhibited in mean lower learning rates.

Our findings indicated the presence of reduced episodic verbal LTM capacities in DD although our previous data documented dyslexics performed similarly to NR on some explicit learning tasks but not on implicit ones (Vicari *et al*., 2003) and theoretical framework (Nicolson & Fawcett, 2007) have proposed procedural learning deficits but intact explicit learning abilities in DD. A possible interpretation for confounding results is that similar behavioural outcomes can be achieved by different memory systems (Nicolson & Fawcett, 2007). Declarative and procedural memory systems form a dynamically interacting network and a dysfunction or underuse of one system, as the procedural network, can lead to a reduced learning in the other system, as the declarative system. Although we are aware that no task is exclusively implicit or explicit, further studies, in which tasks are capable of differentiating between functional systems, are needed.

However, the verbal LTM deficit is not isolated, but it is the expression of a more generalized impairment of LTM, which is independent from the nature of information that must be remembered (i.e. verbal, visual-object or visual-spatial). Consequently, these results do not support the hypothesis that the LTM deficit in dyslexics is exclusively related to specific difficulties in verbal information processing (Vellutino *et al*., 1995). By contrast, our findings are consistent with previous reports, which showed LTM deficits in dyslexics for both visual and verbal material (Watson & Willows, 1995).

Two alternative accounts may be proposed for a deficit involving the long-term maintenance of multi-modal information, as we observed in the dyslexics participating in the present study. Information coding difficulties due to reduced verbal, visuo-perceptual and attentional capacities must be initially considered.

Following this hypothesis and concerning verbal LTM, it can be supposed that dyslexics exhibit verbal LTM deficits as a consequence of their well-documented reduced phonological processing and lexical-semantic abilities (Vellutino *et al*., 1995). A reduced vocabulary, in fact, is considered a common trait characterizing dyslexics (Gabrieli, 2009) and it may have a negative effect on verbal LTM capacities by interfering with deep, elaborative encoding of the incoming information (Jones, Gobet, & Pine, 2007). On the other hand, reduced visual perceptual abilities in dyslexics have been extensively reported (for a review see,



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Stein & Walsh, 1997) and converging data document impaired visual-spatial and motion perception capacities in DD (Felmingham & Jakobson, 1995; Talcott, Hansen, Assoku, & Stein, 2000). Reduced capacity to allocate visual and auditory attentional resources has also been documented in dyslexic individuals (e.g. Facoetti *et al*., 2000). For example, in a recent study from our group (Menghini, Finzi, Carlesimo, & Vicari, in press), we investigated verbal, visual-spatial and visual-object Working Memory abilities in children and adolescents with DD and normal readers. Results documented poor performances of individuals with DD compared to normal readers on all the span tasks administered, thus showing that Working Memory deficit in DD is not just limited to a dysfunction of the phonological component, but it also engages visual-object and visual-spatial data. Attentional and visuo-spatial perceptual abilities were also investigated in the study (Menghini *et al*., accepted), and they resulted significantly deficitary in children and adolescents with DD with respect to normal readers.

A second hypothesis for the finding of multiple modality LTM dysfunction in DD is that these individuals suffer from deficits in long-term storage mechanisms, thus resulting in a reduced formation and/or in an accelerated decay over time of memory traces. The controversy between a deficitary encoding of incoming information vs impaired storage capacities may not be solved based on the presently reported data. Experimental paradigms testing delayed retention of verbal and/or visual data after controlling for effective encoding of the study material could be of help in this regard.

Results of the hierarchical regression analyses, relating reading to LTM abilities in DD individuals, showed that, in addition to verbal measures, also individual differences in non-verbal LTM tasks turn out to be good predictors of their reading difficulties, accounting for 12.9% of unique variance in word reading. These results reinforce the view that reading difficulties in dyslexic children are not only related to a phonological disorder, but that they also depend on non-verbal cognitive impairments. These data on visual-spatial and visual-object LTM capacities in DD are relatively new and further studies investigating the causal relationship between reading and non-verbal LTM abilities are needed.

Our results are consistent with a growing number of studies which supports the hypothesis of DD related to multiple cognitive deficits rather than to a mere effect of a phonological disorder as well documented by recent study (Menghini *et al*., 2010). Moreover, in dyslexic children individual differences in non-phonological abilities accounted for a relevant quota of unique variance of word as well as non-word reading after controlling for age, IQ and phonological skills (Menghini *et al*., 2010). Finally, a reduced ability to learn procedural skills has been repeatedly documented in individuals with DD (Nicolson & Fawcett, 1990; Nicolson, Fawcett, & Dean, 2001).

Nonetheless, as noted by others (Fawcett & Nicolson, 2007), the matter remains controversial (for example, see Ramus, Pidgeon, & Frith, 2003). To address this issue and try to reconcile different hypotheses a three-level—brain, cognition, and behaviour—description of phonological, magnocellular and cerebellar hypothesis has been proposed (Fawcett & Nicolson, 2007). Accordingly to this view, reading deficits arise primarily from phonological problems, but may also arise from more general automatization problems or from eye control difficulties. The phonological problems may arise from Sylvian fissure abnormalities alone, or from any combination of Sylvian fissure, cerebellar



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and/or magnocellar abnormalities. This analysis provides a plausible explanation for why there is a very high percentage of phonological problems in DD, but that the incidence of cerebellar problems is lower, as is the incidence of magnocellular problems.

In conclusion, we report evidence that children with DD suffer from reduced explicit LTM not only for verbal material as predicted by the 'core phonological deficit' hypothesis but also for visual and spatial material. As a consequence, to try to better understand possible factors linked to the peculiar reading pattern of children with DD, other components, beyond typically studied aspects (i.e. verbal abilities), have to be taken into account.

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