A DEFICIT IN ENCODING THE ORDER OF VISUAL SEQUENCES IN DEVELOPMENTAL DYSLEXIA. A NON-PHONOLOGICAL DEFICIT

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A Non-Phonological Deficit

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The present thesis tested the hypothesis of Stanovich, Siegel, & Gottardo (1997) that surface dyslexia is the result of a milder phonological deficit than that seen in phonological dyslexia coupled with reduced reading experience. We found that a group of adults with surface dyslexia showed a phonological deficit that was commensurate with that shown by a group of adults with phonological dyslexia (matched for chronological age and verbal and non-verbal IQ) and normal reading experience. We also showed that surface dyslexia cannot be accounted for by a semantic impairment or a deficit in the verbal learning and recall of lexical-semantic information (such as meaningful words), as both dyslexic subgroups performed the same. This study has replicated the results of our published study that surface dyslexia is not the consequence of a mild retardation or reduced learning opportunities but a separate impairment linked to a deficit in written lexical learning, an ability needed to create novel lexical representations from a series of unrelated visual units, which is independent from the phonological deficit (Romani, Di Betta, Tsouknida & Olson, 2008). This thesis also provided evidence that a selective nonword reading deficit in developmental dyslexia persists beyond poor phonology. This was shown by finding a nonword reading deficit even in the presence of normal regularity effects in the dyslexics (when compared to both reading and spelling-age matched controls). A nonword reading deficit was also found in the surface dyslexics. Crucially, this deficit was as strong as in the phonological dyslexics despite better functioning of the sublexical route for the former. These results suggest that a nonword reading deficit cannot be solely explained by a phonological impairment. We, thus, suggested that nonword reading should also involve another ability relating to the processing of novel visual orthographic strings, which we called 'orthographic coding'. We then investigated the ability to process series of independent units within multi-element visual arrays and its relationship with reading and spelling problems. We identified a deficit in encoding the order of visual sequences (involving both linguistic and non-linguistic information) which was significantly associated with word and nonword processing. More importantly, we revealed significant contributions to orthographic skills in both dyslexic and control individuals, even after age, performance IQ and phonological skills were controlled. These results suggest that spelling and reading do not only tap phonological skills but also order encoding skills.

Keywords: adults with developmental dyslexia, surface and phonological dyslexia, lexical learning, print exposure, lexical-semantic impairments, nonword reading deficit, regularity effect, control children, order encoding, sequential processing, same-different array matching.

To my personal, social and professional development throughout my ten-year stay in the United Kingdom!

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Chapter 1

Low Print Exposure and Lexical-Semantic Impairments: Can they explain Developmental Dyslexia?

1 INTRODUCTION

1.1 Theoretical accounts of developmental dyslexia and its subtypes

Developmental dyslexia is a common neurocognitive disorder with genetic predisposition (potential gene markers for dyslexia have been identified in chromosomes 2, 3, 6, 15 and 18, Cardon et al., 1994, 1995; Willcutt & Pennington, 2000; Fisher & Smith, 2001), which affects the learning process in one or more areas of reading, spelling, writing ('agraphia'), and sometimes numeracy ('dyscalculia') despite normal intelligence, conventional instruction and adequate socio-cultural opportunities. Dyslexia is independent of socio-economic or language background. Accompanying weaknesses may be identified in areas of short-term memory (STM), speed of processing, sequencing, auditory/visual perception, spoken language and motor skills. Dyslexia was first introduced to the scientific literature more than a century ago, when a single case study of a bright boy who was unable to read was reported (Morgan, 1896; the disorder was then discussed under the term 'congenital word blindness', Hinshelwood, 1917). Approximately 5 to 10 % of the UK and US population is affected (Eden & Moats, 2002). Typically, more males than females are affected (2:3 to 4:5), although this gender discrepancy has also been attributed to selection bias (Habib, 2000; Shaywitz & Shaywitz, 2003). According to Shaywitz & Shaywitz (2003), up to 50% of children of parents with dyslexia, 50% of siblings of children with dyslexia and 50% of parents of children with dyslexia may exhibit symptoms of the disorder.

Decades of intensive research in cognitive neuropsychology, neuroscience and genetics have resulted in a number of proposals to account for dyslexia. There has been strong converging evidence that the underlying cause of the disorder is a 'phonological deficit' (Snowling, 1981, 2000, 2001; Bradley & Bryant, 1983; Wagner

& Torgesen, 1987; Stanovich, 1988; Wilding, 1989, 1990; Rack, Snowling, & Olson, 1992; Stanovich & Siegel, 1994; Lyon, 1995; Shankweiler et al., 1995; Share, 1995; Frith, 1997; Ramus et al., 2003; Bishop & Snowling, 2004; Ziegler & Goswami, 2005). According to the phonological deficit hypothesis, a difficulty in the short-term retention, segmentation, manipulation, storage and retrieval of the constituent phonemes of words in individuals with developmental dyslexia is the consequence of underspecified phonological representations. Deficits in the representation and use of phonological information result in poor grapheme-to-phoneme recoding leading to problematic acquisition of the alphabetic principle (Bryant & Bradley, 1985; Stanovich, 1988; Brady & Shankweiler, 1991; Griffiths & Snowling, 2002; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Ramus & Szenkovits, 2008). Poor phonological awareness (the ability to segment and manipulate the constituent sounds of the oral language) has been consistently reported in dyslexics (Blachman, 2000; Snowling, 2001; Vellutino et al., 2004, for a review).

According to the dual-route model of word recognition (Coltheart, 1978; Frith, 1985; Patterson & Morton, 1985; Coltheart et al., 1993; Castles and Coltheart, 1993) skilled readers use two different mechanisms in order to pronounce printed words: a 'sublexical' mechanism, which involves using the grapheme-to-phoneme conversion rules and a 'lexical' mechanism, which involves accessing the representations of whole words. Castles & Coltheart (1993) proposed that the two mechanisms are distinct in both developing and skilled readers, and hence there should be two main patterns of developmental dyslexia. Within the dual-route model framework, phonological dyslexia is characterised by a difficulty using the sublexical route mainly used to process nonwords, while surface dyslexia is characterised by a difficulty using the lexical route mainly used to process words with more atypical or unusual grapheme-to-phoneme mappings (exception, irregular or strange words). It has been well established that phonological dyslexics have more problems with processing nonwords than irregular words due to underspecified phonological representations (Temple & Marshall, 1983; Seymour & McGregor, 1984; Snowling, Stackhouse, & Rack, 1986; Temple, 1986; Snowling & Hulme, 1989; Funnell & Davison, 1989; Seymour & Evans, 1993), while surface dyslexics have more problems with processing irregular words than nonwords due to poor orthographic representations (Boder, 1973; Coltheart, Masterson, Byng et al., 1983; Temple, 1984;

Goulandris & Snowling, 1991; Hanley, Hastie, & Kay, 1992; Seymour & Evans, 1993; Castles & Coltheart, 1993, 1996; Mc Bride-Chang & Petersen, 1996; Valdois et al., 2003; Brunsdon, Coltheart, & Nickels, 2005). The phonological dyslexics have been found to differ qualitatively from both their chronological-age matched (CA) controls on both phonological and orthographic tasks and their younger reading-age matched (RA) controls on phonological but not on orthographic tasks, thus, fitting a 'developmentally deviant' profile (Snowling, 1981; Stanovich, Nathan, & Vala-Rossi, 1986; Lundberg & Høien, 1989; Stanovich & Siegel, 1994; Manis, Seidenberg, Doi, Mc-Bride-Chang, & Petersen, 1996; Stanovich, Siegel, & Gottardo, 1997; Curtin et al., 2001). By contrast, the surface dyslexics have been found to perform just like their younger RA controls but worse than their CA controls on both phonological and orthographic tasks, thus, fitting a 'developmentally delayed' profile (Bryant & Impey, 1986; Castles & Coltheart, 1993; Plaut & Shallice, 1994; Manis et al., 1996; Stanovich et al., 1997; Samuelsson, Finnström et al., 2000; Bailey, Manis, Pedersen, & Seidenberg, 2004). The phonological dyslexics are also less likely to produce phonologically plausible errors than the surface dyslexics, but more likely to make exception word errors that involve visual approximations to the target words than the surface dyslexics (Manis et al., 1996). The different orthographic symptoms shown suggest that there are distinct patterns of dyslexia at the extreme ends of the distribution of performance. The heterogeneity of the dyslexic manifestations and the report of dyslexic cases with no phonological impairments cannot be accounted for by the phonological deficit hypothesis, thus, raising the interesting possibility that some patterns of dyslexia (i.e. surface dyslexia) might reflect a non-phonological cognitive deficit (Romani & Stringer, 1994; Romani, Ward, & Olson, 1999; Di Betta & Romani, 2006; Romani, Di Betta, Tsouknida, & Olson, 2008).

Manis, Seidenberg, Doi, Mc Bride-Chang, & Petersen (1996) proposed that the deviant profile of phonological dyslexia is the result of poor phonological representations, while the delayed profile of surface dyslexia could be the result of orthographic deficits or could be attributable to a slower rate of learning or resource limitation (resembling 'mild retardation'), which leads to the slower mastery of grapheme-to-phoneme associations (see also Olson et al., 1994; Harm & Seidenberg, 1999; Windfuhr & Snowling, 2001). However, the hypothesis of a 'mild retardation' as a result of a developmental lag does not fit with the results of the surface group and single case studies of our research team (for a group study: Romani, Di Betta, Tsouknida, & Olson, 2008; for a single case study: Romani & Stringer, 1994; Romani, Ward, & Olson, 1999), which found normal IQ levels. This hypothesis is also not very consistent with the studies that have genotyped for DNA markers of reading disability (RD) or tested for brain structure differences in sib pairs (where at least one member had reading difficulties) and found a quantitative trait locus for RD (Cardon et al., 1994; Pennington, 1994; Olson, 2008). It also does not fit well with those studies that found no correlation between the degree of IQ-discrepancy and the differential heritability of orthographic deficits (Stevenson, Graham et al., 1987; Olson, Rack, Conners, DeFries, & Fulker, 1991; Stevenson, 1991).

Another account of phonological and surface dyslexia was provided by Stanovich, Siegel, & Gottardo (1997). The authors argued that both patterns of dyslexia arise from a core phonological deficit, but that the surface dyslexics have a 'milder phonological deficit conjoined with impoverished reading experience' (see also Manis et al., 1996; Harm & Seidenberg, 1999; Griffiths & Snowling, 2002). Stanovich et al. (1997) investigated phonological and reading abilities in phonological and surface dyslexic third graders compared to the CA and RA controls. They found that the phonological dyslexics showed a deviant profile, as they performed lower for both their chronological and reading age (on the phonological tasks when used both control comparisons and on the reading tasks when used the CA control comparison), while the surface dyslexics showed a delayed profile, as they performed normally for their reading age but lower for their chronological age (on both phonological and reading tasks). It was, thus, argued that both the phonological and the surface dyslexics suffered from a phonological deficit, but that this deficit was milder for the surface dyslexics. However, Stanovich et al. (1997) have not measured print exposure in the surface dyslexics to demonstrate that surface dyslexia is the result of poor experience in reading.

These accounts have prompted the controversial suggestion of the phonological deficit hypothesis that surface dyslexia might not be a separate impairment, but that it might arise from a mild retardation or a milder phonological deficit exacerbated by some non-specific disadvantage related to environmental factors, such as 'reduced learning opportunities' or 'poor print exposure'. The phonological deficit hypothesis has been challenged by connectionist models which have simulated both phonological and surface dyslexic profiles, by manipulating the phonological and orthographic input, respectively (Seidenberg & Mc Clelland, 1989; Plaut, Mc Clelland, Seidenberg, & Patterson, 1996; Manis, Seidenberg, Doi, Mc Bride-Chang, & Petersen, 1996; Harm & Seidenberg, 1999, 2004). These manipulations were based on variations of the so-called 'triangle model', which consists of three sets of interconnected representations: 'phonological', 'semantic' and 'orthographic' (Seidenberg & Mc Clelland, 1989).

Harm & Seidenberg (1999) have simulated the performance of phonological dyslexics by creating a connection system which learned to read with faulty phonological representations. This system was created by: a) imposing a degree of weight decay, b) removing a set of phonological clean-up units and c) adding Gaussian noise to the phonological activations. Such manipulations of varying degrees of severity impaired the model's capacity to represent phonological codes (but enhanced the employment of more general processing resources) resulting in poor nonword performance relative to exception word performance. They have also simulated the performance of surface dyslexics by: a) decreasing the amount of training provided to the model, b) altering parameters of the learning algorithm to produce a non-optimal learning rate, c) reducing the number of hidden units (an intervening layer of units between orthographic and phonological mappings) and d) degrading the orthographic input. Such manipulations of varying degrees of reduction in the number of hidden units slowed down the model's capacity to form grapheme-to-phoneme connections resulting in poor exception word performance relative to nonword performance. The behavioural equivalent of the first manipulation in the simulation of the surface dyslexic profile resembles inadequate reading experience, the second manipulation resembles reduced learning opportunities, the third manipulation resembles mild retardation and the fourth manipulation could resemble orthographic deficits.

However, a severe deficit in the phonological output would impair the model's capacity to learn the pronunciations of both nonwords and exception words (mixed dyslexia), while a milder deficit in the phonological output would impair the model's capacity to learn the pronunciations of nonwords but not of exception words (pure phonological dyslexia). Likewise, a small reduction of hidden units would impair the model's capacity to learn the pronunciations of exception words mainly, while a larger reduction of hidden units would show a disproportionate impairment with exception words compared to regular words or novel words with regular pronunciations. However, a recent study by Bailey et al. (2004) found that fourth and fifth grade children with phonological and surface dyslexia were less accurate than the CA controls at learning both regular and irregular pronunciations assigned to novel words.

Unfortunately, it is hard to predict the patterns of performance in phonological and surface dyslexia via the connectionist models, as no reading or chronological-age match control comparisons are provided to shed light on the deviant vs. delay distinction. In addition, connectionist models have not used an *a priori* definition of the sublexical or lexical component to simulate the dyslexic patterns or addressed the fundamental basis for the phonological impairment (i.e. whether it is specific to the phonological system or the result of a more peripheral sensory processing deficit). Finally, they have not included a mechanism for learning regularities from print-to-sound.

Further evidence against the phonological hypothesis that surface dyslexia is not a separate impairment but the result of a mild retardation and some non-specific disadvantage related to environmental factors, such as reduced learning opportunities, has been provided by our laboratory. In both their group and single case studies, Romani and colleagues have found that surface dyslexics had normal IQ levels (both verbal and performance) but showed a selective deficit in learning novel orthographic representations ('written lexical learning') in laboratory conditions, where learning opportunities were equated across groups (for a group study: Di Betta & Romani, 2006; Romani, Di Betta, Tsouknida, & Olson, 2008; for a single case study: Romani & Stringer, 1994; Romani, Ward & Olson, 1999). These results suggest that surface dyslexia is an independent impairment linked to a specific deficit in written lexical learning and cannot be accounted for by a mild retardation or reduced learning opportunities.

The present study complements and extends the results of Romani, Di Betta, Tsouknida, & Olson (2008) by measuring reading experience in both a population of adults with developmental dyslexia who showed a surface pattern of impairment in comparison with control individuals matched for chronological age, gender, education, performance and verbal IQ to the dyslexic population. It also measures reading experience in a group of adults with surface dyslexia in comparison with adults with phonological dyslexia (as defined by their spelling performance on nonword vs. irregular words) and control individuals matched for chronological age, performance and verbal IQ to the surface group. To achieve this, we used the Author Recognition Test, (refer to section 2.2.12 for a description), which is analogous to the measures used by previous researchers (Stanovich & West, 1989; Cunningham & Stanovich, 1990, 1991; Cipielewski & Stanovich, 1992; Stanovich & Cunningham, 1992, 1993; Stanovich, 1993; Lewellen et al., 1993; Mc Bride-Chang, Manis, Seidenberg, Custodio, & Doi, 1993; Castles, Datta, Gayan, & Olson, 1999; Cunningham, Perry, & Stanovich, 2001; Griffiths & Snowling, 2002). Our aim is to investigate the hypothesis that the poor orthographic lexicon in the surface dyslexics is the result of a milder phonological deficit than that seen in phonological dyslexia coupled with reduced reading experience (Stanovich et al., 1997). To measure phonological abilities we used tasks measuring both phonological STM and phonological awareness abilities. In addition, we examine the contribution of print exposure and different types of lexical learning (spoken, written, russian) to both reading and spelling skills of both dyslexic and control individuals, beyond the contribution of phonological processing skills, performance IQ and age.

1.2 Exposure to print and reading skills in control and dyslexic individuals

Phonological processing skills and the extent to which individuals engage in reading activities play a significant role to the efficiency of orthographic skills. However, there is a strong consensus that exposure to reading materials relates more strongly to the development of word recognition skills (build-up of the orthographic lexicon), while plays only an indirect role in the development of phonological processing (Stanovich & West, 1989; Cunningham & Stanovich, 1990; Cipielewski & Stanovich, 1992; Barker, Torgesen, & Wagner, 1992; Juel, 1994; Olson et al., 1994). Numerous studies have emphasized the importance of reading experience in reading and cognitive growth in control young and older individuals. For example, Stanovich

& West (1989) found that differences in the volume of reading experience in control adults, as measured by the Author Recognition Test (ART) and the Magazine Recognition Test (MRT), accounted for unique variance in the reading performance, independently of phonological processing skills. These results suggest that the adequacy of the orthographic lexicon is environmentally mediated, as it is linked not only to phonological processing skills but also to experience in reading. Later, Cunningham & Stanovich (1990) used an analogous measure of print exposure for children, the Title Recognition Test (TRT), which employed titles of books read outside the school curriculum. They showed that print exposure and phonological awareness skills had independent effects on reading performance in control third and fourth graders. Moreover, Stanovich and colleagues demonstrated that reading volume can account for a considerable amount of variance in knowledge and vocabulary acquisition among control children (Cunningham & Stanovich, 1991) and young adults (Stanovich & Cunningham, 1992; West & Stanovich, 1991). In another study, Stanovich & Cunningham (1993) also showed that differential reading experience in young adults, as indexed by scores on the ART, TRT and Newspaper Recognition Checklist (NRC), predicted variance in measures of general knowledge (which tapped cultural and multicultural literacy and practical knowledge), even after variance in general cognitive ability[1] was controlled.

Furthermore, Stanovich and colleagues investigated whether differential experience with print mediates age-related growth in declarative knowledge (as indexed by general cultural literacy and vocabulary) in college students, with a mean age of 19.1 years, and older individuals, with a mean age of 79.9 years (Stanovich, West & Harrison, 1995). They found that within each of the age groups, exposure to print was a significant predictor of declarative knowledge and vocabulary, even after differences in working memory, general cognitive ability (as measured by the Scholastic Aptitude Test) and educational level were controlled. More recently, Stanovich and colleagues measured orthographic processing (using Letter String, Orthographic Choice and Homophone Choice tasks), phonological processing (using Phonological Sensitivity, Nonword Repetition and Pseudoword Reading tasks) and print exposure (using the TRT) in control third graders (Cunningham, Perry, &

[1] As measured by high-school grade point average (GPA), Raven Advanced Progressive Matrices, Nelson-Denny Reading Test-Comprehension subtest and an arithmetical test.

Stanovich, 2001). They found that TRT abilities predicted a significant amount of variance in orthographic processing independently of phonological processing ability. In addition, Griffiths & Snowling (2002) measured the influence of reading experience, as reflected by scores on both the TRT and the ART measures, in individual differences in exception word reading of dyslexic children. They found that reading experience, as indexed by both reading age and print exposure, explained a significant amount of variance in exception word reading, while phonological awareness abilities did not make a significant contribution.

A number of studies have also shown that print exposure is implicated in growth in reading comprehension. In their longitudinal study, Anderson, Wilson, & Fielding (1988) observed that home reading time, as estimated by children's records of daily activities, predicted growth in reading comprehension in second to fifth-grade reading ability. In addition, Cipielewski & Stanovich (1992) examined whether engagement in reading accounted for individual differences in the growth of reading comprehension over a two-year school period (third to fifth grade), using more reliable measures, such as the ART and the TRT. They found that print exposure is both a consequence of developed reading comprehension and a significant contributor to further growth in that ability. Mc Bride-Chang, Manis et al. (1993) also examined TRT abilities in fifth to nine-grade poor readers and found that print exposure made a significant contribution to word reading and reading comprehension, even after phonological skills were accounted for. More importantly, Echols, West, Stanovich, & Zehr (1996) examined the relation between children's TRT and ART abilities and growth in a variety of reading subskills (i.e. reading comprehension, receptive and sight vocabulary, general information, spelling, verbal fluency) over a two-year school period (fourth to sixth grade). It was found that print exposure was an independent contributor to growth in verbal skills, even after age, recognition memory and previous performance in the same cognitive competency area were controlled. Cunningham & Stanovich (1997) also examined whether speed of early (Grade 1) reading acquisition (Stanovich, Cunningham, & Freeman, 1984) could predict tendencies to engage in reading activities in later (Grade 11) school life. It was found that lifetime reading habits, as measured by the ART and the MRT, in the later school years, were predicted by speed of early reading acquisition. This finding was true, even after controlling for reading comprehension ability in the later school years.

Individual differences in involvement to reading activities also predicted differences in the growth in reading comprehension throughout the elementary grades and thereafter.

Evidence against the hypothesis of reduced reading experience in surface dyslexia has been provided by several studies that measured print exposure in individuals with surface dyslexia as compared to individuals with phonological dyslexia and their chronological or reading-age matched controls. Castles, Datta, Gayan, & Olson (1999) used a test including names of books and magazines to measure reading experience in children with surface and phonological dyslexia (based on their respective nonword and irregular reading performance). They found that the surface dyslexic children obtained comparable scores on this measure with the phonological dyslexic children (z-scores: -1.3, for the surface group, and -1.0, for the phonological group). This indicates that poor print exposure cannot fully explain the poor lexical representations in surface dyslexia. In their longitudinal study, Manis, Seidenberg, Doi et al. (1996) found that young poor readers showed a small and unreliable deficit in exposure to print for their chronological age, as measured by their performance on the TRT. However, a subgroup of nine poor readers, classified as surface dyslexics (on the basis of their exception word reading), showed a marginally reduced ($p=.10$) reading experience for their chronological age. In another study, Manis, Seidenberg, Stallings et al. (1999) failed to find significant differences between the phonological and the surface dyslexics in the TRT scores. More recently, Gustafson (2001) used a questionnaire including 10 questions about reading habits in surface and phonological (and mixed-type) dyslexic children. Results showed that the surface-type children tended to report fewer books at home than the RA controls (or mixed-type children), but not fewer than the phonological-type children. Although the results of this study are in line with previous findings that a home literacy environment can predict early reading achievement (Leseman & de Jong, 1998; Sénéchal, Lefevre, Thomas, & Daley, 1998; de Jong & Leseman, 2001), they do not fully support the hypothesis that low print exposure can explain the poor lexical representations seen in surface dyslexia, as a poor literacy environment was also reported for the phonological-type children. In support of this claim, no differences were found on questions relating to children's current reading. Comparable TRT scores between surface and phonological dyslexic children have also been found by

Bailey, Manis, Pedersen, & Seidenberg (2004). The authors found no significant differences between the phonological or the surface dyslexic children and the RA controls. However, the CA controls scored higher than both dyslexic subgroups.

1.3 Lexical-semantic impairments in surface dyslexia

In terms of the dual-route model of reading, surface dyslexia arises from a primary reliance on the sublexical route by which pronunciations are assigned using spelling-to-sound correspondences that are consistent and regular. The characteristic reading pattern of surface dyslexia arises in the process of translating words with atypical spelling patterns into their corresponding phonology resulting in regularization errors. A problem with processing irregular words in surface dyslexia is attributed to poor semantic representations due to a difficulty using the lexical-semantic route. The lexical-semantic route is used to access the stored representations of words as a whole (word-specific information). According to Patterson & Hodges (1992), the integrity of lexical representations depends on the interaction between semantics and phonology. That is, semantic representations bind phonological representations together with semantic glue: the 'semantic binding hypothesis' by Patterson, Graham, & Hodges (1994). The authors argued that an impaired semantic system results in less stable lexical representations and this yields a surface dyslexic pattern. The interaction between semantics and phonology has also been supported by the 'summation hypothesis' of Hills & Caramazza (1991), which assumes that lexical representations are selected via the sum of the semantic system and the translation from orthography to phonology. Recently, Jefferies, Frankish, & Lambdon Ralph (2006) have also highlighted the importance of the semantic and phonology interaction in phonological coherence.

The lexical-semantic contribution also explains why recall is better for words vs. nonwords (Brener, 1940; Hulme, Maughan, & Brown, 1991; Romani et al., 1999, 2008; Di Betta & Romani, 2006), high vs. low frequency words (Watkins & Watkins, 1977; Gregg, Freedman, & Smith, 1989; Hulme et al., 1997; Roodneys & Quinlan, 2000), concrete vs. abstract words (Bourassa & Besner, 1994; Walker & Hulme, 1999) and semantically grouped vs. ungrouped words (Poirier & Saint-Aubin, 1995; Siant-Aubin & Poirier, 1999). Since words are remembered through their meanings as well as through their phonology, a poor interaction between semantics and phonology should yield poor performance on tasks of verbal recall and learning (i.e. verbal paired associates of the WMS-R and Rey Auditory Verbal Learning Test). Verbal recall and learning tasks involve the integration of semantic information and tap both STM and LTM. One view is that the conceptual or semantic component of these tasks is associated with LTM, while the lexical or phonological component is associated with verbal STM. One model that can accommodate the separate contributions of verbal STM and LTM in word recall is Baddeley's (2000) model of working memory. The central executive component of the model is a flexible system responsible for the control and regulation of cognitive processes including temporary activation of LTM (Baddeley, 1998), coordination of multiple tasks (e.g., Baddeley, Della Sala, Gray, Papagno, & Spinnler, 1997), shifting between tasks or retrieval strategies (Baddeley, 1996) and selective attention and inhibition (Baddeley, Emslie, Kolodny, & Duncan, 1998). This component is linked directly with three other subsystems: the phonological loop, which is responsible for temporary storage of verbal information, the visuospatial sketchpad, which stores representations of visual or spatial nature, and the episodic buffer, which is responsible for integrating information from different components of working memory and LTM into unitary episodic representations. In the Baddeley model, the episodic buffer component is responsible for integrating phonological information from temporary stores with lexical and semantic information from LTM systems. Word learning taps the episodic buffer, which integrates information from temporary memory subsystems such as the phonological loop to support the verbatim recall of individual words, with semantic information held in the LTM.

Patterson, Graham, & Hodges (1994) showed that individuals with semantic dementia (gradual loss of semantics) who show typical symptoms of surface dyslexia had more difficulty recalling unknown words (i.e. words with deteriorated meanings) than known words (i.e. words with preserved meanings). Results from other studies on semantically impaired patients with primary progressive aphasia[2] who also exhibit typical symptoms of surface dyslexia showed poor memory acquisition of pairs of words with and without semantic relations (as measured by the verbal paired

[2] A neurobehavioral disorder distinguished by slowly progressive language deterioration with relative sparing of other cognitive abilities and continued independence in activities of daily living (Mesulam, 1982; Weintraub, Rubin, & Mesulam, 1990). Language characteristics include loss of expressive vocabulary, severe anomia, semantic paraphasias, and impaired single word comprehension.

associates of the WMS-R) and poor delayed recall of single words (as measured by the RAVLT) (Graff-Radford et al., 1990; Green et al., 1990; Scheltens, Hazenberg, Lindeboom, Valk, & Wolters, 1990; Watt, Jokel, & Behrmann, 1997; Zakzanis, 1999). It has been suggested that memory acquisition and delayed recall deficits are secondary to language disorders or may represent a modality-specific memory deficit (Snowden et al., 1996; Zakzanis, 1999). In addition, Howes, Bigler, Lawson, & Burlingame (1999) found that their surface dyslexic patients were impaired at recalling stories, on both immediate and delayed conditions (as measured by the Test of Memory and Learning, TOMAL, of Reynolds & Bigler, 1994). This finding suggests that verbal recall is underpinned by activations from both phonological and semantic representations (see also Caza et al., 2002; Jefferies et al., 2005).

The 'multi-capacity STM model' of Martin, Shelton, & Yaffee (1994) maintains that the lexico-semantic contribution to verbal recall has to be realized through the semantic STM buffer. This suggests that an impairment in the recall of words with meanings is reflected by an impairment in the semantic memory[3]. More recently, Duff et al. (2005) found that memory for words (as measured by the verbal paired associates of the WMS-R and the RAVLT) is strongly associated with executive functioning[4]. This association is consistent across both immediate and delayed memory indices. They found that individuals who performed well on memory measures also performed well on the executive function tasks, while individuals who performed poorly on the memory measures also performed poorly on the executive function tasks. The high degree of overlap between verbal memory and executive functioning has also been shown by other studies on clinical cases (for <u>schizophrenic patients</u>: Fossati et al., 1999; Bryson et al., 2001; for <u>executive function impaired patients</u>: Tremont et al., 2000; for <u>mixed neurological patients</u>: Vanderploeg et al., 1994; for <u>patients with closed head injury</u>: Proctor et al., 2000; for <u>patients with frontal lobe lesions</u>: Luria, 1966).

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[3] Semantic memory refers to that portion of the LTM containing general knowledge about objects, facts, concepts as well as words and their meanings (Nebes, 1989; Patterson & Hodges, 1995; Tulving, 1972, 1995).

[4] This is a set of high-level cognitive abilities that influence more basic abilities (i.e. attention, memory and motor skills). Executive functions are necessary for goal-directed behaviour. They include the ability to initiate and stop actions, monitor and adapt behaviour to changing situations and to plan future behaviour when faced with novel tasks. They also influence memory abilities by allowing people to employ strategies than can help them remember information. The ability to form concepts and think in an abstract manner are often considered components of executive function.

2 METHOD

2.1 Participants

Dyslexic participants were recruited through several sources: the Disability and Additional Needs Unit of Aston University, the Student Counselling Centre of the University of Birmingham, the Birmingham Adult Dyslexia Group and advertisements posted at Aston University. The criteria for inclusion in the study were the following:

a) English as a native language.
b) Normal IQ (within 1SD) on the Weschler Adult Intelligence Scale-Revised (WAIS-R, Weschler, 1981).
c) Performance of at least 2SDs[5] below the control mean on tasks assessing either spelling or reading of words or nonwords. For reading trade-offs, speed and accuracy were taken into account. Therefore, participants were included in the study only if poor performance (≤2 SDs) in one measure did not correspond to above average performance in the other measure.
d) No history of neurological and psychological problems.

Control participants were recruited mainly through the Research Participation Scheme (RPS) of Aston University and advertisements posted at Aston University. Older controls were recruited through word of mouth. The criteria for inclusion in the study were the following:

a) English as a native language.
b) Normal IQ on the Weschler Adult Intelligence Scale-Revised (WAIS-R, Weschler, 1981).
c) No family history of spelling/reading difficulties.
d) No history of neurological and psychological problems.

For the purposes of the lexical learning tasks we used (for a description, refer to section 2.2.10), subjects had to have no prior knowledge of Dutch and Russian.

[5] According to the regression method used, at least in the UK, whereby there must be a significant discrepancy between the level of reading/spelling ability and the level of ability predicted by an individual's Full-Scale Intelligence Quotient.

We assessed a total of 100 adults consisting of 55 dyslexics (20 male and 35 female, 31 with a prior diagnosis of dyslexia and 24 self-referred for suspected dyslexia without previous formal assessment, mean age=27.2, SD=10.3, 44 with university education and 11 with secondary education) and 45 controls (9 male and 36 female, mean age=26.2, SD=11.1, 34 with university education and 11 with secondary education). The main concern of our dyslexic adults was more spelling than reading problems. This is consistent with previous research suggesting that spelling is a major and under-researched complaint in the adult population (Bruck, 1993; Holmes & Castles, 2001). From the total population, two dyslexics were excluded from the study because their performance on both reading and spelling tasks of words and nonwords was less than 2SDs from the control mean. Nine additional dyslexics and five controls were also excluded from the study because of incomplete data on critical tasks (i.e. single word and nonword reading and phonological processing). This left us with 44 dyslexics and 40 controls. Both groups were matched for age, gender, education, performance IQ and verbal IQ (the demographic data and cognitive performance of the dyslexics and controls and the group comparisons are presented in Table 1:1). From the 44 dyslexics, 23 had a formal diagnosis of dyslexia, 13 were self-referred for suspected dyslexia and 8 were self-referred as controls, but were found to perform at least 2SDs below the control mean in reading or spelling tasks of words or nonwords. Most of the impairments shown by the eight subjects affected nonword processing, which, to some extent, could explain their clinical under-detection. Since our study tapped variation with both word and nonword processing, these subjects were included in the dyslexic group. They showed a similar profile to the dyslexics but they were generally less severely impaired.

All participants were submitted to measures of performance and verbal IQ, reading comprehension, text reading, reading and spelling of single words and nonwords, phonological STM (digit span, nonword serial recall and word serial recall), phonological awareness (phoneme counting and spoonerisms), lexical learning (spoken and written) lexical-semantic learning (verbal paired associates of the WMS-R and RAVLT, both immediate and delayed versions) and print exposure (ART).

Testing was carried out in a quiet room at either Aston University or the University of Birmingham. All participants were assessed individually. The dyslexic individuals attended five to six separate sessions, each lasting for approximately two hours (including breaks, as required). They received course credits, payment or a detailed psychological assessment report for their participation. The control individuals attended four to five separate sessions, each lasting for approximately two hours (including breaks, as required). They received course credits or a payment for their participation.

Our study obtained the ethical approval of the Human Sciences Committee of Aston University. A thorough risk assessment including details of possible hazards, which could affect the health, safety or welfare of any participant was also undertaken. To ensure that the risks associated to test anxiety were controlled, we: a) explained all testing procedures in detail, b) had participants working at their own pace, c) reassured participants that everybody finds some tasks difficult, d) highlighted that participation is voluntary and that withdrawal is possible at any time during the testing without any consequences, e) made sure that testing was terminated as soon as the participant showed excessive anxiety. For claims against malpractice, the psychologist ultimately responsible for the testing had: a) a criminal record bureau enhanced disclosure, b) a chartered status, c) extensive competence and practice in cognitive testing. The administrator of the tests was under close supervisory control. All testing results were used for research purposes only. All personal details were strictly confidential and coded in an anonymous format. All data and testing materials were stored in password-protected computers or locked away in filing cabinets. Informed consent was obtained by all participants prior to the start of the experiment. Copies of the consent forms including information about the study given to the dyslexic and control participants are presented in Appendix 1.

In our published study (Romani, Di Betta, Tsouknida, & Olson, 2008), we assessed a smaller population consisting of 32 dyslexic and 38 control adults with university and secondary education and used the same inclusion criteria. We chose to investigate an adult rather than a younger population because: a) children have been extensively studied in the dyslexia literature and b) adults are more suitable to reveal the importance of other, non-phonological abilities in orthographic performance, since phonological skills have a reduced effect on orthographic performance at a later developmental stage (for reading and spelling: Bus & Van Ijzendoorn, 1999; Ehri, Nunes et al., 2001; for reading: Badian, 1995, 2000; De Jong & Van der Leij, 1999), whereas they play a crucial role in the early developmental phases of literacy acquisition and development (for reading: Perrin, 1983; Griffith, 1991; Leong, 1999; for spelling: Wagner & Torgesen, 1987; Goswami & Bryant, 1990; Windfuhr & Snowling, 2001). By studying adults, we also allow future longitudinal studies to track the contribution of different cognitive skills to orthographic performance at different developmental stages.

2.2 Materials (procedure and scoring)

Participants were submitted to the following tasks in a semi- random order:

2.2.1 General information questionnaire

To ensure that the inclusion criteria were fulfilled, we devised a list of questions which aimed at exposing the subjective and/or the documented information (in case of a formal diagnosis of dyslexia) about the participant's:

a) preschool and school history (i.e. long absences from school, changes of teachers or schools midyear)
b) possible problems occurring prenatally, at birth, or in the early developmental years (i.e. serious injuries, hospitalisations, severity of chickenpox or measles, mother's medication or allergies during pregnancy)
c) abilities in crucial developmental stages (i.e. crawling, general activity level, speech development)
d) possible hearing problems
e) possible colour-blindness
f) possible vision problems
g) handedness (right, left, ambidexterity)
h) family history of specific learning difficulties (SLD), left handedness or ambidexterity
i) parental attitudes and methods of managing problems
j) interests, personal and social adjustment (including eating and sleeping habits)
k) personal judgement of their spelling and reading abilities and reading habits

For the general information questionnaire, see Appendix 2.

2.2.2 **<u>Wechsler Adult Intelligence Scale-Revised (WAIS-R)</u>** (Wechsler, 1981).

This is a standardised test used to obtain an estimate of the non-verbal (performance) and verbal intelligence levels. This measure indicates areas of strengths and weaknesses, but also highlights deficits which give rise to SLD. The Performance IQ assesses problem-solving abilities by means of visuospatial tasks and the Verbal IQ assesses the use and understanding of the spoken language by means of verbal questions.

To measure Performance IQ, we administered the full set of subtests:

a) ***<u>Picture completion</u>***. This is a test of visual observation, attention, concentration and discrimination. It requires the detection of important missing parts of familiar pictures of objects with increasing difficulty.

b) ***<u>Picture arrangement</u>***. This is a measure of visuo-temporal sequencing and social awareness abilities. It requires the logical arrangement of a set of pictures (set out in a specified random order) depicting stories of increasing difficulty.

c) ***<u>Block design</u>***. This is a measure of spatial perception and 3D thinking and draws upon manual dexterity and speed. It requires the reproduction of pictorial designs of increasing difficulty using cubes with white and red blocks.

d) ***<u>Object assembly</u>***. This is a measure of assembly skills. It requires the reproduction of different constructions of increasing difficulty using a set of pieces (set out in specified random order and directions) depicting the constituent parts of the construction.

e) ***<u>Digit symbol</u>***. This is a measure of recording speed of symbolic information paired with numbers. It is, thus, a test of visual STM and hand co-ordination abilities.

Performance on the above subtests was timed. The Performance IQ score was calculated by the composite scaled scores of all six subtests.

To measure Verbal IQ, we administered the following two subtests:

a) ***<u>Vocabulary</u>***. This is a measure of the individual's knowledge of word meanings of increasing complexity (progressively less frequent and more abstract words) and the ability to verbalise ideas.

b) ***Similarities***. This is a measure of abstract thinking, logical verbal reasoning and deduction abilities through comparisons of same-different concepts. The subject is required to determine in what aspect two words are regarded as similar on the basis of information recalled from the LTM.

Performance on the above subtests was not timed. The scaled scores of each of the two subtests are reported.

Administration and scoring were carried out according to the standardised instructions. Scaled scores ranged from 1 (the lowest) to 19 (the highest).

2.2.3 Single word spelling

To measure word spelling skills, we used the following lists:

a) ***List 1 (Schonell, 1985)***. This is a standardised list consisting of 120 words, from which 60 were regular[6] and 60 irregular[7]. Words were matched for *length* (for regular: mean=7.1, SD=2.8, range=3-14; for irregular: mean=5.9, SD=1.8, range=3-10). This list was primarily intended for use with children in order to obtain a comparative estimate of the individual's ability to spell phonetic and non-phonetic words. The Regular Test is a collection of words whose constituent units have high degree of correspondence between phoneme and grapheme. This test can provide an indication of the degree to which an individual is able to master common standard letter combinations (i.e. 'ch', 'st', 'th', 'ng', and 'tion'). It can also provide an indication of the power of phonetic analysis abilities, more particularly with regular vowel formations. Finally, it provides a check on purity of pronunciation and capacity for syllabification. The Irregular Test is composed solely of words containing pitfalls, such as silent or double letters, indeterminate vowels and confusing vowel digraphs.

b) ***List 2 (Holmes & Ng, 1993)***. This is a standardised list consisting of 90 words, from which 20 were regular, 20 irregular, 20 morphophonemic[8], 20

[6] Words whose spelling relies on the most common grapheme-to-phoneme option.

[7] Words which have unusual spelling patterns or do not follow the usual grapheme-to-phoneme correspondence.

[8] Words whose spelling relies on the knowledge of related words from which they derive (word-specific).

idiosyncratic[9] and 10 orthographic[10]. In total, there were 20 words with regular spellings and 70 words with irregular spellings. Both types of words were matched for *frequency* (for regular: mean=5.5, SD=5.0; for irregular: mean=5.4, SD=5.4) and *length* (for regular: mean=9.1, SD=1.7, range=5-12; for irregular: mean=8.6, SD=1.6, range=5-14).

c) ***List 3 (Romani & Ward, unpublished)***. This list has been produced by our laboratory and consisted of 154 words, from which 77 were regular and 77 irregular. The letters of the regular words were all common realizations of the corresponding phonemes occurring at least 30% of the time, according to Hanna, Hanna, Hodges, & Rudolf (1966). The irregular words contained at least one uncommon graphemic realisation occurring at least 10% of times or less for the corresponding phoneme, according to Carroll, Davies, & Richman (1971). Regular and irregular words were closely matched for high and low *frequency*, HF and LF (for HF regular vs. irregular: mean=368.1, SD=520.0 vs. mean=367.0, SD=519.5; for LF regular vs. irregular: mean=10.2, SD=11.5, vs. mean=10.4, SD=11.1) and *length* (for HF regular vs. irregular: mean=4.5, SD=0.7 vs. mean=4.5, SD=0.7; for LF regular vs. irregular: mean=4.4, SD=0.8, vs. mean=4.7, SD=0.8, range=3-6, for all).

There were 344 words in total, from which 157 were regular words and 187 irregular words. They were matched for *length* (for regular: mean=6.1, SD=2.5; for irregular: mean =6.1, SD =2.2). The irregular words were of slightly higher *frequency* than the regular words. According to the MRC psycholinguistic database (Coltheart, 1981), the mean was 105, SD=206, for regular words, and 176, SD=794, for irregular words. According to the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995), the mean was 1.460, SD=3.604, for regular words, and 2.598, SD=9.619, for irregular words.

The spelling lists were carried out in the order presented above and administered prior to the reading task, so that the subjects were not familiar with a

[9] Words whose spelling relies only on rote memory.
[10] Words which could be spelled as two separate words but the correct spelling is represented by a single word (i.e. recurring, youthful).

word before spelling it. A native English speaker tape-recorded all words (presented in blocked lists). Words were presented one at a time. Subjects were asked to write down the spellings. There was no time limit to respond or corrective feedback. In case of self-corrections, the last response was considered for scoring. Homophones[11] were presented with a clarifying sentence. Each misspelled word was counted as one error. Fragments and 'do not know' responses were also counted as errors. Performance is reported in percentage of errors made in the combined lists. Stimuli items for all three spelling lists are presented in Appendix 3.

2.2.4 <u>Single nonword spelling</u> (Kay, Lesser & Coltheart, 1992; PALPA[12], subtest 45).

This list consisted of 24 monosyllabic made-up words that derived from substituting one or two phonemes in real English words. The nonwords conformed to the English phonotactic constraints. Nonwords were matched for *length* (mean=4.5, SD=1.1, range=3-5,). The pronunciation and spelling of the original words was used to guide those of the nonwords. A native English speaker tape-recorded all nonwords. Stimuli were presented one at a time. Subjects were instructed to spell the nonwords in the best possible way and write down their answers. There was no time limit to respond or corrective feedback. In case of self-corrections, the last response was considered for scoring. Nonwords were considered correct, if they: a) involved phonologically plausible renditions of the target, (i.e. *'boke'* for *'boak'*), by analogy with either regular words (by use of spelling-to-sound rules) or irregular words (by use of word-specific associations), b) contained a legal sequence of letters and c) did not include unusual/irregular correspondences (occurring with less than 1% probability according to Hanna et al., 1966). The first criterion facilitated comparison with previous studies using the same scoring procedures (Baron, 1979; Baron & Treiman, 1980; Treiman & Baron, 1981, Treiman, 1984). Each correctly spelled nonword received one point. Performance is reported in percentage of incorrect responses. Stimuli items are presented in Appendix 4.

[11] A word pronounced the same as another word but differs in meaning (i.e. 'pair' and 'pear').
[12] Psycholinguistic Assessment of Language Processing in Aphasia (PALPA).

2.2.5 <u>Single word and nonword reading</u> (computerised)

To measure reading skills, we used the following lists:

a) ***List 1 (Seidenberg, Waters, Barnes, & Tanenhaus, 1984, Experiment 3).*** This list consisted of 52 words that derived by crossing two factors: spelling-to-sound regularity (regular vs. exception) and frequency (high vs. low). There were 26 regular and 26 exception words of high and low frequency (13 for each frequency type). Regular and exception words were matched for *mean bigram frequencies* (for HF regular vs. exception words: 9514 vs. 9213: for LF regular vs. exception words: 97 vs. 97), *median word frequencies* (for HF regular vs. exception words: 3942 vs. 3875; for LF regular vs. exception words: 52 vs. 50), both according to Caroll, Davies, & Richman, 1971), and *length* (for regular: mean=4.2, SD=0.6; for irregular: mean=4.2, SD=0.7, range:3-5, for both).

b) ***List 2 (Seidenberg, Waters, Barnes, & Tanenhaus, 1984, Experiment 4).*** This list consisted of 90 words of high and low frequency. There were 30 regular consistent words[13], 30 regular inconsistent words[14] and 30 strange words[15] (15 for each frequency type). They were matched for *mean bigram frequencies* (for HF vs. LF regular consistent: 103 vs. 79; for HF vs. LF regular inconsistent: 113 vs. 92; for HF vs. LF strange: 27 vs. 22, according to Mayzner & Tresselt, 1965), *median word frequencies* (for HF vs. LF regular consistent words: 638 vs. 18; for HF vs. LF regular inconsistent: 672 vs. 24; for HF vs. LF strange words: 707 vs. 17, according to Caroll, Davies, & Richman, 1971) and *length* (for regular: mean=4.1, SD=0.4, range=3-5; for strange words: mean=4.7, SD=0.8, range=3-6).

c) ***List 3 (Kay, Lesser, & Coltheart, 1992; PALPA, subtest 31).*** This list consisted of 80 words and 80 nonwords of high and low frequencies (40 for each frequency type). Words and nonwords were presented in an alternating order so that the subject was unable to tell beforehand whether the stimulus appearing on the screen was a word or a non-word, thus, reinforcing

[13] Words with letter patterns always pronounced the same way in any position within the word (i.e. –ust in 'dust').

[14] Words with letter patterns which have a different phonological realisation from words with the same orthographic sequence (i.e. –ave, in 'save' and 'have').

[15] Words that are both orthographically and phonologically irregular.

orthographic processing skills (also involved in reading processes). Nonwords derived from substituting one or two graphemes in real English words. They also respected the phonotactic constraints of the English language. Words and nonwords were matched for *length* (mean=5.8, SD=1.3; for both, range: 3-9, for both).

There were 222 real words in total, from which 86 were classified as regular and 56 as irregular words. They were matched for *length* (for regular: mean=4.1, SD=0.5; for irregular, mean=4.4, SD=0.8). Irregular words were of slightly higher *frequency* than regular words. According to the MRC psycholinguistic database (Coltheart, 1981), the mean frequency was 392, SD=1170, for regular words, and 407, SD=927, for irregular words. According to the CELEX database (Baayen et al., 1995), the mean was 4314, SD =8449, for regular words, and 6924, SD=2141, for irregular words.

The reading lists were carried out in the order presented above. Words or nonwords were presented one at a time at the centre of the computer screen in a randomised order. They appeared in boldface, 18-point Courier New lowercase font and remained on the screen for 500ms. A fixation point at the centre of the screen preceded each item to help focus. Participants were asked to read the words or nonwords aloud as fast and accurately as possible. They were instructed to produce one answer at a time and to speak it as soon as they knew the full pronunciation. If they were unable to work out the pronunciation of the target item, they were asked to say 'I do not know'. No corrective feedback was provided. A short practice preceded the main reading task. Responses were spoken to a microphone connected to the voice key machine which measured reaction time (RT). Stimuli disappeared from the screen as soon as a vocalisation was produced. Unreasonably low RTs (resulting from the subject's triggering the voice key with a vocalization other than a fluent pronunciation of the target item), unreasonably high RTs (resulting from either a complete lack of response or an extremely delayed response), RTs more than 2SDs from the subject's mean RT or RTs corresponding to 'do not know' responses were removed from the analysis. Mispronunciations and 'do not know' responses were counted as errors and recorded on the scoring sheet. In the case of words, responses were considered correct if they were accurately pronounced, while in the case of nonwords, responses were considered correct if they were possible phonological renditions of the target letter string according to Hanna et al. (1966). Very uncommon grapheme-to-phoneme correspondences (occurring with less than 1% probability, according to Hanna et al., 1966) were counted as errors. Variations of regional pronunciations were taken into account. Performance was measured in terms of both speed and accuracy to ensure that the pattern of results obtained with one measure is consistent with the other. Reading speed is reported in number of milliseconds taken to respond, while reading accuracy is reported in percentage of errors made in the combined lists. Stimuli items for all three reading lists are presented in Appendix 5.

2.2.6 Reading comprehension

This task involved a text extract (taken from the scholastic book, "How to prepare for the SAT I", Green & Wolf, 1997, 19th Edition) in a 12-point Times New Roman font in double-line spacing. The passage was one page and a half-long. Participants were given 10 minutes to read the passage to themselves and answer nine multiple-choice questions (without referring back to the passage). Each correctly answered question received one point. Performance is reported in number of incorrect answers. The task is presented in Appendix 6.

2.2.7 Text reading

This task involved another text extract (taken from the same book with the reading comprehension task) in a 12-point Times New Roman font in double-line spacing. The passage was one page and a half-long and contained 466 words. Participants were asked to read it out loud as fast and accurately as possible. The experimenter tape-recorded the reading process and transcribed it in the absence of the participant. No corrective feedback was provided. Mispronunciations and missing words or lines were counted as errors (the number of the errors corresponded to the number of the misread or missed words). Performance was measured in terms of both speed and accuracy and is reported in number of seconds taken to read the whole text and in number of errors made throughout reading, respectively. The task is presented in Appendix 7.

2.2.8 <u>Phonological STM</u>

To measure the ability to retain the serial order of strings of phonological information in the STM, we used the following tasks:

a) ***Digit span***. This task required the serial repetition of sequences of digits of increasing length. Digit span lists ranged from four to eight items (10 sequences for each length). Digits were read by the experimenter at a rate of about one per second. Testing at each length continued unless the participant made no more than two correct recalls or unless all sequences had been attempted. A value of 0.1 was assigned to each sequence repeated correctly. The final score was the maximal span of digits that could be recalled without errors.

b) ***Nonword serial recall***. This task required the serial repetition of made-up words that respected the phonotactic constraints of the English language. It consisted of 30 sequences of three monosyllabic, disyllabic and polysyllabic nonwords (10 for each length). Nonwords were read by the experimenter at a rate of about one per second. Participants were instructed to recall as many nonwords as possible in the order of presentation and to indicate the order of any missed items. Recalls were considered correct if the participant repeated the exact nonword in its original order. Each correct recall received one point. Performance is reported in percentage of incorrect recalls.

c) ***Word serial recall***. This task required the serial repetition of words (concrete and more abstract of medium and high frequency). It consisted of 30 sequences of five monosyllabic, disyllabic and polysyllabic words (10 for each length). Procedure and scoring were the same with those for nonwords. Performance is reported in percentage of incorrect recalls.

Stimuli items for all three phonological STM tasks are presented in Appendix 8.

2.2.9 <u>Phonological Awareness</u>

To measure the ability to segment words or nonwords into their constituent sounds and manipulate the sounds of pairs of words, we administered the following tasks classically used in dyslexia:

a) ***Phoneme counting*** (Perin, 1983). This task consisted of 48 stimuli. There were 32 words and 16 nonwords. The number of phonemes varied from two to five. The items were read by the experimenter one at a time. Participants were asked to report the number of the sounds making up each item. There were no time limits or corrective feedback for their response. A short practice trial preceded the main task. In the case of the words, half had the same number of sounds as letters (i.e. *'gap'*, three sounds corresponding to three letters), whereas the other half had a discrepant number between sounds and letters (i.e. *'knock'*, three sounds corresponding to five letters). Each correct answer received one point. Performance is reported in percentage of incorrect responses.

b) ***Spoonerisms***. This task consisted of 70 pairs of words. Participants were read two words and were asked to exchange the beginning sounds of each of the words in order to obtain: a) two different real words (i.e., if given *'moon'-'nap'*, subjects had to produce *'noon'-'map'*), b) two nonwords (i.e., if given *'dare'-'night'*, subjects had to produce *'nare'-'dight'*), and c) one real word and one nonword (i.e., if given *'bond'-'chair'*, subjects had to produce *'chond'-'bear'*). There were no time limits or corrective feedback for their response, but word pairs were repeated a maximum of two times. A short practice preceded the main task. Each correct response received one point. Performance is reported in percentage of incorrect responses.

Stimuli items for both phonological awareness tasks are presented in Appendix 9.

2.2.10 Lexical learning

To measure the ability to set up novel lexical/formal representations for pairs of pictures and new words ('lexical learning'), we used two spoken and three written nonword tasks. The paired associates we used included pictures of real objects or animals[16] (in black and white drawings) and their corresponding nonsense names (displayed in 10X11cm poster cards). Nonwords derived from either real English words (for spoken: N =10, mean letter number=5.4, SD=1.4, range=3-8; for written:

[16] The majority of the new-word learning tasks used in children included pairs of pictures of nonsense shapes and nonwords or pairs of words and nonwords. In our new-word learning task, we have included real pictures and nonwords so that the learning of the corresponding nonwords is stressed.

N=9, mean letter number=5.9, SD =1.0, range=5-8) or real, but unfamiliar to the subjects, Dutch words (for spoken: N=14, mean letter number=5.1, SD=2.0, range=3-9; for written: N=24, mean letter number=5.8, SD=1.9, range=4-10), pronounced however, like English words and respected English phonotactic/orthotactic constraints, or Russian words[17] in the Cyrillic alphabet (N=6, mean letter number=3.8, SD=0.4, range=3-4). Participants had to learn the associations between the pictures and the made-up words. They were first introduced to the stimuli by being presented with each of the paired associates at a time. Immediately after each display, they were asked to repeat the nonword, if spoken, or to copy it down, if written. Testing did not begin unless all nonwords were produced correctly. The written nonwords were either in the lowercase, boldface, 22-point Bell MT font, for those based on English words, or in the uppercase, boldface, 20-point Courier New font, for those based on Dutch words. Russian characters were in both lowercase and uppercase manuscript style (3 for each case). The order of task modality and the type of nonwords were counterbalanced and distributed over three separate sessions to avoid sequence effects. In the testing phase, participants were asked to recall the corresponding nonword on presentation of the picture alone (to speak it or to write it down, depending on the task modality). In the case of an incorrect or missing response, the stimulus card was displayed again and participants were asked to repeat the spoken nonword or copy down the written nonword. The task was discontinued when all words were recalled correctly or after a maximum of five learning attempts in the full list. The score was the number of items recalled correctly out of the five attempts. Performance is reported in percentage of incorrect responses in all five trials. Stimuli items are presented in Appendix 10.

2.2.11 Lexical-semantic learning (immediate and delayed)

To measure the ability to learn and retain lexical items, such as real words, single and pairs, with and without semantic relations (tapped by episodic memory, which is linked to semantic memory[18]), we administered the following tasks:

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[17] They consisted of sequences of characters, which were closer to symbols than to alphabetical letters.
[18] Episodic and semantic memory are two systems in the LTM (explicit or declarative) organised in a hierarchical way. The episodic memory, which enables the conscious recollection of specific personal past events within a temporal context, is a specific subsystem of the semantic memory, and, therefore, episodic memory cannot exist without semantic memory (Tulving, 1972, 1983, 1984).

a) ***Rey Auditory Verbal Learning Test (RAVLT)*** (Rey, 1964). This test consisted of a list of 15 words read at a rate of one per second by the experimenter. Subjects were asked to recall as many of them as possible in any order (immediate learning). The same procedure was repeated another four times irrespective of the learning outcome. Participants were then read a second list of 15 different words and were asked to recall as many of them as possible. Immediately thereafter, they were asked to recall the words included in the first list from memory. They were instructed to retain the original words in memory as they would be asked to recall them again from memory after 20 minutes of intervening activity (delayed recall). Only, the learning of the words included in the original list was measured (for both immediate and delayed recall). Each correct recall in any order received one point. The score was the number of words recalled correctly out of the five attempts (for the immediate task) and the number of words recalled correctly after 20 minutes of filled delay (for the delayed task). Performance is reported in percentage of incorrect recalls (for both tasks). Stimuli items are presented in Appendix 11.

b) ***Verbal paired associates of the WMS-R*** (Wechsler, 1987). This test consisted of 8 pairs of words read by the experimenter at the rate of one pair every 3 seconds. There were 4 'easy' word pairs (where components were semantically related, i.e. *'baby'*-*'cry'*) and 4 'hard' word pairs (where components were not semantically related to each other, i.e. *'cabbage'*-*'pen'*). Subjects were asked to remember the associations between the words making up the pairs. After the presentation of the full list of words, participants were presented with one of the two words and were asked to recall the other (immediate learning). This procedure was repeated a total of three times (5 seconds were allowed to respond). The test was discontinued if all eight items were answered correctly on the third trial. If not, they were read again. A total of six trials were allowed. Participants were then asked to remember the paired associates, as they would be asked after 20 minutes of filled delay (delayed recall). Each correct association received one point. The test was carried out according to the standardised instructions. Performance is reported in percentage of incorrect recalls in the first three trials. Stimuli items are presented in Appendix 12.

2.2.12 <u>Author Recognition Test (ART)</u> (Clark-Carter, 1997).

This test measures extracurricular reading experience for text (print exposure). The rationale for this test is that individuals who read more extensively outside of the schooling curriculum will be able to identify author names that are not directly taught as part of the reading curriculum in school or college. It consisted of a list of 15 real author names (contemporary, classic, modern classic, popular fiction and horror, 3 for each category) embedded among 15 foils (not real author names) to discourage guessing. It has thus a signal-detection logic in that the number of correct items checked can be controlled for differential response bias (tendency to produce socially desirable responses) by taking into account the number of foils checked. The foil names ere drawn from the reference list of a textbook ('Doing Quantitative Psychological Research', Clark-Carter, 1997). Participants were instructed to place a tick beside each author name they knew was an actual author. They were told that some author names were not actual authors and that guessing could be easily detected. Scoring on the task was determined by taking the proportion of the 15 target names that were checked and subtracting the proportion of foils checked. This is the discrimination index from the two-high threshold model of recognition performance (Snodgrass & Corwin, 1988). Performance is represented in percentage of errors made. Stimuli items are presented in Appendix 13.

3 RESULTS

3.1 Overview of the participants' performance

Table 1:1 presents the demographic data and general performance of the dyslexic and control adults on tasks measuring performance IQ and verbal IQ (as indexed by scores on the Vocabulary and the Similarities subtests of the WAIS-R) and orthographic skills of different types (i.e. reading comprehension, reading of text and reading and spelling of single words and nonwords). The dyslexic z-scores (from the control mean performance) representing highly significant results (***, for $p \leq .001$, **, for $p \leq .01$) are highlighted in boldface yellow, while those representing less significant results (*, for $p \leq .05$) are highlighted in boldface green. Marginal results (for $p \leq .09$) are presented in italics and not significant results (for $p \geq .10$) are marked as n.s.

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Table 1:1. Demographic and defining characteristics of the 44 dyslexics and 40 controls (for text comprehension: 43 dyslexics and 38 controls; for text reading speed and accuracy: 40 dyslexics and 40 controls). 'Impaired' is defined as 2SDs from the control mean.

		DYSLEXICS				CONTROLS		COMPARISON	
		Mean	**SD**	**z-score**	**% impaired**	**Mean**	**SD**	**value**	**p**
Age	years	**27.7**	10.6	0.2	9.1	**25.5**	10.5	F=0.9	n.s
Sex	male : female	**15:29**				**08:32**		χ^2=1.4	n.s
Education	university : secondary	**33:11**				**31:9**		χ^2=0.0	n.s
Performance IQ	scaled score	**107.0**	12.1	-0.1	0.0	**108.8**	13.8	F=0.4	n.s
Vocabulary	scaled score	**10.6**	2.3	-0.1	4.5	**10.7**	2.4	F=0.1	n.s
Similarities	scaled score	**12.8**	2.7	0.3	0.0	**11.9**	3.0	F=2.1	n.s
Reading text									
Comprehension	N err	**4.7**	2.1	0.6	11.4	**3.6**	1.9	F=2.1	**
(out of 9 questions)								F=6.5	
Speed	ms	**242.5**	99.7	1.8	29.5	**178.6**	35.7	F=14.6	***
Accuracy	N err	**12.9**	11.6	2.5	38.6	**3.6**	3.7	F=23.2	***
(out of 466 words)									
Reading									
Words	RT	**660.9**	231.0	2.1	36.3	**526.3**	63.1	F=12.7	***
	% err	**5.9**	3.4	3.3	65.9	**2.2**	1.1	F=42.1	***
Nonwords	RT	**1048.2**	672.0	3.4	40.9	**657.7**	114.0	F=13.1	***
	% err	**27.8**	13.2	5.6	86.4	**7.2**	3.7	F=90.4	***
Spelling									
Words	% err	**23.0**	11.7	4.8	77.2	**8.1**	3.1	F=61.2	***
Nonwords	% err	**25.5**	17.0	2.3	47.7	**9.7**	6.8	F=30.0	***

The dyslexics did not differ from the controls in age, gender, education, performance IQ and verbal IQ (in either the Vocabulary or the Similarities subtests). In our published study (Romani, Di Betta, Tsouknida, & Olson, 2008), both the dyslexics and the controls were also matched for age, performance IQ and Vocabulary, but the dyslexic scores on the Similarities subtest were slightly higher than the control scores.

Consistently with the characteristics of other groups with developmental dyslexia reported in the literature, our dyslexic group made more errors at spelling words and nonwords and was both slower and more error prone at reading words and nonwords (with computerised presentation) compared to the matched controls. These results replicate those of our published study (see also Di Betta & Romani, 2006). In addition to the published study, we found that in reading comprehension, the dyslexics were less impaired. This is consistent with an ability to compensate for a difficulty with word decoding by capitalising on semantic and syntactic cues. Finally, in text reading, the dyslexics were both slower and more error-prone than the matched controls. The individual z-scores of the dyslexics on all types of orthographic tasks are presented in Appendix 14.

As shown in Table 1:1, the majority of our dyslexic participants were severely impaired in word spelling and nonword reading accuracy, consistently with the results of our published study, where we used the same spelling and reading tasks of words and nonwords. Fewer participants were impaired in nonword spelling and word reading accuracy and even fewer were impaired in word and nonword reading speed. Using another criterion, ≤1SD from the control mean, only four participants were not impaired in word spelling and five participants were not impaired in nonword reading accuracy. In addition, only one participant performed normally in reading across the board and another one performed normally in spelling. Therefore, whichever the criterion, the majority of our dyslexic participants were impaired both in reading and spelling. For simplicity, we refer to our reading and spelling impaired group as 'dyslexics', since they all showed 'dyslexic-type problems' in orthographic tasks and in other tasks associated with dyslexia.

The profile of the dyslexic groups we have used in both our published and the present study is more consistent with surface than with phonological dysgraphia. As shown in Table 1:1, word spelling is more impaired than nonword spelling. This indicates that most dyslexic individuals have acquired at least rudimentary conversion rules and that the main problem is the quality of the orthographic lexical representations. However, in reading, the pattern is reversed. Nonword reading is more impaired than word reading in terms of both speed and accuracy. Since performance in nonword spelling indicates relatively good sublexical conversion skills, the severely impaired performance on nonword reading has to be attributed to a different source of impairment other than a phonological deficit (refer also to Chapters 2 and 3 for evidence).

As in our published study, we measured sublexical phonology (by using phonological STM, in addition to the word serial recall task, and phonological awareness tasks), the ability to learn paired associates of familiar pictures and novel words, both spoken and written (by using lexical learning tasks of English nonwords and Dutch words) and the ability to learn single real English words (by using the immediate version of the RAVLT). In addition to the published study, we measured the ability to learn paired associates of familiar pictures and novel words consisting of non-letter-like characters (by using a lexical learning task of Russian words in the Cyrillic alphabet) and the ability to learn single real English words (by using the delayed version of the RAVLT) and pairs of real English words (by using both the immediate and the delayed versions of the verbal paired associates subtest of the WMS-R). We finally measured print exposure (by using the Author Recognition Test).

Given the well-established phonological core deficit (Frith, 1997; Snowling, 2001; Bishop & Snowling, 2004; Vellutino et al., 2004, for a review) and the new-word learning deficit in dyslexics (Fildes, 1921; Otto, 1961; Gascon & Goodglass,1970; Vellutino, Steger, Harding, & Phillips, 1975; Nelson & Warrington, 1980; Vellutino, Scanlon, & Spearing, 1995; Romani & Stringer, 1994; Howard & Best, 1997; Wimmer, Mayringer, & Landerl, 1998; Mayringer & Wimmer, 2000; Messbauer & De Jong, 2003; Di Betta & Romani, 2006; Romani et al., 2008), we expected to find poor performance on both phonological and new-word learning tasks.

We also expected to find better performance with familiar words (with meanings) than with unfamiliar words (Brener, 1940; Hulme, Maughan, & Brown, 1991; Romani et al., 1999, 2008; Di Betta & Romani, 2006). Finally, we expected to find normal print exposure in our dyslexic population that showed a surface pattern of impairment in line with previous studies on surface dyslexic individuals (Manis et al., 1996, 1999; Castles et al., 1999; Gustafson, 2001; Bailey et al., 2004). Performance on the sublexical phonology, lexical learning, lexical-semantic learning and print exposure tasks are presented in Table 1:2 for both the dyslexics and the controls.

Table 1:2. Performance of the 44 dyslexics and 40 controls on the sublexical phonology, lexical learning, lexical-semantic learning and print exposure tasks (for lexical-semantic learning: 42 dyslexics and 39 controls; for print exposure: 42 dyslexics and 40 controls).

		DYSLEXICS				CONTROLS		COMPARISON	
		Mean	SD	z-score	% impaired	Mean	SD	F	p
Phonological STM									
Digit Span	raw score	**5.7**	0.8	-1.5	29.5	**6.8**	0.7	38.9	***
Nonword serial recall	% err	**34.1**	14.1	1.0	22.7	**23.9**	10.5	13.8	***
Word serial recall	% err	**37.8**	10.8	1.0	18.2	**27.9**	10.1	19.0	***
Phonological Awareness									
Phoneme counting	% err	**18.8**	16.4	0.9	22.7	**9.8**	10.3	9.0	**
Spoonerisms	% err	**22.0**	20.2	3.0	54.5	**5.4**	5.6	25.3	***
Lexical Learning									
Spoken	% err	**65.3**	14.7	1.5	36.4	**44.8**	13.8	43.4	***
Written	% err	**52.3**	19.7	1.6	38.6	**27.9**	15.0	39.9	***
Russian	% err	**71.7**	16.7	0.7	4.5	**56.0**	21.3	14.2	***
Lexical-Semantic Learning									
Immediate									
RAVLT	% err	**26.2**	12.0	0.4	9.5	**22.7**	8.8	2.2	n.s
WMS-R word pairs	% err	**14.5**	12.2	1.2	30.1	**7.1**	6.2	11.6	***
Delayed									
RAVLT	% err	**27.8**	18.5	0.7	7.1	**17.3**	15.2	7.7	***
WMS-R word pairs	% err	**5.1**	8.8	*0.5*	7.1	**2.2**	5.6	2.9	*n.s*
Print Exposure									
ART	% err	**26.1**	8.7	0.0	2.4	**26.2**	7.1	0.00	n.s

As expected, the dyslexics showed a phonological deficit, as indexed by poor performance on all phonological STM and phonological awareness tasks. Difficulties in all tasks were of medium severity with the exception of an exceptionally poor performance on the Spoonerisms task[19]. These results are consistent with those of our published study. Individual z-scores on the sublexical phonology tasks are presented in Appendix 15.

The dyslexics were also significantly impaired in both spoken and written lexical learning task, which is in line with the results of our published study. In addition to the published study, we found that the dyslexics showed also a significant but weaker impairment in the russian lexical learning task, which taps the ability to create new lexical representations from a series of unrelated symbolic units. Results from performance on the lexical-semantic learning tasks showed that, in the immediate condition, the dyslexics had no problem learning real single words, which is consistent with the results of our published study. However, the dyslexics had a significant difficulty in learning pairs of real words with and without semantic relations. In the delayed condition, patterns were somewhat the opposite. The dyslexics were poor at recalling the learnt single words, but only very mildly poor at recalling the learnt pairs of words (p=.09). However, despite the difficulties seen in both delayed recall tasks, only three dyslexics performed more than 2SDs below the control mean. The difficulties seen in learning new word associations and in the delayed recall of single words indicate deficits at the phonological as well as at the semantic level. These results fit with the idea of poor semantic memory in surface dyslexia. A number of other studies in aphasic patients who show typical symptoms of surface dyslexia have also found poor performance on the paired associates of the WMS-R and poor delayed recall on the RAVLT (Graff-Radford et al., 1990; Green et al., 1990; Scheltens, Hazenberg, Lindeboom, Valk, & Wolters, 1990; Watt, Jokel, & Behrmann, 1997; Zakzanis, 1999). Finally, ART scores revealed normal print exposure in the dyslexics. Individual z-scores on the lexical learning, lexical-semantic learning and print exposure tasks are presented in Appendix 16.

[19] The large impairment shown in the Spoonerisms task could be because orthographic knowledge may contribute more to this task than to the Phoneme Counting task. For arguments that orthographic knowledge modulates phonological awareness, see Castles, Holmes, Neath, & Kinoshita, 2003; Castles & Coltheart, 2004.

3.2 Relations among tasks

We investigated how performance on the phonological, lexical learning (spoken, written and russian), lexical-semantic learning (immediate and delayed) and print exposure tasks among dyslexic and control individuals were related to variations in their spelling and reading abilities of words and nonwords. We conducted Pearson's 2-tailed correlations (partialing out age) and regression analyses (controlling for age, performance IQ and phonological abilities). Table 1:3 presents the correlation results.

Table 1:3. Partial correlations among the spelling and reading tasks of words and nonwords on one side, and the sublexical phonology, lexical learning, lexical-semantic learning and print exposure tasks on the other side in the dyslexics and controls (degrees of freedom, df, for all tasks: 41 dyslexics and 37 controls; except for lexical-semantic learning: 39 dyslexics and 36 controls; for print exposure: 39 dyslexics and 37 controls).

	Spelling				Reading Speed				Reading Accuracy			
DYSLEXICS	**words**	**p**	**nonwords**	**p**	**words**	**p**	**nonwords**	**p**	**words**	**p**	**nonwords**	**p**
Sublexical Phonology												
Digit span	0.13	.42	**0.33**	.03	0.16	.30	0.22	.15	0.04	.82	**0.35**	.02
Nonword serial recall	*0.28*	.07	**0.45**	.00	**0.32**	.04	**0.47**	.00	0.05	.76	**0.35**	.02
Word serial recall	0.20	.21	**0.32**	.04	0.18	.26	0.19	.22	0.07	.64	*0.28*	.07
Phoneme counting	0.16	.32	**0.61**	.00	**0.35**	.02	**0.46**	.00	0.08	.60	**0.43**	.00
Spoonerisms	**0.49**	.00	**0.38**	.01	**0.51**	.00	**0.57**	.00	**0.34**	.03	**0.36**	.02
Phonological Ability[20]	**0.34**	.02	**0.56**	.00	**0.43**	.00	**0.56**	.00	0.17	.29	**0.47**	.00
Lexical Learning												
Spoken	**0.40**	.01	*0.28*	.07	0.26	.10	0.21	.19	**0.48**	.00	**0.35**	.02
Written	**0.55**	.00	0.18	.24	*0.26*	.09	0.17	.28	**0.56**	.00	**0.40**	.01
Russian	0.18	.25	0.07	.66	-0.04	.80	-0.13	.41	**0.31**	.04	**0.30**	.05
Lexical-Semantic Learning												
Immediate												
RAVLT	-0.18	.26	0.08	.62	-0.25	.11	*-0.30*	.06	-0.17	.28	-0.15	.34
WMS-R word pairs	-0.02	.90	-0.01	.97	0.00	.98	-0.03	.84	-0.01	.93	-0.10	.54
Delayed												
RAVLT	0.001	.99	-0.03	.86	-0.21	.19	*-0.30*	.06	0.00	.99	-0.05	.76
WMS-R word pairs	0.10	.53	0.02	.92	0.17	.30	0.12	.45	0.22	.16	0.16	.31
Print Exposure	*0.29*	.06	-0.04	.79	0.07	.67	0.06	.72	**0.36**	.02	0.17	.29

(continued)

[20] This is a single composite score from performance on the digit span, nonword serial recall, phoneme counting and spoonerisms (we did not include word serial recall, as it involves a semantic component, which is additive to STM recall).

	Spelling				Reading Speed				Reading Accuracy			
CONTROLS	words	p	nonwords	p	words	p	nonwords	p	words	p	nonwords	p
Sublexical Phonology												
Digit span	0.27	.10	*0.28*	.09	*0.29*	.08	0.15	.36	0.21	.19	**0.37**	.02
Nonword serial recall	0.24	.14	0.15	.37	0.24	.15	0.16	.33	0.26	.11	**0.50**	.00
Word serial recall	0.24	.15	0.16	.32	0.19	.25	0.00	.98	*0.31*	.06	**0.37**	.02
Phoneme counting	**0.32**	.05	0.18	.27	0.27	.10	0.21	.20	**0.39**	.01	**0.33**	.04
Spoonerisms	0.24	.15	0.20	.22	**0.47**	.00	**0.35**	.03	0.13	.41	0.12	.48
Phonological Ability	**0.34**	.04	0.25	.12	**0.36**	.02	0.24	.14	**0.33**	.04	**0.46**	.00
Lexical Learning												
Spoken	**0.54**	.00	**0.40**	.01	**0.32**	.05	0.21	.20	0.17	.31	0.11	.51
Written	*0.28*	.09	*0.27*	.09	0.17	.29	0.14	.39	0.16	.33	0.19	.25
Russian	0.24	.14	0.08	.62	0.12	.47	0.18	.26	0.26	.11	0.15	.36
Lexical-Semantic Learning												
Immediate												
RAVLT	**0.32**	.05	**0.35**	.03	**0.33**	.04	0.26	.11	0.14	.40	*-0.22*	.18
WMS-R word pairs	0.26	.12	*0.30*	.06	0.16	.34	0.01	.96	**0.32**	.05	0.24	.14
Delayed												
RAVLT	0.24	.14	-0.10	.54	0.07	.68	0.10	.56	0.20	.23	-0.06	.73
WMS-R word pairs	*0.29*	.07	0.06	.70	-0.18	.27	-0.01	.95	0.01	.95	0.17	.30
Print exposure	0.11	.49	0.18	.27	-0.07	.66	0.02	.92	**0.45**	.00	0.17	.29

In the dyslexics, the patterns of correlations between orthographic performance and phonological or lexical learning performance varied depending on whether the output was lexical or non-lexical. That is, phonological processing was more strongly associated with nonword than with word processing, while lexical learning was more strongly associated with word than with nonword processing. More specifically, word spelling and reading accuracy correlated more strongly with lexical learning, while nonword spelling and nonword reading speed correlated more strongly with phonological processing. However, word reading speed showed a significant relationship with phonological processing only. Our results are consistent with those of our published study (see also Di Betta & Romani, 2006, for a significant correlation between spoken and written learning and word spelling). We also found that nonword reading accuracy was significantly associated with both phonological processing and lexical learning compared to the weaker respective associations found in our published study (where we investigated a smaller dyslexic group). In addition, we found that, russian learning was also significantly associated with word and nonword reading accuracy, but in a lesser degree than spoken and written learning. However, differently from spoken and written learning, russian learning did not correlate significantly with word spelling. On the other hand, lexical-semantic learning (both immediate and delayed) did not show significant associations with either word or nonword processing. This confirms the suggestion made by previous researchers that poor verbal learning and recall is a secondary deficit in individuals with language disorders. In addition, print exposure correlated significantly with word reading accuracy, which is in line with previous findings (Manis et al., 1993; Griffiths & Snowling, 2002). We also examined whether print exposure showed significant associations with other types of reading skills, such as reading comprehension and text reading speed and accuracy. Results showed no significant correlations with reading comprehension ($r=-.06$, $p=.70$, $df=38$), or text reading speed ($r=.19$, $p=.26$, $df=36$), but a significant correlation with text reading accuracy ($r=.40$, $p=.01$, $df=36$).

In the controls, the patterns of correlations of phonological processing and lexical learning were less selective across lexical and non-lexical processing. In comparison with the dyslexics, phonological processing correlated less weakly with orthographic performance. Performance on the majority of the phonological tasks was significantly associated with nonword reading accuracy. From the lexical learning tasks, only spoken learning showed a significant relationship with the orthographic performance. In particular, spoken learning correlated with both word and nonword spelling as well as with word reading speed. Previous studies that were, however, carried out in control children have also found a significant relationship between phonological paired associate learning and orthographic performance (Reitsma, 1983, 1989; Ehri & Saltmarsh, 1995; Windfuhr & Snowling, 2001; Hulme, Goetz et al., 2007). On the other hand, performance on both immediate versions of the lexical-semantic learning tasks showed significant associations with both word and nonword processing, unlike the dyslexics. That is, RAVLT correlated with both word and nonword spelling as well as with word reading speed, just like spoken learning, while WMS-R word pairs correlated with word reading accuracy. However, performance on both delayed versions of the lexical-semantic tasks showed no significant associations with either word or nonword processing, as for the dyslexics. In addition, print exposure correlated significantly with word reading accuracy, which is in line with previous findings (Stanovich & West, 1989; Barker et al., 1992; Cunningham & Stanovich, 1990, 1997). We also examined whether print exposure showed significant associations with reading comprehension and text reading speed and accuracy. Results showed no correlation with text reading speed ($r=.10$, $p=.58$, $df=35$), but correlations with reading comprehension and text reading accuracy that, however, fell just outside significance ($r=.28$, $p=.09$, $df=35$ and $r=.29$, $p=.08$, $df=35$, respectively). A significant correlation with reading comprehension has been found by previous studies that were, however, carried out in control children (Anderson et al., 1988; Cipielewski & Stanovich, 1992; Echols et al., 1996; Cunningham & Stanovich, 1997).

3.3 Predicting Reading and Spelling

Romani and colleagues have shown that surface dyslexia is a separate impairment (from phonological dyslexia) that is linked with a deficit in written lexical learning (Romani et al., 1999, 2008; Di Betta & Romani, 2006). In our published study, we showed that a written lexical learning deficit in adults with developmental dyslexia that resembled a surface dyslexic pattern predicted word spelling and word reading accuracy abilities, independently of a phonological processing deficit and performance IQ (Romani et al., 2008).

The present study complements and extends the results of the published study by examining the contribution of different types of lexical learning (spoken, written and russian) and print exposure to both reading and spelling skills of words and nonwords in both adults with developmental dyslexia (also resembling a surface dyslexic pattern) and control adults, beyond the contribution of phonological processing skills, performance IQ and age. To determine this, we conducted a series of stepwise regression analyses. We used performance on the orthographic tasks as 'dependent variables' and performance on the lexical learning and print exposure tasks as 'independent variables'. No regression analyses were conducted for the contribution of a lexical-semantic learning deficit to orthographic skills in the dyslexics as no significant correlations with orthographic performance were found.

We derived a single composite measure of phonological ability by running a principal component analysis on the data from digit span, nonword serial recall, phoneme counting and spoonerisms. This yielded a single factor with an eigenvalue greater than one, which accounted for 69% of the variance and received high loadings from all components: digit span=.85, nonword serial recall=.89, phoneme counting=.79 and spoonerisms=.78. Age and performance IQ were always entered at the first step (X1). In the case of lexical learning, the phonological factor and lexical learning (spoken, written, russian) were entered alternately at the second step (X2). Results are presented in Table 1:4 for both the dyslexics and the controls. In the case of print exposure, the phonological factor was entered at the second step and print exposure and lexical learning (spoken, written, russian) were entered alternately at the third step (X3). Results for both the dyslexics and the controls are presented in Table 1:5. R square change scores are the improvement in R square (when X1 and then X2 and so on are added), which show the percentage of variance explained in the dependent variable. The 'p' statistic shows the significance level of the contribution made by each predictor in explaining variance in the dependent variable.

Table 1:4. Regression equations showing the contribution of spoken, written and russian learning to orthographic skills in the dyslexics and controls, after age, performance IQ and phonological processing skills have been controlled.

		Spelling				Reading Speed				Reading Accuracy			
		words		nonwords		words		nonwords		words		nonwords	
DYSLEXICS	df	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p
1 Age+Performance IQ	2,41	**19.4**	.01	**14.7**	.04	**20.9**	.01	**17.2**	.02	6.2	.27	6.8	.23
2 Phonological factor	1,40	*5.9*	.08	**22.9**	.00	**13.3**	.01	**24.2**	.00	0.8	.57	**17.4**	.00
3 Spoken learning	1,39	**7.8**	.05	0.8	.47	1.7	.32	0.4	.62	**17.1**	.01	4.6	.12
3 Written learning	1,39	**20.1**	.00	0.6	.53	4.1	.12	1.2	.36	**25.2**	.00	**11.4**	.01
3 Russian learning	1,39	0.0	.92	1.5	.34	2.1	.26	**6.2**	.04	4.2	.18	3.9	.16
2 Spoken learning	1,40	**9.0**	.03	3.1	.22	3.8	.17	2.2	.30	**17.9**	.00	*8.2*	.06
3 Phonological factor	1,39	3.7	.16	**20.6**	.00	**11.2**	.01	**22.4**	.00	0.0	.93	**13.8**	.01
2 Written learning	1,40	**20.1**	.00	0.6	.59	4.1	.15	1.2	.44	**25.2**	.00	**11.4**	.02
3 Phonological factor	1,39	*5.9*	.06	**22.9**	.00	**13.3**	.01	**24.2**	.00	0.8	.51	**17.4**	.00
2 Russian learning	1,40	0.0	.88	1.1	.47	1.8	.34	5.3	.10	4.3	.17	4.5	.16
3 Phonological factor	1,39	*5.9*	.09	**23.3**	.00	**13.7**	.01	**25.0**	.00	0.7	.59	**16.8**	.00

(continued)

		Spelling				Reading Speed				Reading Accuracy			
		words		nonwords		words		nonwords		words		nonwords	
CONTROLS	df	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p
1 Age+Performance IQ	2,37	**15.4**	.05	**30.0**	.00	10.6	.13	3.2	.55	**38.5**	.00	**18.1**	.03
2 Phonological factor	1,36	4.2	.18	1.1	.45	5.4	.14	3.1	.28	2.4	.23	**10.8**	.03
3 Spoken learning	1,35	**21.2**	.00	**7.8**	.04	5.3	.13	2.9	.30	0.2	.76	0.0	.99
3 Written learning	1,35	2.0	.35	1.8	.34	0.1	.88	0.3	.73	0.0	.98	0.0	.89
3 Russian learning	1,35	2.5	.30	0.0	.92	0.1	.83	2.3	.36	2.0	.27	0.5	.61
2 Spoken learning	1,36	**19.1**	.00	**7.1**	.05	4.2	.19	2.3	.36	0.1	.85	0.1	.83
3 Phonological factor	1,35	*6.2*	*.06*	1.8	.32	6.5	.10	3.7	.24	2.6	.23	**10.7**	.03
2 Written learning	1,36	2.6	.29	2.1	.30	0.2	.76	0.5	.65	0.0	.88	0.3	.73
3 Phonological factor	1,35	3.5	.22	0.9	.51	5.2	.15	2.9	.31	2.4	.24	**10.6**	.03
2 Russian learning	1,36	1.6	.41	0.1	.84	0.0	.99	1.5	.45	1.4	.37	0.1	.87
3 Phonological factor	1,35	5.0	.14	1.1	.47	5.5	.14	3.8	.23	3.1	.18	**11.3**	.02

In the dyslexics, age and performance IQ accounted for a significant amount of variance in the prediction of word and nonword spelling and word and nonword reading speed. When entered both second and last, the phonological factor and lexical learning made unique contributions to orthographic performance. The phonological factor predicted mainly nonword processing, while written learning predicted mainly word processing. Our results are consistent with those of our published study. Likewise written learning, spoken learning predicted word processing but more weakly. When entered both second and last, the phonological factor made also a significant but less strong contribution to word reading speed, while written learning made also a significant but less strong contribution to nonword reading accuracy. In addition, russian learning was a significant but less strong predictor of nonword reading speed. This was, however, true when it was entered last. The independence of a lexical learning impairment from a phonological impairment is consistent with the results of our published study (see also Romani & Stringer, 1994, for a dissociation between written learning and phonological abilities in an adult with developmental surface dysgraphia; Di Betta & Romani, 2006, for an independence of written and spoken learning in a group of adults with developmental dyslexia) and other studies in dyslexic children (Aguiar & Brady, 1991; Ehri & Saltmarsh, 1995) .

In the controls, age and performance IQ accounted for a significant amount of variance in the prediction of word and nonword spelling and word and nonword reading accuracy. The phonological factor was less predictive of orthographic performance compared to the dyslexics. However, when entered both before and after lexical learning, it made a significant contribution to nonword reading accuracy. From the lexical learning tasks, only spoken learning made a unique contribution to orthographic performance. That is, spoken learning accounted for both word and nonword spelling (more strongly for the former). This was true when entered both before and after the phonological factor. The independence of new-word learning from phonological processing has also been reported by other studies in control children (Reitsma, 1983, 1989; Windfuhr & Snowling, 2001; Hulme, Goetz, et al, 2007).

Table 1:5. Regression equations showing the contribution of print exposure to orthographic skills in the dyslexics and controls, after age, performance IQ, phonological processing and lexical learning skills have been controlled.

		Spelling				Reading Speed				Reading Accuracy			
		words		nonwords		words		nonwords		words		nonwords	
DYSLEXICS	df	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p
1 Age+Performance IQ	2,39	**16.2**	.03	**16.3**	.03	**18.6**	.02	**15.0**	.04	5.7	.32	6.1	.29
2 Phonological factor	1,38	3.5	.20	*7.5*	.06	**9.6**	.03	**17.4**	.00	0.6	.63	*7.7*	.07
3 Print exposure	1,37	**15.1**	.01	0.8	.54	3.4	.18	4.5	.11	**19.0**	.00	**9.0**	.05
4 Spoken learning	1,36	**7.0**	.05	0.2	.75	1.8	.33	0.4	.64	**15.1**	.01	3.3	.21
4 Written learning	1,36	**12.1**	.01	0.2	.75	2.1	.29	0.1	.83	**14.0**	.01	*7.4*	.06
4 Russian learning	1,36	0.1	.77	0.4	.66	2.0	.31	*5.6*	.07	3.1	.22	5.8	.10
3 Spoken learning	1,37	**9.3**	.03	0.3	.70	2.4	.27	0.7	.53	**18.9**	.00	4.5	.16
4 Print exposure	1,36	**12.8**	.01	0.7	.57	2.9	.22	4.2	.13	**15.3**	.00	*7.7*	.06
3 Written learning	1,37	**21.2**	.00	0.5	.61	4.0	.15	1.0	.46	**25.2**	.00	**12.9**	.02
4 Print exposure	1,36	**6.0**	.05	0.5	.64	1.5	.37	3.6	.16	**7.8**	.04	3.5	.19
3 Russian learning	1,37	0.8	.54	0.3	.72	1.3	.42	4.2	.12	5.5	.14	*7.8*	.06
4 Print exposure	1,36	**14.4**	.01	0.9	.51	4.1	.14	*5.9*	.06	**16.6**	.01	*6.9*	.07

(continued)

		Spelling				Reading Speed				Reading Accuracy			
		words		nonwords		words		nonwords		words		nonwords	
CONTROLS	df	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p
1 Age+Performance IQ	2,37	**15.4**	.05	**30.0**	.00	**10.6**	.13	3.2	.55	**38.5**	.00	**18.1**	.03
2 Phonological factor	1,36	4.2	.18	1.1	.45	5.4	.14	3.1	.28	2.4	.23	**10.8**	.03
3 Print exposure	1,35	0.1	.82	1.0	.47	2.6	.30	0.1	.82	**9.9**	.01	0.5	.62
4 Spoken learning	1,34	**22.4**	.00	**9.0**	.03	4.2	.18	2.7	.32	0.9	.42	0.0	.93
4 Written learning	1,34	2.1	.34	2.2	.29	0.1	.98	0.3	.76	0.2	.73	0.1	.25
4 Russian learning	1,34	2.4	.31	0.1	.87	0.2	.75	2.4	.35	1.2	.36	0.4	.65
3 Spoken learning	1,35	**21.2**	.00	**7.8**	.04	5.3	.13	2.9	.30	0.20	.76	0.0	.99
4 Print exposure	1,34	1.4	.37	2.3	.25	1.5	.42	0.0	.96	**10.7**	.01	0.5	.62
3 Written learning	1,35	2.0	.35	1.8	.34	0.1	.88	0.3	.73	0.0	.98	0.0	.89
4 Print exposure	1,34	0.3	.73	1.4	.40	2.5	.31	0.1	.85	**10.1**	.01	0.6	.61
3 Russian learning	1,35	2.5	.30	0.0	.92	0.1	.83	2.3	.36	2.0	.27	0.5	.61
4 Print exposure	1,34	0.0	.90	1.1	.47	2.7	.29	0.3	.75	**9.2**	.02	0.4	.66

In the dyslexics, print exposure made a significant and independent contribution to both word reading accuracy and word spelling. This was true when entered both before and after lexical learning (spoken, written, russian), independently of the contribution of age, performance IQ and phonological processing skills. It also made an independent but less significant contribution to nonword reading accuracy. This was true when entered before lexical learning only. A significant contribution of print exposure to word reading accuracy in dyslexia is in line with previous studies on dyslexic children (McBride-Chang et al., 1993; Leseman & de Jong, 1998; Sénéchal, Lefevre, Thomas, & Daley, 1998; de Jong & Leseman, 2001; Griffiths & Snowling, 2002). No previous study has looked at the contribution of print exposure to word and nonword spelling or nonword reading in dyslexic individuals.

In the controls, print exposure predicted word reading accuracy. This was true when entered both before and after lexical learning (spoken, written, russian), independently of age, performance IQ and phonological processing skills. A significant contribution of print exposure to word reading accuracy in control individuals is in line with previous studies on control adults (Stanovich & West, 1989) and control children (Cunningham & Stanovich, 1990). No previous study has looked at the contribution of print exposure to word and nonword spelling or nonword reading in control individuals.

3.4 Dyslexic subtypes and patterns of cognitive impairments

Previous studies have categorized children as phonological or surface dyslexics according to their relative abilities to read irregular words (as an indication of lexical processing) and nonwords (as an indication of non-lexical processing). This methodology was pioneered by Castles & Coltheart (1993).

3.4.1 Method for the selection of the dyslexic subtypes

Consistently with the method used by more recent studies (Castles et al., 1999; Curtin, Manis, & Seidenberg, 2001; Bailey et al., 2004) and with the method used in our published study, we used the z-score discrepancy (from the control distribution) by subtracting irregular word from nonword z-score performance, which takes the overall level of performance into account. However, differently from the majority of the studies that have investigated reading abilities and have, thus, used the reading criterion in order to select dyslexic subtypes, we used the spelling criterion (in our published studies we have used both a reading accuracy and a spelling criterion). We used the spelling criterion because: a) the main complaint of our dyslexic population was spelling, b) when we considered both reading and spelling criteria, we found stronger and clearer patterns of performance with the spelling rather with the reading criterion, and c) nonword spelling seems to be a more direct measure of sublexical conversion skills than nonword reading (refer to Chapter 2 for evidence, where we found that a nonword reading deficit persists despite equivalent sublexical conversion skills). The latter is also manifested by the differential performance of our dyslexic individuals in the nonword reading and nonword spelling tasks (where an impairment is more severe with nonword reading rather than with nonword spelling) in comparison with both the chronological-age matched controls and the reading and spelling-age matched younger controls (refer to the results of Table 2:1 of Chapter 2 for the younger control comparison).

Given this method, subjects whose performance fell in the top third irregular vs. nonword spelling z-score discrepancy were allocated to the 'surface group', while subjects whose performance fell in the bottom third irregular vs. nonword spelling z-score discrepancy were allocated to the 'phonological group'. Thus, we assigned 34.1% of the total dyslexic population to the surface group and another 34.1% to the phonological group (N=15 for each; for the surface group: 6 male and 9 female, 9 with university education and 6 with secondary education; for the phonological group: 4 male and 11 female, 11 with university education and 4 with secondary education; matched for gender and education, $\chi^2=0.15$, $p=.70$, for both). Individual z-scores of all 44 dyslexics and their division into subgroups are presented in Appendix 17.

3.4.2 Overview of the dyslexic subgroups' performance

Tables 1:6 and 1:7 present the demographic and cognitive characteristics of the surface and phonological dyslexics and comparisons to each other and the controls on tasks measuring performance IQ, verbal IQ (as indexed by scores on the Vocabulary and the Similarities subtests of the WAIS-R), orthographic skills of different types (i.e. reading comprehension, reading of text, reading and spelling of single words, irregular words and nonwords), sublexical phonology, lexical learning, lexical-semantic learning and print exposure. The dyslexic z-scores (from the control mean performance) representing highly significant results (***, for $p \leq .001$, **, for $p \leq .01$) are highlighted in boldface yellow, while those representing less significant results (*, for $p \leq .05$) are highlighted in boldface green. Marginal results (for $p \leq .09$) are presented in italics and not significant results (for $p \geq .10$) are marked as n.s.

Table 1:6. Demographic and defining characteristics of the 15 surface dyslexics and 15 phonological dyslexics (for text reading speed and accuracy: 15 surface dyslexics and 14 phonological dyslexics). 'Impaired' is defined as 2SDs from the control mean.

		SURFACE DYSLEXICS		PHONOLOGICAL DYSLEXICS		SURFACE VS. PHONOLOGICAL		SURFACE VS. CONTROLS		PHONOLOGICAL VS. CONTROLS	
		z-score	**% impaired**	**z-score**	**% impaired**	**F**	**p**	**F**	**p**	**F**	**p**
Age	years	0.4	20.0	0.2	6.7	0.2	n.s	2.0	n.s	0.6	n.s
Performance IQ	scaled score	-0.2	0.0	-0.3	0.0	0.02	n.s	0.6	n.s	0.9	n.s
Vocabulary	scaled score	0.2	0.0	-0.3	0.0	2.9	n.s	0.2	n.s	1.5	n.s
Similarities	scaled score	0.4	6.7	0.0	6.7	1.4	n.s	1.8	n.s	0.001	n.s
Reading text											
Comprehension (out of 9 questions)	N err	*0.6*	13.3	**1.0**	13.3	1.3	n.s	3.2	*n.s*	11.7	***
Speed	ms	**2.5**	26.7	**1.3**	28.6	1.2	n.s	14.6	***	10.4	***
Accuracy (out of 466 words)	N err	**3.2**	53.3	**2.2**	28.6	0.6	n.s	21.6	***	19.2	***
Reading											
Words	RT	**3.1**	40.0	**1.5**	26.7	1.2	n.s	17.0	***	6.1	*
Irregular	RT	**2.1**	93.5	**1.3**	60.0	4.1	*n.s*	57.0	***	16.2	***
Nonwords	RT	**4.1**	53.3	**3.2**	26.7	0.1	n.s	18.5	***	10.0	***
Words	% err	**5.5**	80.0	**2.4**	66.7	8.5	***	68.6	***	39.6	***
Irregular	% err	**3.1**	46.7	**0.7**	13.3	10.4	***	43.0	***	5.1	*
Nonwords	% err	**6.7**	100.0	**5.6**	80.0	0.7	n.s	120.0	***	73.1	***
Spelling											
Words	% err	**7.4**	100.0	**2.9**	46.7	11.9	***	140.0	***	25.4	***
Irregular	% err	**7.1**	100.0	**2.5**	46.7	18.7	***	170.5	***	25.2	***
Nonwords	% err	**1.4**	33.3	**4.1**	86.7	10.4	***	12.7	***	66.3	***

The surface dyslexics did not differ from the phonological dyslexics in age, performance IQ and verbal IQ (in either the Vocabulary or the Similarities subtests). Both dyslexic subtypes did not also differ from the controls in the same variables. These results are consistent with those of our published study, when either selection method was considered.

The surface and the phonological dyslexics performed also the same in text reading (for all comprehension, speed and accuracy) and nonword reading in terms of both speed and accuracy. The absence of a significant group difference in nonword reading speed and accuracy is not what we would normally expect to find given that the surface dyslexics are better with nonword processing than the phonological dyslexics. A severe nonword reading deficit in the surface dyslexics does not fit within the dual-route version of the phonological deficit model (refer also to Chapter 2), which expects at least more impaired nonword reading in individuals with poorer use of the sublexical route. This finding suggests that nonword reading is not as a direct measure of sublexical conversion skills (as nonword spelling is) and that it should also tap another ability, such as visual/orthographic coding relating to the ability to process independent units within novel visual strings (refer also to Chapters 2 and 3). In word reading, the surface dyslexics were less accurate than the phonological dyslexics but as slow as them. In irregular word reading, the surface dyslexics were also less accurate than the phonological dyslexics but only very mildly slower than them. The spelling results are the reflection of the selection criterion. In comparison to the controls, both dyslexic subgroups performed significantly worse on all types of orthographic tasks, except for a very mildly poor performance on the reading comprehension task for the surface group. In addition, we found that the surface dyslexics did not differ from the phonological dyslexics in reading comprehension. This finding argues against the view that surface dyslexia arises from a 'semantic impairment'. The results from all group comparisons on the nonword and irregular word reading and spelling tasks are consistent with those of our published study (when the spelling method was used). Individual z-scores (from the control distribution) of both dyslexic subtypes on all types of orthographic tasks are presented in Appendix 18.

According to the results of our published study (with both selection methods), we would expect to find a better ability to learn familiar than unfamiliar words for both dyslexic subgroups and a more pronounced deficit in written lexical learning in the surface dyslexics in comparison with the phonological dyslexics. According to the proposal of Stanovich et al. (1997), we would expect to find a phonological impairment in both dyslexic subtypes, with, however, the surface dyslexics showing a milder phonological impairment than the phonological dyslexics coupled with reduced print exposure. Results of the performance of both dyslexic subtypes on the sublexical phonology, lexical learning, lexical-semantic learning and print exposure tasks in comparison to each other and the controls are presented in Table 1:7.

Table 1:7. Performance (in z-scores from the control distribution) of the 15 surface dyslexics and 15 phonological dyslexics on tasks of sublexical phonology, lexical learning, lexical-semantic learning and print exposure (for RAVLT: 14 surface dyslexics and 15 phonological dyslexics; for print exposure: 15 surface dyslexics and 13 phonological dyslexics).

		SURFACE DYSLEXICS		PHONOLOGICAL DYSLEXICS		SURFACE VS. PHONOLOGICAL		SURFACE VS. CONTROLS		PHONOLOGICAL VS. CONTROLS	
		z-score	% impaired	z-score	% impaired	F	p	F	p	F	p
Phonological STM											
Digit Span	raw score	**-1.6**	26.7	**-1.8**	33.3	0.3	n.s	32.1	***	32.3	***
Nonword serial recall	% err	**0.9**	13.3	**1.3**	26.7	0.7	n.s	8.3	***	14.3	***
Word serial recall	% err	**1.1**	13.3	**1.2**	20.0	0.07	n.s	15.5	***	16.4	***
Phonological Awareness											
Phoneme counting	% err	0.4	6.7	1.7	46.7	5.2	*	1.8	n.s	17.8	***
Spoonerisms	% err	**4.0**	66.7	**3.7**	66.7	0.04	n.s	34.2	***	31.9	***
Phonological Ability	factor	**1.7**	46.7	**2.3**	53.3	1.1	n.s	31.4	***	32.7	***
Lexical Learning											
Spoken	% err	**2.0**	60.0	**1.6**	40.0	1.5	n.s	46.7	***	32.3	***
Written	% err	2.3	53.3	**1.4**	40.0	4.2	*	47.5	***	20.0	***
Russian	% err	**1.0**	13.3	**0.7**	0.0	0.8	n.s	12.1	***	6.8	**
Lexical-Semantic Learning											
Immediate											
RAVLT	% err	0.3	14.3	*0.7*	13.3	0.6	n.s	0.6	n.s	3.9	*n.s*
WMS-R word pairs	% err	**1.0**	26.6	**1.1**	33.3	0.01	n.s	6.8	**	7.9	***
Delayed											
RAVLT	% err	**1.1**	14.3	0.6	6.7	1.2	n.s	9.7	***	3.7	*n.s*
WMS-R word pairs	% err	0.5	13.3	0.2	0.0	0.4	n.s	1.8	n.s	0.4	n.s
Print Exposure											
ART	% err	0.2	0.0	-0.4	7.7	1.9	n.s	0.6	n.s	1.2	n.s

Both the phonological and the surface dyslexics showed a phonological impairment compared to the matched controls. When compared the dyslexic subgroups to each other, we found that the phonological and the surface dyslexics were equally poor in the majority of the sublexical phonology tasks, except for the Phoneme Counting task, where the surface dyslexics performed normally and, thus, better than the phonological dyslexics. A lack of a significant group difference in the sublexical phonology tasks is not what we would expect to find according to the studies that found weaker phonological deficits for the surface dyslexics when comparing to the phonological dyslexics (Manis et al., 1997; Stanovich et al., 1997). It is, however, consistent with those studies that found equal phonological deficits in both dyslexic subtypes (Sprenger-Charolles, Cole et al., 2000; Ziegler, Castel et al., 2008). It is also consistent with the reports that phonological and surface dyslexia lie on a phonological deficit continuum (Manis et al; 1996; Harm & Seidenberg, 1999; Snowling, 2001; Griffiths & Snowling, 2002). The phonological deficits seen in our surface dyslexics must be seen within the context of their general cognitive performance, which is more severely impaired than that of our phonological dyslexics (refer to the z-scores performances of both dyslexic subgroups as presented in Tables 1:6 and 1:7). Individual z-scores of both dyslexic subtypes on the sublexical phonology tasks are presented in Appendix 19. Phonological deficits in the phonological and surface dyslexics were also found in our published study, where we carried out the same sublexical phonology tasks with the present study, except for the word serial recall task. It was found that the phonological dyslexics performed generally worse than the surface dyslexics on the sublexical phonology tasks (with both selection methods).

In addition to the published study, we found that both dyslexic subgroups performed as well as the controls in the print exposure task. We also found that the surface dyslexics did not differ from the phonological dyslexics in reading experience despite their cognitive profile was more severely impaired. Our results are in line with previous reports in the dyslexia literature, as reviewed in the Introduction (Manis et al., 1999; Castles et al., 1999; Gustafson, 2001; Bailey et al., 2004). Individual z-scores of both dyslexic subtypes on the print exposure task are presented in Appendix 20.

Taken together, our results from performance of the surface dyslexics on the sublexical phonology and print exposure tasks provide evidence against the view that the poor lexical representations in surface dyslexia are the result of a 'milder phonological deficit coupled with reduced reading experience' (Stanovich et al., 1997).

In contrast, we found that both the phonological and the surface dyslexics showed a clear impairment in the learning of novel phonological and orthographic representations involving linguistic stimuli (spoken and written lexical learning). Our results replicate those of our published study, even when both selection methods were used. We also found that both dyslexic subgroups showed an additional but weaker impairment in the learning of novel orthographic representations involving non-linguistic stimuli (russian lexical learning). A lexical learning deficit was true despite learning trials being equated both across different types of stimuli and groups. When compared the dyslexic subgroups to each other, we found that the surface dyslexics did not differ from the phonological dyslexics but in written lexical learning, where the surface dyslexics performed worse. This result is in line with that of our published study (when the spelling method was used) and provide evidence against the hypothesis that surface dyslexia is not a separate impairment but the result of 'reduced learning opportunities'. Instead, they further support the hypothesis originally put forward by Romani, Ward, & Olson (1999) that surface dyslexia is an independent impairment accounted for by 'a written lexical learning deficit' (see also Romani & Stringer, 1994; Romani et al., 1999, 2008; Di Betta & Romani, 2006) despite equated learning opportunities. Individual z-scores of both dyslexic subtypes on the lexical learning tasks are presented in Appendix 20.

The group interaction between written learning and phonological ability in the surface and phonological dyslexics is depicted in Figure 1.

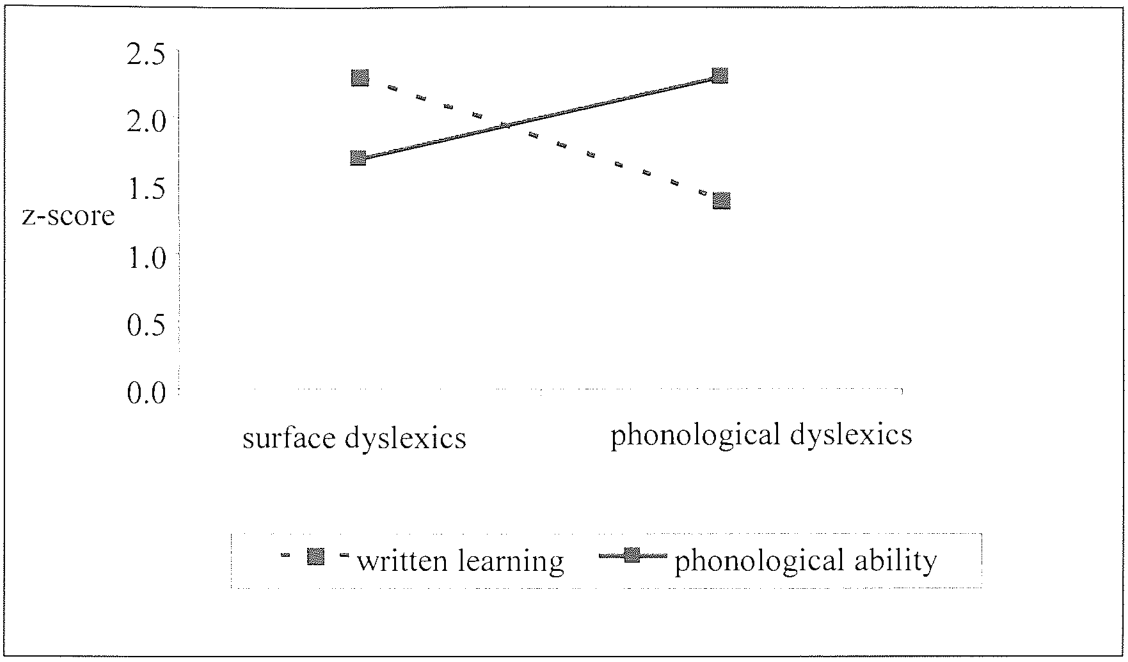

Figure 1. Mean z-scores (from the control distribution) of the surface and phonological dyslexics reflecting written learning and phonological ability.

The surface dyslexics showed a greater impairment in written learning (more than 2SDs from the control mean) than in phonological ability, whereas the phonological dyslexics showed the opposite pattern. We found an interaction between type and subgroup, $F(1,28)=5.8$, $p=.02$, $MSE=1.6$, but no significant effects of type, $F(1,28)=.14$, $p=.71$, $MSE=1.6$, or group, $F(1,28)=.18$, $p=.67$, $MSE=2.5$. The absence of a significant effect of type was true for the surface dyslexics, $F(1,14)=2.4$, $p=.14$, MSE==1.4, and almost true for the phonological dyslexics, $F(1,14)=3.4$, $p=.09$, $MSE=1.8$).

The individual z-scores of the surface and phonological dyslexics on written learning and phonological ability are depicted in Figure 2.

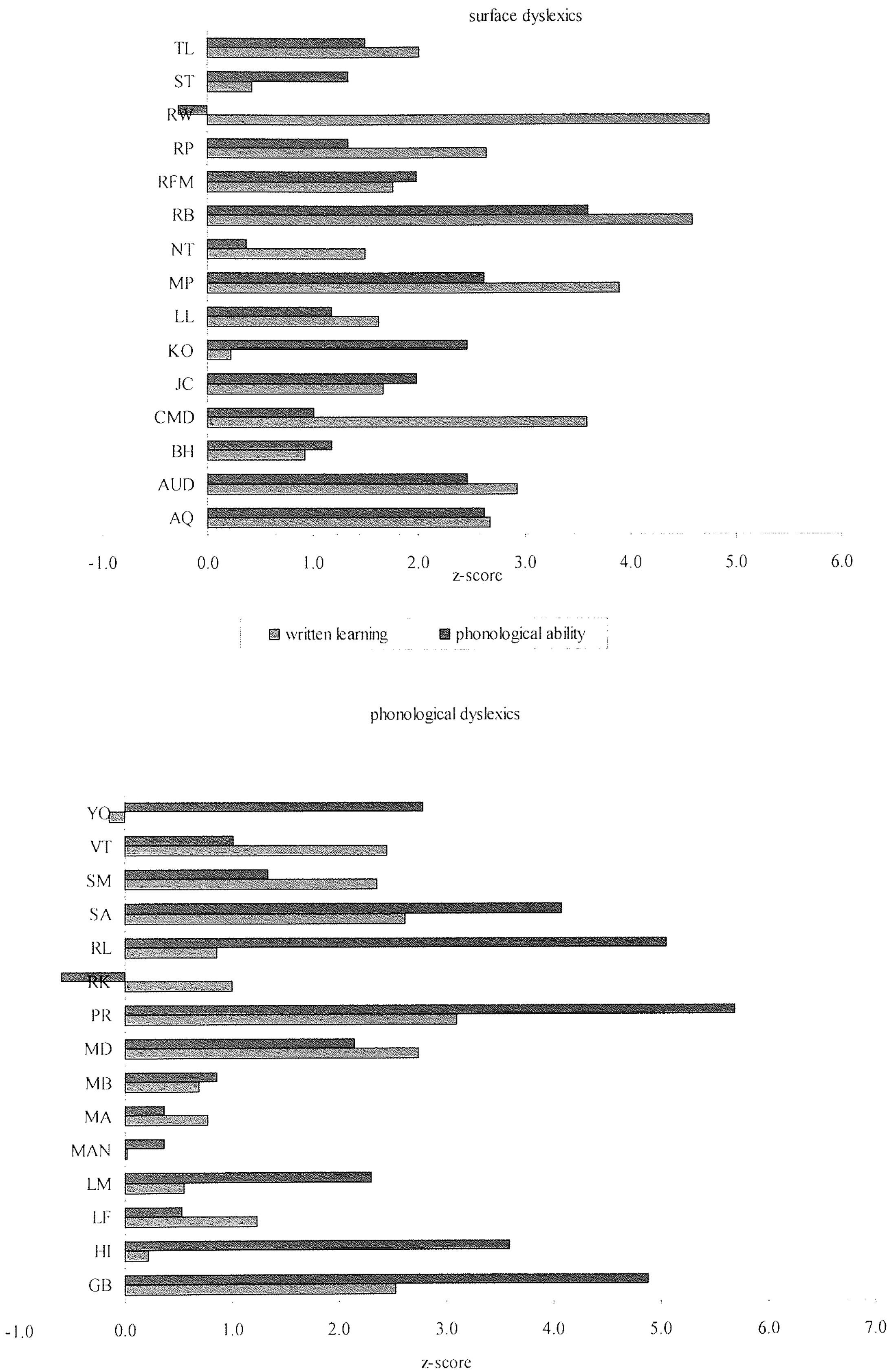

Figure 2. Individual z-scores (from the control distribution) of the surface and phonological dyslexics reflecting written learning and phonological ability.

From each of the dyslexic subgroups, 4 participants were severely impaired (more than 2SDs from the control mean) in both phonological ability and written learning. Overall, 7 surface dyslexics were severely impaired in written learning, while 8 phonological dyslexics were severely impaired in phonological ability.

Results from performance on the lexical-semantic learning tasks showed that, in the immediate condition, both dyslexic subgroups had no significant problems learning real single words when compared to the controls, which is in line with the results of our published study (when both selection methods were used). However, they had significant difficulties in learning pairs of real words with and without semantic relations. When compared the dyslexic subgroups to each other, we found that the surface dyslexics were as good as the phonological dyslexics at learning real single words, which is in line with the results of our published study (when both selection methods were used) and as poor as the phonological dyslexics at learning real word pairs. In the delayed condition, the surface dyslexics were poor at recalling the learnt single words, while the phonological dyslexics were only very mildly poor compared to the controls. In contrast, both dyslexic subgroups performed normally at recalling the learnt word pairs. When compared the dyslexic subgroups to each other, we found no significant differences in the recall of either the learnt single words or the learnt word pairs. These results were true even after learning opportunities were equated across groups. Individual z-scores of both dyslexic subtypes on the immediate and delayed versions of the lexical-semantic learning tasks are presented in Appendix 20.

Results from performance on the various learning tasks indicate that the surface dyslexics suffer from difficulties with learning both real words and nonwords, which is not, however, the result of 'reduced learning opportunities'. However, we showed that a written lexical learning deficit is prominent in surface dyslexia, while a lexical-semantic learning deficit (immediate or delayed) is only secondary to surface dyslexia. These results confirm the view that surface dyslexia is the result of a 'written lexical learning impairment' and not the result of a 'semantic impairment'.

4 GENERAL DISCUSSION

The aim of the present study was to test the predictions of Stanovich, Siegel, & Gottardo (1997) that surface dyslexia is the result of a 'milder phonological deficit than that seen in phonological dyslexia coupled with reduced reading experience'. To achieve this, we investigated phonological skills (as indexed by tasks measuring both phonological STM and phonological awareness) and reading experience (as indexed by the Author Recognition Test) in both adults with developmental dyslexia showing symptoms of surface dyslexia compared to control individuals and adults with developmental surface dyslexia compared to those with developmental phonological dyslexia (as defined by their performance on nonword vs. irregular word spelling) and control individuals. All comparison groups were matched for chronological age and IQ levels (both verbal and non-verbal). We found phonological deficits in both the surface and the phonological dyslexics, as Stanovich et al. (1997) predicted, but that the surface dyslexics showed equal phonological deficits to the phonological dyslexics and normal reading experience commensurate with the phonological dyslexics. Our findings argue against the view that poor lexical representations in surface dyslexia can be explained by a milder phonological deficit conjoined with reduced reading experience. The equally impaired phonological abilities in our surface and phonological dyslexic groups must be realised within the more impaired performance of the former group across tasks compared to the latter group. Studies examining phonological abilities in surface and phonological dyslexics groups have reported inconsistent results. That is, some of them have shown comparable phonological deficits (Sprenger-Charolles, Cole et al., 2000; Ziegler, Castel, et al., 2008), while others have shown a milder phonological deficit for the surface dyslexics (Manis et al., 1997; Stanovich et al., 1997; Romani et al., 2008). Phonological deficits and normal reading experience were also present in the general group of dyslexics. Evidence for comparable print exposure in the surface and phonological dyslexics has also been provided by previous studies, which were, however, limited (Manis et al., 1999; Castles et al., 1999; Gustafson, 2001; Bailey et al., 2004).

The present study also showed that individuals with surface dyslexia can have normal IQ levels (verbal and/or non-verbal). These results are in line with our published study, even when both spelling and reading accuracy selection criteria were considered (Romani, Di Betta, Tsouknida, & Olson, 2008) for the definition of surface dyslexia.

As in our published study (when both selection criteria were used), we showed that surface dyslexia cannot be explained by 'reduced learning opportunities'. This was shown by measuring the ability to learn real single words (as indexed by the immediate version of the Rey Auditory Verbal Learning Test) and novel single words paired with pictures (as indexed by spoken and written lexical learning tasks involving linguistic stimuli) in both the surface dyslexics and the general group of dyslexics as compared to the matched controls, where learning conditions were equated across both groups and different types of stimuli. We also provided comparisons between the surface and the phonological dyslexics. We found that both the surface dyslexics and the general group of dyslexics were good at learning real single words (spoken) but poor at learning novel single words (both spoken and written) despite equal learning opportunities. In addition, the surface dyslexics did not differ from the phonological dyslexics but only in written lexical learning, where an impairment was more severe for the surface dyslexics despite equally impaired phonological abilities. A written lexical learning deficit in surface dyslexia was also found by other studies (Romani & Stringer, 1994; Castles & Holmes, 1996; Romani, Ward, & Olson, 1999; Di Betta & Romani, 2006; Romani, Di Betta, Tsouknida, & Olson, 2008). Our results support the theory originally put forward by Romani, Ward, & Olson (1999) that surface dyslexia is a separate impairment from phonological dyslexia linked with a deficit in recombining visual units of a given linguistic sequence into a new lexical representation, called a 'written lexical learning deficit' (see also Di Betta & Romani, 2006; Romani et al., 2008).

In addition to the published study, we measured other types of learning abilities in both the surface dyslexics and the general group of dyslexics compared to the matched controls, under equated learning conditions. We measured the ability to learn pairs of real words with and without semantic associations (as indexed by the immediate version of the verbal paired associates of the WMS-R), the ability to recall the learnt pairs of words and real single words after a filled delay (as indexed by the delayed versions of the verbal paired associates of the WMS-R and the RAVLT) and the ability to learn novel single words consisting of non-linguistic stimuli, paired with pictures (as indexed by the russian lexical learning task). We also provided comparisons between the surface and the phonological dyslexics. We found that both the surface dyslexics and the general group of dyslexics were poor in the immediate learning of the real word pairs. In the delayed recall tasks, we found that both the surface dyslexics and the general group of dyslexics were poor at recalling the learnt real single words but not the learnt real word pairs. The surface dyslexics did not differ from the phonological dyslexics in the immediate or delayed learning of the lexical-semantic information. In addition, both the surface dyslexics and the general group of dyslexics were poor at learning novel non-linguistic sequences. This ability was, however, less severely impaired than the ability to learn novel linguistic sequences (both written and spoken). This suggests that the dyslexics might have capitalised on their normal visuospatial abilities (as shown in Table 3:3 of Chapter 3; see also Di Betta & Romani, 2006) in order to create new lexical representations for the symbol strings. The surface dyslexics were as poor in this ability as the phonological dyslexics.

Our results from performance on the various types of learning tasks showed that the surface dyslexics have troubles learning both real words and nonwords. However, the comparable difficulties with learning words with meanings (both immediate and delayed learning) in the surface and phonological dyslexics suggest that a lexical-semantic learning impairment is not specific to surface dyslexia but only secondary (in line with the reports of Graff Radford et al., 1990; Green et al., 1990; Scheltens et al., 1990; Watt et al., 1997; Zakzanis, 1999 derived from aphasic patients that show typical symptoms of surface dyslexia). On the other hand, the more pronounced difficulty with learning written nonwords in the surface dyslexics, despite equally impaired phonological abilities with the phonological dyslexics, suggests that a written lexical learning impairment is specific to surface dyslexia. This was also supported by the absence of a significant relationship between lexical-semantic learning (immediate or delayed) and orthographic performance (reading or spelling) in the general group of dyslexics who showed symptoms of surface dyslexia. In contrast, a written lexical learning impairment explained orthographic disorders, independently of phonological processing, performance IQ and age. In particular, written lexical learning was a strong predictor of word spelling and word reading accuracy problems and a less strong predictor of nonword reading accuracy problems.

This is in line with the results of our published study. Contributions to word spelling and word reading accuracy problems remained significant, even after reading experience was controlled. The independence of a written lexical learning impairment from a phonological impairment indicates that written lexical learning in dyslexia is not the result of a single underlying phonological deficit (related to the quality and specification of the phonological representations), but that it taps unique resources in orthographic performance. In addition, we found that the surface dyslexics showed normal reading comprehension commensurate with the phonological dyslexics. Taken together, these findings suggest that poor lexical representations in surface dyslexia cannot be accounted for by a semantic impairment but by an impaired ability to learn novel visual/orthographic representations.

A written lexical learning deficit in surface dyslexia is more consistent with the suggestion by Harm & Seidenberg (1999) that surface dyslexia could be simulated by reducing the quality of the visual input. Goulandris & Snowling (1991) have argued that poor visuospatial memory was responsible for the orthographic difficulties seen in their surface dyslexic patient, J.A.S. However, poor visuospatial abilities are rare in dyslexia. In addition, no visuospatial impairments have been found in other single case studies of surface dyslexia/dysgraphia (Hanley et al., 1992; Castles & Coltheart, 1996; Romani et al., 1999) or group studies (Di Betta & Romani, 2006; present study Chapter 3). If a problem of visual memory is present in dyslexia, this would involve a difficulty in processing visual sequences more than a difficulty in processing visuospatial patterns (Valdois, Bosse, & Tainturier, 2004; Pammer, Lavis, Hansen, & Cornelissen, 2004; Hawelka & Wimmer, 2005; Hawelka, Huber, & Wimmer, 2006; Bosse, Tainturier, & Valdois, 2007; Jones, Branigan, & Kelly, 2008; Lassus-Sangosse, N'guyen-Morel, & Valdois, 2008; for a review see section 1.1.3 of Chapter 3). Thus, a deficit in written lexical learning could be related to a difficulty in processing multi-element visual strings due to either a difficulty in processing sequences in parallel (due to a reduced visuospatial span, Bosse, Tainturier, & Valdois, 2007) and/or a difficulty in processing serial order (Romani et al., 1999). As we show in Chapter 3, there is a significant association between written lexical learning and both simultaneous and sequential processing of visual units.

In addition to the published study, we assessed the contribution of other types of lexical learning that involved new spoken words consisting of letters (spoken lexical learning) and new written words consisting of symbols (russian lexical learning) to orthographic performance in the dyslexics. We found that spoken lexical learning accounted for word spelling and word reading accuracy problems, just like written learning but more weakly, independently of phonological processing, performance IQ and age. Contributions remained significant even after reading experience was controlled. Significant associations between spoken lexical learning and word processing in the dyslexics were also found in our published study (see also Di Betta & Romani, 2006). In addition, russian lexical learning accounted for nonword reading speed problems. A contribution was, however, marginal after reading experience was controlled. In addition, we showed that the independence of lexical learning from the phonological ability is also true in the control individuals. However, we found that only spoken lexical learning made a significant independent contribution to orthographic performance in the control individuals, predicting word and nonword spelling skills. This might suggest that control individuals rely more on phonological than on orthographic representations in order to spell words and nonwords. Contributions remained significant, even after reading experience was controlled. Previous studies have also found that phonological paired associate learning (PAL) predicted orthographic skills in control young readers, independently of phonological processing skills (Reitsma, 1983, 1989; Ehri & Saltmarsh, 1995; Windfuhr & Snowling, 2001; Hulme, Goetz et al., 2007).

Finally, in line with previous studies, we found that print exposure is a significant determinant of word reading accuracy skills in both dyslexics and controls (for dyslexics: Mc Bride-Chang et al., 1993; Leseman & de Jong, 1998; Sénéchal, Lefevre, Thomas, & Daley, 1998; de Jong & Leseman, 2001; Griffiths & Snowling, 2002; for controls: Stanovich & West, 1989; Cunningham & Stanovich, 1990; Chateau & Jared, 2000 Cunningham & Stanovich, 1997; Braaten, Lie, Andreassen, & Olaussen, 1999). This is true, even after phonological processing, performance IQ, age and lexical learning were controlled. Uniquely, we found that print exposure is also a significant determinant of word spelling skills in the dyslexics, independently of phonological processing, performance IQ, age and lexical learning.

5 CONCLUSION

The present study provided evidence that surface dyslexia cannot be explained by a 'milder phonological deficit than the phonological dyslexics conjoined with poor reading experience'. This was shown by finding equally poor performance on the majority of the sublexical phonology tasks (tapping both phonological STM and phonological awareness abilities) and equally normal reading experience in both the surface and the phonological dyslexics (as defined by their spelling performance on nonwords vs. irregular words). We also showed that surface dyslexia cannot be explained by 'reduced learning opportunities', as the surface dyslexics did not differ from the phonological dyslexics in either the immediate learning or the delayed recall of the learnt lexical-semantic information despite learning trials being equated across groups. However, the surface dyslexics showed a more pronounced difficulty than the phonological dyslexics in learning novel visual/orthographic representations, called a 'written lexical learning deficit', despite equal learning opportunities across groups. This finding is in favour of the original claim made by Romani, Ward, & Olson (1999) that surface dyslexia is a separate impairment from the phonological impairment linked with a specific deficit in written lexical learning (see also Di Betta & Romani, 2006; Romani, Di Betta, Tsouknida, & Olson, 2008). A written lexical learning impairment was a strong predictor of word spelling and word reading accuracy disorders and a less strong predictor of nonword reading accuracy disorders, independently of phonological processing skills, performance IQ and age. We further showed that surface dyslexia cannot be explained by a 'semantic deficit' as the surface dyslexics did not differ from the phonological dyslexics in reading comprehension. Finally, we provided further evidence against the hypothesis that surface dyslexia is the result of a 'mild retardation', by showing that surface dyslexics can have normal IQ levels (commensurate with those of the phonological dyslexics in this study).

Chapter 2

A Selective Nonword Reading Deficit in Developmental Dyslexia. Is Poor Phonological Ability the Sole Responsible Factor?

1 INTRODUCTION

1.1 Evidence for a selective nonword reading deficit and typical regularity effects in developmental dyslexia

According to the dual-route model of word recognition (Coltheart, 1978; Morton & Patterson, 1980), reading can be accomplished by two alternate pathways: a lexical/direct route, which relies on the retrieval (from the mental lexicon) of word-specific knowledge from orthography and a sublexical/indirect route, which relies on the use of spelling-to-sound correspondence rules that encode generalisable mappings between letters and sounds. The lexical route is used to process irregular words (which do not conform to spelling-to-sound correspondence rules) but fails to process nonwords (for which there are no stored lexical representations and for which the employment of phonological skills is needed). The sublexical route is instead used to process nonwords, but fails to process irregular words. Regular words, on the other hand, can be processed either by the sublexical (when they strictly obey to the grapheme-phoneme conversion rules) or the lexical route (when they do not strictly obey to the grapheme-phoneme conversion rules). Superior performance in processing regular over irregular words indicates some use of the sublexical route for accessing the lexicon. This phenomenon is called the 'regularity effect' and its existence is taken as evidence of phonological recoding. In contrast, equivalent performance on both regular and irregular words indicates almost exclusive reliance on the lexical route. Therefore, in the case that the sublexical route is less available as a result of impairment, the expected advantage for regular over irregular words will be eliminated or reduced.

Subtypes of developmental dyslexia have often been interpreted as a particular difficulty in acquiring one or the other reading procedure. In the case of phonological dyslexia, the sublexical route is used less effectively resulting in poor nonword processing (Beauvois & Dérouesné, 1979; Shallice, 1981; Roeltgen, Sevush, & Heilman, 1983; Campbell & Butterworth, 1985; Seymour, 1986; Henry, Beeson, Stark, & Rapcsak, 2007), whereas in the case of surface dyslexia, the lexical route is used less effectively resulting in poor irregular processing (Beauvois & Dérouesné, 1981; Coltheart, Masterson et al., 1983; Roeltgen & Heilman, 1984; Patterson, Marshall, & Coltheart, 1985; Rapcsak & Beeson, 2004). Nonword reading has often been used in order to give an indication of phonological skills and this can be interpreted in relation to word reading. The comparison of nonwords with irregular words has been most commonly used as a measure for the differential use of phonological reading strategies.

The phonological deficit hypothesis, as interpreted within the dual-route framework, maintains that a difficulty in establishing an efficient spelling-to-sound translation routine (poor use of the sublexical route) is caused by deficits in the segmental language representations and awareness at the phoneme level (Liberman & Shankweiler, 1985; Stanovich, 1986, 1991; Goswami & Bryant, 1990; Fowler, 1991; Olson, 1994; Share, 1995; McBride-Chang, 1995, 1996; Elbro, 1996; Metsala, 1997). Such deficits in the phonological language domain ultimately influence the development of the phonological processes for use in reading and spelling. Two predictions are normally assumed to be consistent with the phonological deficit hypothesis with respect to individuals with poor sublexical conversion skills relative to reading-age matched younger control individuals: a) a selective nonword reading deficit (dyslexics are qualitatively different from controls with the same reading age in nonword reading) and b) an absent or reduced regularity effect. Thus, the phonological deficit hypothesis assumes that the poor use of the sublexical route should yield no or reduced regularity effect, whereas the efficient use of the sublexical route should yield an increased advantage for regular over irregular words.

To date, ample evidence has provided support for a selective nonword reading deficit in developmental dyslexia. In principle, such a deficit could arise from a difficulty parsing the letter string, segmenting the oral speech into phonemes, converting print to sound and blending together subword segments (or any of these in combination). The nonword reading deficit has often been interpreted within the context of the dual-route model of word recognition to indicate that the sublexical route is relatively more impaired than the lexical route in dyslexics (Snowling, 1980; Frith & Snowling, 1983; Rack, 1985; Pennington et al., 1986; Olson, Kliegel, Davidson, & Foltz, 1985; Holligan & Johnston, 1988; Olson et al., 1989; Levinthal & Hornung, 1992; Stanovich & Siegel, 1994; Siegel, Share, & Geva, 1995). However, the majority of studies has provided evidence against the hypothesis of reduced or absent regularity effects in dyslexia. Taken together, the results obtained from the nonword reading and regularity studies are apparently contradictory.

To compare dyslexic and control reading profiles, three techniques have been used: the chronological-age-match comparison, the reading-age-match comparison and the case series approach. Using the first technique, it is difficult to know whether the different reading profiles in the dyslexics and the CA controls are features of their different reading levels or defining characteristics of the groups. This is the advantage of the second technique, which rules out the possibility that the differences in reading ability are caused by the different levels of reading ability and are better suited at making inferences about distinctive characteristics of subjects. A reading-level-match comparison, thus, allows us to evaluate the 'developmental lag hypothesis' in the case of same reading profiles[21] (Backman, Mamen, & Ferguson, 1984; Bryant & Goswami, 1986; Stanovich, Nathan, & Zolman, 1988) or the 'phonological deficit hypothesis' in the case of deviant reading profiles (Snowling, 1980; Rack, 1985; Holligan & Johnston, 1988; Levinthal & Hornung, 1992; Frith & Snowling, 1993; Stanovich & Siegel, 1994). The third technique uses experimental measures in individual case studies of dyslexia (Seymour, 1986; Snowling, Stackhouse, & Rack, 1986). However, in order to determine the nature of any observed differences, a large number of different cases must be assessed. The present study has used a reading-age-match comparison.

[21] Dyslexics perform poorly on phonological reading tasks, but not more so than younger normal individuals with the same reading age.

Rack, Snowling & Olson (1992) presented a qualitative review of the studies that found nonword reading deficits in dyslexics in comparison with younger controls matched for word recognition (see also the meta-analytic review of Ijzendoorn & Bus, 1994). The majority of the studies found a selective nonword reading deficit (that persisted even in comparison with reading-age matched controls), consistent with the phonological deficit hypothesis, while a small number of studies found no selective nonword reading deficit (as shown by equivalent nonword reading in the dyslexics and controls with the same reading age), consistent with the developmental lag hypothesis. The former set of studies is presented in Table 2:1, while the second set of studies is presented in Table 2:2.

Table 2:1. Studies finding a selective nonword reading deficit in dyslexics as compared with reading-age matched controls (Rack, Snowling, & Olson, 1992).

Table 2:2. Studies finding no selective nonword reading deficit in dyslexics as compared with reading-age matched controls (Rack, Snowling, & Olson, 1992).

In addition, Herrmann, Matyas, & Pratt (2006) presented an updated meta-analytic review of the studies that found nonword reading deficits in dyslexics relative to RA controls. The additional and more recent nonword reading studies are presented in Table 2:3, while the test instruments used are presented in Table 2:4. The majority of these studies found a selective nonword reading deficit, while only a small number found no selective nonword reading deficit (Pennington, Van Ordern, Smith, Green, & Haith, 1990; Vellutino, Scanlon, & Tansman, 1994; Stothard & Hulme, 1995; Snowling, Goulandris, & Defty, 1996).

Table 2:3. Studies finding a nonword reading deficit in dyslexics as compared with reading-age matched controls (Herrmann, Matyas, & Pratt, 2006).

Table 2:4. Test instruments used the studies of the nonword reading deficits in dyslexics (Hermann, Matyas & Pratt, 2006).

We now review additional studies finding a nonword reading deficit in dyslexic individuals, other than those reviewed by Rack et al. (1992) and Herrmann et al. (2006). The majority of these studies found a selective nonword reading deficit and are, thus, in support of the phonological deficit hypothesis. For example, Bruck (1990) found that a nonword reading deficit was also persistent in adult dyslexic readers (see also Pennington et al., 1990; Greenberg et al., 1997, refer to Table 2:3). The author examined phonological recoding in 20 dyslexic college students and 35 six-grade controls matched for word recognition (using the Word Recognition and Oral Reading subtests of the Durrell Analysis of Reading Difficulty, Durrell, 1955) by measuring reading speed and accuracy of words and nonwords (similar to real words and consisting of one and two syllables). Results showed that both groups were worse at reading nonwords than words in terms of both speed and accuracy. In word reading, the dyslexics were slower than the RA controls but made as many errors as them. In nonword reading, the dyslexics were both slower and less accurate than the RA controls.

Similarly, Ben-Dror, Pollatsek, & Scarpatti (1991) examined reading speed and accuracy of words and nonwords (created by replacing one letter of the real words) in 20 dyslexic college students and 20 controls matched for word recognition (using the Word Identification subtest of the WRMT-R). They found that both groups had more difficulty reading nonwords than words in terms of both speed and accuracy. Both latency and error data showed that the dyslexics performed lower for their reading age and exhibited larger lexicality effects (difference between word and nonword reading), confirming the presence of a nonword reading deficit. Badian (1993) also found significant nonword reading differences at a two-year follow-up (age of 9) of dyslexic and non-dyslexic poor readers matched on a composite measure of word recognition and word attack at age 7. In addition, Stanovich & Siegel (1994) measured nonword reading in two groups of reading disabled children, one with an aptitude-achievement discrepancy and another with low aptitude (without a discrepancy) as compared with control readers matched for first to fifth reading grade levels (using the Reading Test of the WRAT-R). They found that both reading disabled groups made more errors than expected for their reading age in a number of nonword reading tasks (GFW[22] Pseudoword Reading, Woodcock Word Attack,

[22] GFW=Goldman, Fristoe, & Woodcock (1974) Sound Symbol Test.

Experimental Pseudowords 1 and 2). More recently, Johnston & Morrison (2007) measured nonword reading in 53 high-IQ and 56 low-IQ reading disabled children in comparison with 62 high-IQ and 43 low-IQ controls matched for reading age (on the Word Recognition test of the BAS). Results showed that a nonword reading deficit was evident in both high and low-IQ poor readers. With regard to response times, this deficit persisted even in comparison with the RA controls. With regard to accuracy, this deficit persisted for the high-IQ readers but not for the low-IQ readers.

Nonword reading deficits in dyslexics have also been found in other languages with more regular orthographies than English. For example, Wimmer (1996) investigated the performance of 21 German dyslexic children and 21 second-grade controls matched for reading age (using a text reading speed test and a frequent content word reading speed task) on reading tasks of words (using the frequent content word test) and nonwords (using the analogous nonword reading task, where nonwords were created by exchanging the initial letters of the frequent content words and a Japanese nonword task, where nonwords consisted of alphabetic letters, easy to pronounce and showing no or little similarity to German spellings). In word reading, both groups performed normally for their reading age in terms of both speed and accuracy. In nonword reading, the dyslexics performed generally worse than expected for their reading age in terms of both speed and accuracy (for <u>speed</u>: performance was lower on both nonword reading tasks; for <u>accuracy</u>: performance was lower on the Japanese nonword reading task and somewhat lower on the analogous nonword reading task). In addition, Landerl, Wimmer, & Frith (1997) contrasted reading words with reading nonwords (derived from the words by exchanging the consonantal onsets) in 18 German and 18 English dyslexic children as compared with 18 and 21 control children, respectively, matched for reading age (for <u>German</u>: using the Salzburger Lese- und Rechtschreibtest, Landerl, Wimmer, & Moser, 1997; <u>for English</u>: using the Word Recognition test of the BAS). The stimuli were mainly identical across the two orthographies in terms of meaning (for words), orthography and phonology[23]. Results showed that dyslexics from both languages were both slower and less accurate at reading nonwords than words. Overall, the English dyslexics were both slower and less accurate than the German dyslexics at reading

[23] The similarity between the items rules out the possibility that any reading differences were due to visual or articulatory differences in the two orthographies.

both words and nonwords. A nonword reading deficit was present in both languages. With regard to speed, a deficit persisted in both languages even in comparison with the RA controls. In addition, the English dyslexics showed a more severe deficit than the German dyslexics. With regard to accuracy, the German dyslexics were slightly more error-prone for their reading age, while the English dyslexics were a lot more error-prone for their reading age. More recently, Ziegler, Perry, Wyatt, Ladner, & Schulte-Körne (2003) also provided a German-English comparison. They contrasted word with nonword reading in 19 German and 30 English dyslexic children compared to 16 and 20 control children, respectively, matched for reading age (for German: using the Salzburger Lese- und Rechtschreibtest; for English: using the Woodcock Word Identification test). The stimuli were mainly identical across the two languages in terms of orthography and phonology. Results showed significant differences between the dyslexics of both languages and the RA controls for overall reading speed but not accuracy. The reading speed impairment was of similar size across the two languages. It was also found that all groups were both slower and less accurate at reading nonwords than words. A nonword reading deficit was present in both languages. With regard to speed, the deficit persisted for dyslexics of both languages even in comparison with the RA controls. This deficit was similar in size across the two orthographies. With regard to accuracy, data were less revealing as they failed to distinguish between dyslexics and RA controls of either country.

Rack, Snowling, & Olson (1992) criticised the studies that have found equivalent nonword reading in dyslexic readers and reading-age-matched control readers. They argued that the nonwords used in these studies were of insufficient complexity (as Snowling, 1981, had found deficits only with polysyllabic nonwords). However, this overlooks the study by Johnston, Rugg, & Scott (1987) that failed to find a selective nonword reading deficit using the same set of nonwords that yielded a deficit when presented to another group of poor readers (Holligan & Johnston, 1988). Rack et al. (1992) also argued that the subjects used in the studies finding no specific nonword reading deficit were less matched for IQ levels compared to the studies that found a selective nonword reading deficit (Stanovich, Nathan, & Vala-Rossi, 1986; Stanovich, 1988; Johnston & Morrison, 2007). The authors, thus, concluded that the phonological deficit hypothesis was more plausible than the developmental lag hypothesis (see also Ijzendoorn & Bus, 1994). In addition, the use of text reading tests used by some researchers in order to match subjects for reading level were also criticised by Rack et al. (1992) and Herrmann et al. (2006) who argued that some dyslexics might use the semantic and syntactic context in order to guess the identity of words they do not recognise. Indeed, research findings suggest that poor readers rely on context when reading to a greater extent than control readers do to facilitate word identification difficulties (Juel, 1980; Nation & Snowling, 1998). Moreover, Rack et al. (1992) have also criticised the Woodcock Word Identification test used by some studies for being a predominantly regular word reading test. However, Herrmann et al. (2006) reported that the studies that used this test tended to obtain greater and not smaller nonword reading deficits (also claimed by Rack et al., 1992).

An alternative index of the ability to use spelling-to-sound correspondences involves the comparison of reading regular words with reading irregular words. Control children and adults have more difficulty processing words with irregular pronunciations reflecting the use of spelling-to-sound translation. In children, this effect of regularity has been usually reported in error rates and less frequently in reading times (Laxon, Masterson, & Coltheart, 1991; Laxon, Masterson, & Moran, 1994; Waters, Bruck, & Seidenberg, 1985). In adults, word reading latency has commonly been observed to be slower for irregular words especially those of lower frequency (Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Waters & Seidenberg, 1985; Seidenberg, Bruck, Fornarolo, & Backmann, 1985; Taraban & Mc Clelland, 1987; Szeszulski & Manis, 1987). As proposed by the phonological deficit hypothesis, failure to use spelling-to-sound correspondence rules yields no difference in the processing of regular and irregular words (absent or reduced regularity effect). However, the vast majority of the studies that investigated regularity effects in dyslexic individuals as compared with reading-age matched control individuals found typical regularity effects (mainly of a normal size). These studies can be taken as more representative of the dyslexic population as a whole (subtypes notwithstanding).

Metsala, Stanovich, & Brown (1998) presented a meta-analytic review of the studies testing the hypothesis of absent or reduced regularity effects in dyslexics relative to RA controls. The majority of the studies found normal regularity effects (commensurate with those of the RA controls). A summary of all studies is presented in Table 2:5.

Table 2:5. Studies examining regularity effects in dyslexics as compared with reading-age matched controls (Metsala, Stanovich, & Brown, 1998).

We now review additional studies that examined regularity effects in dyslexic and control readers, other than those reviewed by Metsala et al. (1998). The majority of these studies found significant regularity effects, while only a small number of them found no significant regularity effects. For example, Snowling, Stackhouse, & Rack (1986) found no regularity effects in phonological dyslexics/dysgraphics with a wide chronological and reading age range but significant regularity effects in younger controls matched for reading age (using the Word Recognition test of the BAS). However, this study used a very small number of subjects as it included only four dyslexic cases. Several other single case studies also found no regularity effects (Temple & Marshall 1983, Seymour & Mc Gregor, 1984; Snowling & Hulme, 1989). However, the interpretation of results from single case studies remains controversial, as a focus on the comparison of individual cases might often obscure consistent trends in the dyslexia literature (Schmidt, 1996). Absent regularity effects in dyslexic readers but significant regularity effects in younger control readers were also found by Barron (1980) and Schlapp & Underwood (1988). However, both studies used lexical decision tasks.

On the other hand, when Bruck (1990) examined the reading of regular and irregular words (matched for median frequency, according to Caroll, Davies, & Richman, 1971, word length and initial sound of each word) in dyslexic adults and RA controls she found that the dyslexics exhibited large regularity effects in terms of both speed and accuracy (greater than those exhibited by the RA controls). Stanovich & Siegel (1994) also found that reading disabled children displayed a normal regularity effect (commensurate with that of the RA controls) when tested in word reading accuracy tasks including regular and irregular words (taken from Barron's list, 1970). The results of this study converge with those from Brown (1997) who assessed reading accuracy of regular and irregular words (matched for initial phoneme, word length, word frequency, according to Kucera & Frances, 1967, and positional bigram frequency, according to Solso & Juel, 1980) in 10 dyslexic children and 10 controls matched for reading age (on the Word Recognition test of the BAS). More recently, Johnston & Morrison (2007) examined regularity effects in reading disabled groups of high and low IQ levels compared to RA controls of high and low IQ levels (on the WISC-R) by using tasks of regular and irregular words of low and high frequency (the majority of which were based on those used by Waters et al., 1984, while others were matched for word frequency, according to Caroll et al., 1971). They found normal regularity effects in both high and low-IQ poor readers especially with low-frequency words. However, the data from high-frequency words showed normal regularity effects for the low-IQ poor readers but no significant regularity effects for the high-IQ poor readers (information about the number of subjects tested and the instruments used for a reading-age match for several of these studies is already reported on page 75).

There have been several possible explanatory accounts for the apparently contradictory results obtained from nonword reading and regularity studies. One is that the characteristics amongst dyslexic populations in the different studies have not been the same in the experiments examining nonword reading and in the experiments examining regularity effects (see Stanovich, Nathan, & Zolman, 1988; see also Stanovich, Nathan, & Vala-Rossi, 1986). For example, the phonological deficits could have been less severe in populations that have shown normal regularity effects and more severe in populations that have shown impaired nonword reading. Similarly, some studies that have not reported a selective nonword reading deficit may have employed subjects without large phonological deficits as those studies that have reported a selective nonword reading deficit (Siegel & Ryan, 1988). The same could apply to the regularity studies. However, an inspection of the subject selection criteria used by the studies cited above does not support this conclusion (see the meta-analytic review of Metsala et al., 1998). Another suggestion is that deficits in individuals with reading disabilities are more likely to be observed when the phonological demands of the task are greater (Holligan & Johnston, 1988). For example, nonword reading might impose greater demands on phonological abilities than regular and irregular word reading. An alternative explanation is also the inadequate methodology that has been used in the studies not finding reduced regularity effects in dyslexics. This might involve floor or ceiling effects or inadequate stimulus characteristics. The latter might be related to discrepancies in the definitions of regularity[24]. A final possibility is the heterogeneity within the dyslexic population, as there are several subtypes within this

[24] Some studies used irregular words, where regularity was defined in terms of the correspondence between graphemes and phonemes, and others used exception and consistent words, where the word type was defined in terms of the consistency of the correspondence between the phonological rime of the words and the corresponding orthographic unit. In most of the studies reviewed above, regular and irregular words were not equated for purely orthographic characteristics (as indexed by positional bigram frequency).

population. That is, if impaired phonological representations are the characteristic of one of the several subtypes of dyslexia, then any predicted difference based on the phonological deficit hypothesis will be statistically diluted by the other subtypes. It would, thus, be impossible to find no regularity effect. Even if reliable subtypes have been identified (Castles & Coltheart, 1993; Manis, Seidenberg et al., 1996; Stanovich, Siegel, & Gottardo, 1997) phonological deficits will characterise the most frequent subtypes (Fletcher et al., 1994; Stanovich & Siegel, 1994; Share, 1995; Share & Stanovich, 1995; Stanovich et al., 1997). Finally, the use of different age spans does not appear to account for the observed discrepancies (see the meta-analytic review of Metsala et al., 1998).

A nonword reading deficit has also been found by our research team, Romani, Di Betta, Tsouknida, & Olson (2008) in adults with developmental dyslexia (N=32). This deficit was true for both accuracy and speed. We have also found that a nonword reading accuracy and speed deficit was also present not only in adults with phonological dyslexia, as expected, but also in adults with surface dyslexia, as defined according to their spelling or reading accuracy of nonwords vs. irregular words (N=11 for each dyslexic subtype). The results of our published study are consistent with the results of the present study, where we investigated larger groups of adults with developmental dyslexia (N=44) and adults with developmental phonological and surface dyslexia, as defined according to their spelling performance on nonwords vs. irregular words (N=15 for each dyslexic subtype). Crucially, in both studies, we found that a nonword reading deficit was equally severe in both dyslexic subtypes (*in the published study*, for accuracy: when the spelling criterion was used; for speed: when both the spelling and the reading accuracy criteria were used; *in the present study*, for both accuracy and speed). A nonword reading deficit with regard to speed in a surface dysgraphic patient (AW) was also found by Romani and colleagues despite good word reading (Romani & Stringer, 1994; Romani, Ward, & Olson, 1999). In addition, a nonword reading deficit with regard to accuracy in a surface dyslexic patient (CD) was also found by Coltheart, Masterson et al. (1983) despite good regular word reading. These findings suggest that a nonword reading deficit cannot be fully explained by poor sublexical skills.

The present study tests the predictions of the phonological deficit hypothesis in developmental dyslexia by investigating both lexicality and regularity effects not only in reading (for both accuracy and speed), but also in spelling in 44 adults with developmental dyslexia compared to 31 younger control individuals matched for both reading age (using the combined lists of Seidenberg, Waters, Barnes, & Tanenhaus, 1984, Experiments 3 and 4) and spelling age (using the combined lists of Schonell, 1985, Holmes & Ng, 1993 and Romani & Ward, unpublished). In addition, it provides a comparison of both lexicality and regularity effects in reading and spelling in the distinct dyslexic subtypes consisting of 15 adults with phonological dyslexia and 15 adults with surface dyslexia (as defined by performance on nonword vs. irregular spelling). In this way, we wanted to examine whether lexicality and regularity effects differ in size across the developmental subtypes. Our aim is to show that poor phonological coding is not the only responsible source of the difficulties seen with nonword reading in dyslexia.

2 METHOD

2.1 Participants

We used the original dyslexic population, which consisted of 44 adults with developmental dyslexia, from which 15 subjects belonged to the phonological group and 15 subjects belonged to the surface group (as defined by their spelling performance on nonwords vs. irregular words). In addition, we investigated a control younger population which consisted of children attending a private school (the 'Blue Coat School' situated at Harborne, South Birmingham), where children generally perform well above the national average, and a public school (the 'Westacre Middle School' situated at Droitwich Spa, outside Birmingham), where we selected the children with the top literacy skills (according to teachers' judgment). The criteria used to select the control younger population were the following:

a) English as a native language.
b) Normal IQ (verbal and non-verbal).
c) No family history of spelling/reading difficulties.
d) No history of neurological and psychological problems.

We assessed a total of 35 children (21 male and 14 female, mean age=10.2, SD=0.6, 26 attending Grade 5 and 9 attending Grade 6). All children attended normal school classes. From the total population, 4 children were excluded from the study because of incomplete data. This left us with 31 children (their demographic characteristics are included in Table 2:6).

All children were submitted to measures of verbal and non-verbal IQ, reading and spelling of single words and nonwords, phonological STM (nonword serial recall), and phonological awareness (Rhyme and Spoonerisms subtests of the Phonological Assessment Battery, PhAB).

Testing was carried out in a quiet room at the respective schools. All children were assessed individually and attended two separate sessions, each lasting for approximately 35 minutes. Another separate session lasting for approximately another 35 minutes included just the spelling task, where children were assessed altogether in small groups. The spelling task was administered prior to the reading task, so that the subjects were not familiar with a word before spelling it. Schools received a detailed report describing the mean performance of the children on the various tasks.

The children's study obtained the ethical approval of the Human Sciences Committee of Aston University. A thorough risk assessment was also undertaken (refer to section 2.1 of Chapter 1, for a description). Informed consent was obtained by the school personnel, parents and children prior to the start of the experiment. Copies of information sheets and consent forms given to the teachers, parents and children are presented in Appendix 21.

2.2 Materials (procedure and scoring)

Children were submitted to the following tasks in a semi-random order:

2.2.1 Coloured Progressive Matrices (CPM) (Raven, 1947, reprinted Edition 1995).

This is a standardised test specifically designed for 6 to 16 year-olds and measures non-verbal intellectual abilities. It assesses not only observational skills, but also the ability to educe relationships and make sense out of complex matrices, to develop new insights, to perceive a situation (not immediately obvious by itself) and to handle complex problems[25]. The test consists of three sets (A, Ab and B), each consisting of twelve figures of different complexity with a missing piece. Participants are asked to choose the appropriate piece out of a total of six to complete the figure. Each set involves a different 'theme' for obtaining the missing piece. Administration and scoring were carried out according to the standardised instructions. The raw score was converted to a percentile rank using the appropriate normative tables.

2.2.2 Wechsler Intelligence Scale for Children-III (WISC-III) (Weschler, 1991).

This is a standardized measure of verbal and non-verbal intellectual skills especially designed for 6 to 16 year and 11 month-olds. To measure verbal IQ, we administered the Vocabulary subtest, where subjects are read words of increasing difficulty (N=30) and are then asked to give a verbal definition. Administration and scoring were carried out according to the standardised instructions.

[25] Spearman has called this ability as 'educive', more commonly referred as 'problem-solving'.

2.2.3 Phonological Awareness

We carried out two subtests of the Phonological Assessment Battery (Frederickson, Frith & Reason, 1997). This is a standardised battery especially designed for 6 to 14 year and 11 month-olds and measures phonological processing skills. It consists of six subtests (Alliteration, Naming Speed, Rhyme, Spoonerisms, Fluency and Nonword Reading), from which we administered the following:

a) PhAB Rhyme. The experimenter read sets of three words and the children were asked to say aloud the two words with the same ending sound. It consisted of two parts (part 1 included 12 test items and part 2 included 9 test items). The fist part included easier words than the second part, where words were phonologically similar within the different sets. Performance is reported in percentage of errors. Stimuli items are presented in Appendix 22.

b) PhAB Spoonerisms. This test consisted of two parts. Part 1 included semi-spoonerisms (N=10), where the children were asked to replace the first sound of a word within a new sound. Part 2 included full spoonerisms, where the children are asked to exchange the initial sounds of two words (N=10). Each part was subject to a time limit of three minutes. Performance is reported in percentage of errors. Stimuli items are presented in Appendix 23.

Administration and scoring were carried out according to the standardised instructions.

Children were also submitted to the following tasks same with the dyslexics:

2.2.4 Phonological STM

Nonword serial recall (refer to section 2.2.8, point b of Chapter 1, for a description). Performance is presented in percentage of errors.

2.2.5 Single word spelling (refer to section 2.2.3 of Chapter 1, for a description). Performance is reported in percentage of errors.

2.2.6 Single nonword spelling (refer to section 2.2.4 of Chapter 1, for a description). Performance is reported in percentage of errors.

2.2.7 Single word and nonword reading (refer to section 2.2.5 of Chapter 1, for a description). Performance is reported in percentage of errors.

3 RESULTS

3.1 Overview of the children's performance

Table 2:6 presents the demographic data and general performance of the dyslexic adults and the control children on tasks measuring non-verbal and verbal IQ, and reading and spelling of single words and nonwords. The dyslexic z-scores (from the control children's mean performance) representing highly significant results (***, for $p \leq .001$, **, for $p \leq .01$) are highlighted in boldface yellow, while those representing less significant results (*, for $p \leq .05$) are highlighted in boldface green. Marginal results (for $p \leq .09$) are in italics and not significant results (for $p \geq .10$) are marked as n.s.

Table 2:6. Demographic characteristics and general performance of the 44 dyslexic adults and 31 control children. Comparison results are provided only for performance on the identical tasks. Impaired is defined as 2SDs from the control children's mean.

		DYSLEXIC ADULTS				CONTROL CHILDREN		COMPARISON	
		Mean	**SD**	**z-score**	**% impaired**	**Mean**	**SD**	**F**	**p**
Age	years	**27.7**	10.6			**10.1**	0.7		
Sex	male: female	**15:29**				**19:12**			
Education	university: secondary	**33:11**							
	Grade 5: 6					**22:9**			
WAIS-R Performance IQ	scaled score	**107.0**	12.1						
Raven-CPM	percentile					**90.6**	5.7		
WAIS-R Vocabulary	scaled score	**10.6**	2.3						
WAIS-R Similarities	scaled score	**12.8**	2.7						
WISC-III Vocabulary	scaled score					**15.4**	2.7		
Reading									
Words	RT	**660.9**	231.0	**1.6**	29.5	**537.6**	77.8	8.1	***
Nonwords	RT	**1048.2**	672.0	**1.7**	27.2	**656.3**	225.4	9.7	***
Words	% err	**5.9**	3.4	-0.1	6.8	**6.3**	2.7	0.2	n.s
Nonwords	% err	**27.8**	13.2	**1.4**	34.1	**18.0**	6.9	14.4	***
Spelling									
Words	% err	**23.0**	11.7	0.0	11.3	**23.1**	8.6	0.0	n.s
Nonwords	% err	**25.5**	2.3	0.5	18.2	**20.4**	10.8	2.1	n.s

The dyslexics and the younger controls performed the same on both reading accuracy and spelling tasks of words. This suggests that the two groups showed equivalent lexical knowledge[26]. However, performance on the orthographic tasks of nonwords showed a different pattern. The dyslexics performed worse than the younger controls on the nonword reading task, in terms of both accuracy and speed, but as well as the younger controls on the nonword spelling task. A significant group difference was also found in word reading speed. The individual z-scores of the dyslexics on the spelling and reading tasks of words and nonwords are presented in Appendix 24.

To assess group differences in the reading and spelling tasks of nonwords, we carried out a two-way mixed-model ANOVA. We used the z-score performance (from the control children's mean performance) on the nonword reading (for accuracy and speed combined) and nonword spelling tasks. The within-subjects factor was 'type' (nonword reading vs. nonword spelling) and the between-subjects factor was 'group' (dyslexic adults vs. control children). Results showed significant main effects of type, $F(1,73)=10.0$, $p=.002$, $MSE=1.1$, suggesting an advantage for spelling over reading nonwords, group, $F(1,73)=10.1$, $p=.002$, $MSE=3.8$, suggesting that the dyslexics performed overall worse than the controls with the same reading and spelling age (dyslexics: -1.0, SD=1.7; control children: 0.0, SD=0.7), and an interaction between type and group, $F(1,73)=10.1$, $p=.002$, suggesting that the difference in nonword reading from nonword spelling was greater for the dyslexics compared to the matched controls (dyslexics: -1.1, SD=1.7; control children: 0.0, SD=1.2). A main effect of type was true for the dyslexics (dyslexics: $F(1,43)=19.3$, $p<.001$, $MSE=1.4$; control children: $F(1,30)=.00$, $p=.99$, $MSE=.70$), suggesting that nonword spelling was easier than nonword reading for the dyslexics in relation to the controls. The differential performance of the dyslexics on the nonword reading and nonword spelling tasks (also reminiscent of that when a chronological-age-match comparison was used, refer to Table 1:1 of Chapter 1) suggests that there is also another ability involved in nonword reading, where dyslexics perform lower than their reading age, other than a phonological ability. This is further addressed in the general discussion.

[26] The ability to retrieve the appropriate phonological or orthographic forms of familiar words from a lexicon that encodes item-specific information. It involves memory for specific visual patterns that identify individual words or word parts.

Table 2:7 presents the scores of the dyslexics and the younger controls on the sublexical phonology tasks. The individual z-scores of the dyslexics on the nonword serial recall task are presented in Appendix 25.

Table 2:7. Performance of the 44 dyslexic adults and 31 control children on the sublexical phonology tasks. Comparison results are provided only for performance on the identical tasks.

		DYSLEXIC ADULTS				CONTROL CHILDREN		COMPARISON	
		Mean	**SD**	**z-score**	**% impaired**	**Mean**	**SD**	**F**	**p**
Phonological STM									
Nonword serial recall	% err	**34.1**	14.1	0.4	13.6	**29.2**	11.1	2.6	n.s
Phonological Awareness									
PhAB Rhyme	% err					**6.5**	6.9		
PhAB Spoonerisms	% err					**11.2**	13.7		

We found no significant difference between the dyslexic adults and the matched control children in performance on the nonword serial recall task ($p = .11$).

3.2 A nonword reading deficit in the presence of significant regularity effects in the dyslexics

3.2.1 Lexicality effect

According to the first prediction of the phonological deficit hypothesis, we expect to find a selective nonword reading deficit in dyslexics compared to the reading-age matched younger controls. We examined effects of lexicality in both reading (for both accuracy and speed) and spelling in the dyslexic adults and the reading and spelling-age matched younger controls. We carried out two-way mixed-model ANOVA. The within-subjects factor was 'type' (words vs. nonwords) and the between-subjects factor was 'group' (dyslexic adults vs. control children). Results are presented in Table 2:8.

Table 2:8. Lexicality effects in reading and spelling in the 44 dyslexic adults and 31 matched control children.

		DYSLEXIC ADULTS		CONTROL CHILDREN		COMPARISON	
		Mean	**SD**	**Mean**	**SD**	**F**	**p**
READING % ERRORS	Nonwords	**27.8**	13.2	**18.0**	6.9	14.4	**.00**
	Words	**5.9**	3.4	**6.3**	2.7	0.2	.66
	Difference	**21.9**	11.2	**11.7**	5.3	22.1	**.00**
	Total	**16.9**	7.8	**12.2**	4.5	9.3	**.00**
	F	**df**	**p**	**MSE**			
lexicality	241.6	1,73	**.00**	42.8			
group	9.3	1,73	**.00**	89.3			
lexicality X group	22.1	1,73	**.00**				
dyslexic adults	168.6	1,43	**.00**	62.9			
control children	152.7	1,30	**.00**	14.1			
READING RT	Nonwords	**1048.2**	672.0	**656.3**	225.4	9.7	**.00**
	Words	**660.9**	231.0	**537.6**	77.8	8.1	**.01**
	Difference	**387.3**	464.5	**118.7**	157.4	9.6	**.00**
	Total	**854.6**	445.7	**597.0**	149.1	9.6	**.00**
	F	**df**	**p**	**MSE**			
lexicality	32.9	1,73	**.00**	68645.3			
group	9.6	1,73	**.00**	252298.5			
lexicality X group	9.6	1,73	**.00**				
	F	**df**	**p**	**MSE**			
dyslexic adults	30.6	1,43	**.00**	107891.4			
control children	17.6	1,30	**.00**	12392.6			

(continued)

		DYSLEXIC ADULTS		CONTROL CHILDREN		COMPARISON	
		Mean	**SD**	**Mean**	**SD**	**F**	**p**
SPELLING % ERRORS	Nonwords	**25.5**	2.3	**20.4**	10.8	2.1	.15
	Words	**23.0**	11.7	**23.1**	8.6	0.0	.97
	Difference	**2.5**	16.3	**-2.7**	12.8	2.1	.14
	Total	**24.3**	12.1	**21.8**	7.3	1.1	.31
	F	**df**	**p**	**MSE**			
lexicality	0.0	1,73	.96	112.2			
group	1.1	1,73	.31	217.1			
lexicality X group	2.1	1,73	.14				

Reading and spelling

In terms of reading accuracy and speed, the dyslexics performed lower than the matched younger controls. Both the dyslexics and the matched younger controls read words more accurately and faster than nonwords. The dyslexics exhibited larger lexicality effects than the matched younger controls. In terms of spelling, results showed the opposite pattern. Both subject groups performed the same. There was no lexicality effect, which suggests no advantage for spelling words over nonwords or an interaction between lexicality and group, which suggests that the difference in word from nonword spelling was of similar size in the dyslexics and the matched younger controls.

Nonword reading deficit

The dyslexics were both less accurate and slower at reading nonwords even in comparison with the reading-age matched controls. A selective nonword reading deficit in dyslexia is consistent with the phonological deficit hypothesis as well as with the reports of the majority of the dyslexic studies. In terms of the dual-route model of word recognition, a selective nonword reading deficit indicates that the dyslexics are particularly impaired in their ability to apply spelling-to-sound conversion rules.

3.2.2 Regularity effect

According to the second prediction of the phonological deficit hypothesis, we expect to find no or reduced regularity effect in dyslexics relative to reading-age matched younger controls. We examined effects of regularity in both reading (for both accuracy and speed) and spelling in the dyslexic adults compared to the reading and spelling-age matched younger controls. We carried out two-way mixed-model ANOVA. The within-subjects factor was 'type' (regular vs. irregular words) and the between-subjects factor was 'group' (dyslexic adults vs. control children). Results are presented in Table 2:9.

Table 2:9. Regularity effects in reading and spelling in the 44 dyslexic adults and 31 matched control children.

		DYSLEXIC ADULTS		CONTROL CHILDREN		COMPARISON	
		Mean	SD	Mean	SD	F	p
READING % ERRORS	Irregular	**12.5**	7.2	**15.6**	5.8	3.7	*.06*
	Regular	**2.5**	2.4	**2.5**	2.1	0.0	.90
	Difference	**10.0**	5.8	**13.1**	5.3	1.9	.18
	Total	**7.5**	4.5	**9.0**	3.5	2.3	.13
	F	**df**	**p**	**MSE**			
regularity	307.4	1,73	**.00**	15.8			
group	2.3	1,73	.13	34.1			
regularity X group	1.9	1,73	.18				
READING RT	Irregular	**637.6**	67.8	**520.0**	62.4	58.5	**.00**
	Regular	**621.2**	220.0	**526.4**	63.8	5.4	**.02**
	Difference	**16.4**	210.0	**-6.4**	9.6	0.4	.55
	Total	**629.4**	124.4	**523.2**	62.9	19.1	**.00**
	F	**df**	**p**	**MSE**			
regularity	0.1	1,73	.79	13003.7			
group	19.1	1,73	**.00**	21474.1			
regularity X group	0.4	1,73	.55				

(continued)

		DYSLEXIC ADULTS		CONTROL CHILDREN		COMPARISON	
		Mean	**SD**	**Mean**	**SD**	**F**	**p**
SPELLING % ERRORS	Irregular	**32.2**	14.0	**32.5**	11.5	0.0	.91
	Regular	**12.1**	9.6	**11.8**	5.5	0.0	.88
	Difference	**20.1**	7.0	**20.7**	7.1	0.2	.70
	Total	**22.2**	11.5	**22.2**	8.3	0.0	.99
	F	**df**	**p**	**MSE**			
regularity	615.8	1,73	**.00**	24.7			
group	0.0	1,73	.99	212.4			
regularity X group	0.2	1,73	.70				

In terms of reading accuracy and spelling, the dyslexics and the matched younger controls performed the same. There were significant regularity effects, which suggest that regular words were read and spelled more accurately than irregular words. The dyslexics and the matched younger controls exhibited equal regularity effects. In terms of reading speed, results showed a different pattern. There was no regularity effect, which suggests that regular words were read in the same rate with the irregular words. There was also no interaction between regularity and group, which indicates that the difference in the rate of regular from irregular reading was of similar size in the dyslexics and the matched younger controls.

The presence of normal regularity effects in the dyslexics (that is commensurate with the reading-age matched controls) is contrary to the phonological deficit hypothesis but in line with the reports of the majority of the dyslexic studies that also failed to find reduced or absent regularity effects in dyslexia.

In summary, a selective nonword reading deficit in the presence of normal regularity effects in dyslexics suggest that a selective nonword reading deficit cannot by fully explained by poor conversion rule skills. This is further addressed in the general discussion.

3.3 A nonword reading deficit in the presence of significant regularity effects in the dyslexic subtypes

3.3.1 Lexicality effect

As shown in the previous Chapter, a nonword reading deficit (for both accuracy and speed) was present not only in the phonological dyslexics, as expected, but also in the surface dyslexics (as defined according to the spelling criterion, refer to Table 1:7 of Chapter 1 for results). This is in line with the findings of our published study (where either a spelling or a reading accuracy criterion was used for the selection of the dyslexic subtypes, Romani et al., 2008). Crucially, we found that this deficit was equally severe in both dyslexic subgroups consistent with the results of the published study (for accuracy: when the spelling criterion was used; for speed: when both the spelling and the reading accuracy criteria were used). In the present study, we examined effects of lexicality in both reading (for both accuracy and speed) and spelling in the surface and the phonological dyslexics. We carried out two-way mixed-model ANOVA. The within-subjects factor was 'type' (words vs. nonwords) and the between-subjects factor was 'group' (surface vs. phonological dyslexics). Results are presented in Table 2:10.

Table 2:10. Lexicality effects in reading and spelling in the 15 surface and 15 phonological dyslexic adults.

		SURFACE		PHONOLOGICAL		COMPARISON	
		Mean	**SD**	**Mean**	**SD**	**F**	**p**
READING % ERRORS	Nonwords	**32.1**	13.2	**27.9**	14.3	0.7	.41
	Words	**8.2**	4.3	**4.8**	1.9	8.5	**.01**
	Difference	**23.9**	10.3	**23.1**	13.3	0.0	.86
	Total	**20.2**	8.4	**16.4**	7.7	1.7	.21
	F	**df**	**p**	**MSE**			
type	118.8	1,28	**.00**	70.8			
group	1.7	1,28	.21	131.2			
type X group	0.0	1,28	.86				
READING RT	Nonwords	**1123.9**	670.1	**1027.4**	764.4	0.1	.72
	Words	**723.4**	288.1	**621.4**	224.2	1.2	.29
	Difference	**400.5**	397.7	**406.0**	546.4	0.0	.98
	Total	**923.7**	475.8	**824.4**	122.9	0.3	.58
	F	**df**	**p**	**MSE**			
type	21.4	1,28	**.00**	114180.1			
group	0.3	1,28	.58	469113.5			
type X group	0.0	1,28	.98				

(continued)

		SURFACE		PHONOLOGICAL		COMPARISON	
		Mean	**SD**	**Mean**	**SD**	**F**	**p**
SPELLING % ERRORS	Nonwords	**18.9**	12.1	**37.5**	18.8	10.2	**.00**
	Words	**31.0**	11.4	**17.2**	10.5	11.9	**.00**
	Difference	**-12.1**	9.3	**20.3**	11.2	73.9	**.00**
	Total	**25.0**	10.9	**27.4**	14.1	0.2	.63
	F	**df**	**p**	**MSE**			
type	4.9	1,28	**.04**	52.8			
group	0.2	1,28	.63	317.0			
type X group	73.9	1,28	**.00**				
surface	25.0	1,14	**.00**	43.3			
phonological	49.4	1,14	**.00**	62.3			

Reading and Spelling

In terms of reading accuracy and speed, the surface and the phonological dyslexics were equally poor. There were significant lexicality effects, which suggest that words were read more accurately and faster than nonwords. The surface and the phonological dyslexics exhibited equal lexicality effects. In terms of spelling, results reflected part of the selection criterion. As with the reading error data, both dyslexic subtypes performed equally poorly. There was also a significant lexicality effect. The phonological dyslexics exhibited larger lexicality effects than the surface dyslexics (the opposite direction of the difference on word from the nonword spelling is part of the selection criterion).

Nonword reading deficit

Both the phonological and the surface dyslexics were impaired at reading nonwords in terms of both accuracy and speed. Crucially, the surface dyslexics, who were better with nonword spelling than the phonological dyslexics, were both as error-prone and slow at reading nonwords as the phonological dyslexics.

To assess differences in performance on the reading and spelling tasks of nonwords in the dyslexic subtypes, we carried out two-way mixed-model ANOVA. As for the general group of dyslexics, we used the z-score performance (from the control children's mean performance) on the nonword reading (for accuracy and speed combined) and nonword spelling tasks. The within-subjects factor was 'type' (nonword reading vs. nonword spelling) and the between-subjects factor was 'group' (surface vs. phonological dyslexics). Results showed a significant main effect of type, $F(1,28)=14.6$, $p=.001$, $MSE=1.2$, suggesting an advantage for spelling over reading nonwords and an interaction between type and group, $F(1,28)=15.7$, $p<.001$, suggesting that the difference in nonword reading from nonword spelling was greater for the surface dyslexics compared to the phonological dyslexics (surface dyslexics: -2.2, SD=1.7; phonological dyslexics: 0.0, SD=1.4). A main effect of type was true for the surface dyslexics in relation to the phonological dyslexics (surface dyslexics: $F(1,14)=25.1$, $p<.001$, $MSE=1.5$; phonological dyslexics: $F(1,14)=.01$, $p=.91$, $MSE=.95$). We, however, found no significant main effect of group, $F(1,28)=.87$, $p=.36$, $MSE=6.2$, suggesting that both dyslexic subtypes performed overall the same (surface dyslexics: -1.0, SD=1.7; control children: 0.0, SD=0.7).

To examine whether the equally poor nonword reading performance between the phonological and surface dyslexics was the result of their equally poor performance on the majority of the sublexical phonology tasks (as shown in Table 1:7 of Chapter 1), we carried out separate two-way mixed-model ANOVAs, one for error rates and one for response times, after removing the variance explained by phonological ability. In this way, we wanted to see whether the nonword reading deficit remained beyond the presence of the strong phonological impairment. The within-subjects factor was 'lexicality' (word vs. nonword reading), the between-subjects factor was 'group' (surface vs. phonological dyslexics) and the covariate was 'phonological ability' (digit span, nonword serial recall, phoneme counting and spoonerisms). When controlling for phonological ability, we found a significant main effect of lexicality both on error rates, $F(1,27)=65.6$, $p<.001$, $MSE=53.1$, and response times, $F(1,27)=4.4$, $p=.05$, $MSE=70380.9$, suggesting that nonwords were read less accurately and more slowly than words, even when phonological ability was controlled for. The phonological ability covariate explained a significant amount of variance in both the error rate analysis, $F(1,27)=7.1$, $p=.01$, $MSE=107.7$, and the response time analysis, $F(1,27)=17.3$, $p<.001$, $MSE=296257.0$. The main effect of group was not significant for either error rates, $F(1,27)=3.7$, $p=.07$, $MSE=107.7$, or response times, $F(1,27)=2.3$, $p=.14$, $MSE=296257.0$. However, the interaction effect between lexicality and phonological ability was significant both on error rates, $F(1,27)=10.3$, $p=.003$, and response times, $F(1,27)=18.4$, $p<.001$, suggesting that the effect of phonological ability on reading performance was modulated by lexicality. The interaction effect between lexicality and group was not significant for either error rates, $F(1,27)=0.7$, $p=.41$, or response times, $F(1,27)=0.6$, $p=.43$, confirming that both dyslexic subgroups were equally error-prone and slow at nonword reading. A main effect of lexicality was true for both dyslexic subgroups at least on error rates (surface dyslexics: $F(1,13)=47.4$, $p<.001$, $MSE=55.9$; phonological dyslexics: $F(1,13)=31.7$, $p<.001$, $MSE=36.7$). On response times, a main effect of lexicality was only marginally true for the surface dyslexics in relation to the phonological dyslexics (surface dyslexics: $F(1,13)=3.8$, $p=.07$, $MSE=67967.9$;

phonological dyslexics F(1,13)=0.9, p=.37, MSE=78077.2). In addition, a main effect of phonological ability was true for the phonological dyslexics in relation to the surface dyslexics both on error rates (surface dyslexics: F(1,13)=0.0, p=.85, MSE=152.9; phonological dyslexics: F(1,13)=14.5, p=.002, MSE=61.0) and response times (surface dyslexics: F(1,13)=4.4, p=.06, MSE=365373.8; phonological dyslexics: F(1,13)=14.8, p=.002, MSE=244065.1). Finally, an interaction between lexicality and phonological ability was significant for the phonological dyslexics in relation to the surface dyslexics both on error rates (surface dyslexics: F(1,13)=0.2, p=.69, phonological dyslexics: F(1,13)=20.9, p=.001) and response times (surface dyslexics: F(1,13)=3.3, p=.09; phonological dyslexics: F(1,13)=13.8, p=.003).

3.3.2 Regularity effect

According to the prediction of the phonological deficit hypothesis about absent or reduced regularity effect in individuals with poor sublexical conversion skills relative to a younger control comparison, we expect to find absent or reduced regularity effects in the phonological dyslexics and, thus, an increased advantage for regular words in the surface dyslexics. We examined effects of regularity in both reading (for both accuracy and speed) and spelling in the surface and the phonological dyslexics. We carried out two-way mixed-model ANOVA. The within-subjects factor was 'type' (regular vs. irregular words) and the between-subjects factor was 'group' (phonological vs. surface dyslexics). Results are presented in Table 2:11.

Table 2:11. Regularity effects in reading and spelling in the 15 surface and 15 phonological dyslexic adults.

		SURFACE		PHONOLOGICAL		COMPARISON	
		Mean	**SD**	**Mean**	**SD**	**F**	**p**
READING % ERRORS	Irregular	**17.4**	8.6	**9.5**	4.3	10.4	**.00**
	Regular	**3.9**	2.8	**2.0**	2.3	5.0	**.03**
	Difference	**13.5**	6.7	**7.5**	3.6	9.8	**.00**
	Total	**10.7**	5.5	**5.8**	2.9	9.8	**.00**
	F	**df**	**p**	**MSE**			
type	116	1,28	**.00**	14.4			
group	9.8	1,28	**.00**	38.5			
type X group	9.8	1,28	**.00**				
	Type						
surface	62.5	1,14	**.00**	22.2			
phonological	64.4	1,14	**.00**	6.5			
READING RT	Irregular	**653.6**	40.7	**602.8**	88.4	4.1	**.05**
	Regular	**675.6**	291.1	**583.0**	188.0	1.1	.31
	Difference	**-22.0**	285.6	**19.8**	166.7	0.24	.63
	Total	**664.6**	150.9	**592.9**	121	2.1	.16
	F	**df**	**p**	**MSE**			
type	0.0	1,28	.98	27344.4			
group	2.1	1,28	.16	37431.8			
type X group	0.2	1,28	.63				

(continued)

		SURFACE		PHONOLOGICAL		COMPARISON	
		Mean	**SD**	**Mean**	**SD**	**F**	**p**
SPELLING % ERRORS	Irregular	**43.2**	13.1	**23.5**	11.8	18.7	**.00**
	Regular	**16.6**	9.7	**9.7**	9.3	3.9	*.06*
	Difference	**26.6**	5.4	**13.8**	4.1	53.9	**.00**
	Total	**29.9**	4.5	**16.6**	10.4	11.3	**.00**
	F	**df**	**p**	**MSE**			
type	530.0	1,28	**.00**	11.5			
group	11.3	1,28	**.00**	233.1			
type X group	53.9	1,28	**.00**				
surface	362.8	1,14	**.00**	14.6			
phonological	168.6	1,14	**.00**	8.4			

In terms of reading accuracy and spelling, the surface dyslexics made more errors than the phonological dyslexics. Both the surface and the phonological dyslexics read and spelled regular words more accurately than irregular words. The surface dyslexics exhibited larger regularity effects than the phonological dyslexics. In terms of reading speed, results showed the opposite pattern. Both dyslexic subgroups were equally slow. There was no regularity effect, which suggests that regular words were read as slow as irregular words. There was also no interaction between regularity and group, which suggests that the difference in the rate of regular from irregular reading was of similar size in the surface and the phonological dyslexics.

The reduced regularity effects in the phonological dyslexics compared to the surface dyslexics indicate a more impaired sublexical route consistent with the phonological deficit hypothesis. Similarly, the larger regularity effects in the surface dyslexics indicate more efficient sublexical route consistent with the phonological deficit hypothesis.

In summary, the finding that both the phonological and the surface dyslexics show equally impaired nonword reading performance in the presence of their differential ability to use the sublexical route suggests that a nonword reading deficit cannot be fully explained by poor sublexical skills.

4 GENERAL DISCUSSION

The present study has tested the predictions of the phonological deficit hypothesis, as interpreted within the classical dual-route model of word recognition (Coltheart, 1978; Morton & Patterson, 1980), about a selective nonword reading deficit and absent or reduced regularity effects in dyslexics relative to reading-age matched younger control individuals. We examined nonword reading and regularity effects, in terms of both accuracy and speed, in a population of adults with developmental dyslexia compared to a population of control children with the same reading age (as indexed by performance on a single word accuracy reading task). In line with the first prediction of the phonological deficit hypothesis and the majority of the dyslexic nonword reading studies (refer to Introduction, for a review), we found that the dyslexics are selectively impaired at reading nonwords in terms of both accuracy and speed even in comparison with reading-age matched younger controls. According to the phonological deficit model, a nonword reading performance in the dyslexics that is inferior to their reading age indicates a significant difficulty with using spelling-to-sound correspondence rules. A discrepant nonword reading performance also indicates that the dyslexics are not going through the same developmental stages with the control individuals, because if they were, then nonword reading would be comparable to that of their equated for reading age control individuals. This points to a 'deviant' rather than to a simply 'delayed' dyslexic reading profile. A selective nonword reading deficit that persists even in adulthood was also found by other studies which were, however, very limited (Bruck, 1990; Pennington et al., 1990; Greenberg et al. 1997).

When examined regularity effects in reading, we found that the dyslexics exhibited a normal regularity effect (commensurate with that of the reading-age matched controls). This finding is contrary to the second prediction of the phonological deficit hypothesis, according to which dyslexics ought to show weak or no regularity effect. It is, however, in line with the majority of the reports in the dyslexia literature about an advantage for regular over irregular words in dyslexics (refer to Introduction, for a review), which indicates efficient use of the spelling-to-sound correspondence rules. The regularity effect was observed in terms of error rates but not in terms of response times. The absence of a regularity effect in reading response times might indicate that an implicit speed set caused subjects to respond before the system had settled on a final answer. However, the dyslexics were slower than the reading-age matched controls at reading both regular and irregular words.

A selective nonword reading deficit in dyslexia that persists even in the presence of equivalent sublexical conversion skills (as indexed by a normal regularity effect in the dyslexics) suggests that poor phonological abilities cannot fully account for the difficulties seen with nonword reading in developmental dyslexia.

The present study has also examined lexicality and regularity effects in spelling in dyslexics relative to younger controls with the same spelling age (as indexed by performance on a single word spelling task). Unlike a selective nonword reading deficit in dyslexia, we found that the dyslexics performed poorly on the nonword spelling tasks, but not more so than the control individuals with the same spelling age. However, same with the reading error data, we found a normal regularity effect (commensurate with that of the spelling-age controls).

The discrepant performance of the dyslexics on the nonword reading task on the basis of their reading age suggests that nonword reading should also tap another ability other than a phonological ability. More evidence on this was obtained by comparing nonword reading and regularity effects, in terms of both accuracy and speed, in the distinct dyslexic subtypes consisting of adults with phonological dyslexia and adults with surface dyslexia (as defined according to the difference in the spelling of nonwords from the spelling of irregular words). As expected, we found that the phonological dyslexics were significantly impaired at reading nonwords. This was true for both accuracy and speed. However, a nonword reading deficit for both accuracy and speed was also evident in the surface dyslexics despite better sublexical skills as indexed by better nonword spelling performance. Crucially, both the phonological and the surface dyslexics were equally impaired at reading nonwords in terms of both accuracy and speed (consistent with the results of our published study, where either a spelling or a reading accuracy selection criterion was used, Romani et al., 2008). More importantly, we found that this deficit remained even after poor phonological processing abilities (as indexed by poor performance on the phonological STM and phonological awareness tasks) were covaried. A difficulty with nonword reading in surface dyslexia was also found by Coltheart et al. (1983), Romani & Stringer (1994) and Romani et al. (1999) in their single case studies. A nonword reading deficit that persists even in the context of differential sublexical skills and beyond poor phonological processing abilities indicates that poor phonological skills cannot be the only responsible factor for the deficit in nonword reading.

The differential sublexical skills of the dyslexic subtypes are also supported by finding reduced regularity effects in the phonological dyslexics in both reading accuracy and spelling compared to the surface dyslexics. This is consistent with the view that conversion rule skills are more impaired in the phonological than in the surface dyslexics and thus an advantage for regular over irregular words is reduced. The regularity effect was observed in terms of error rates but not in terms of response times, same with the results of the general group of dyslexics.

Taken together, our findings do not implicate the assumption of the classic dual-route model of word recognition that poor use of the sublexical route should yield problems with nonword reading. Instead, they suggest that a nonword reading deficit is not only the result of poor phonological coding but could also be the result of poor visual/orthographic coding. This could relate to a difficulty processing novel letter sequences. It is possible that, in nonword reading, mild problems with conversion rules are compounded by difficulties in processing visual sequences. A deficit in processing visual strings has been found by a number of recent studies, which we review in Chapter 3 (Valdois, Bosse, & Tainturier, 2004; Pammer, Lavis, Hansen, & Cornelissen, 2004; Hawelka & Wimmer, 2005; Hawelka, Huber, & Wimmer, 2006; Bosse, Tainturier, & Valdois, 2007; Jones, Branigan, & Kelly, 2008; Lassus-Sangosse, N'guyen-Morel, & Valdois, 2008). Such a deficit is also shown in Chapter 3, where we also found a significant relationship with a deficit in nonword reading (refer to Tables 3:9 and 3:10 of Chapter 3). A difficulty in processing visual strings might be related to a more general visual attentional deficit. Indeed, some studies have suggested that focused visuospatial attention is more important for nonword reading than for word reading. For example, Sieroff & Posner (1988) used spatial cueing to manipulate focused visual attention during reading. They found that subjects made more errors at reporting the letters from the unattended side of nonwords compared to words. Moreover, Sieroff, Pollatsek, & Posner (1988) found that patients with hemispatial neglect made more errors on the contralesional side of nonwords compared to words. In support of this claim, recent developments of the dual-route model of reading have included an attentional window that operates on the input to the sublexical route (Perry et al., 2007). Such a model clearly predicts that a focused visual attentional deficit would particularly affect nonword reading. Other non-phonological factors have also been shown to influence the ability to access and pronounce nonwords appropriately. Priming of nonword naming from cues related to orthography (Kay & Marcel, 1981), syntax (Campbell & Besner, 1981) or semantics (Laxon, Smith, & Masterson, 1995) have all been demonstrated.

As shown in the previous Chapter, a nonword reading deficit was significantly associated with both a phonological deficit (as indexed by poor performance on the phonological STM and phonological awareness tasks), which confirms the importance of phonological skills in nonword reading, and a lexical learning deficit. A correlation between nonword reading and lexical learning does not imply that lexical learning is strongly related to non-lexical processing in dyslexia. Instead, our laboratory has found that lexical learning is more strongly related to lexical rather than to non-lexical processing for both reading and spelling skills in dyslexia (Di Betta & Romani, 2006; Romani, Di Betta, Tsouknida, & Olson, 2008, refer also to Table 1:3 of Chapter 1). However, it could suggest that the deficits seen in lexical learning and nonword reading could be influenced by a difficulty at processing novel visual/orthographic strings. Since there are no available lexical representations for the nonwords, one might has to follow a more analytic processing strategy in order to decode the phonological representations of the novel orthographic strings.

Frith's model (1985) has also pointed out the importance of analytic orthographic processing strategies utilized in the alphabetic stage of reading acquisition skills. The model suggests that the analytic orthographic knowledge contributes importantly to the attainment of orthographic skills. In addition, Weekes (1997) investigated to what extent phonological decoding operates in a serial manner by examining length effects in reading latencies for both words (of high and low frequency) and nonwords in adult readers. The author aimed to show that the greater the length effect the more people rely on serial decoding strategies. Results showed that the number of letters affected latency for words (of low but not of high frequency) and nonwords. Crucially, the number of letters continued to affect latency for nonwords but not for (low-frequency) words, even after the effects of orthographic neighbourhood size, number of friends, and average grapheme frequency had been accounted for. It was, thus, concluded that length effects on nonword reading reflect a sequential, non-lexical decoding mechanism. This data is consistent with the view that words as opposed to nonwords benefit from direct parallel orthographic access, whereas nonwords need to be phonologically decoded in a serial letter-by letter-fashion (Coltheart, Rastle, Perry et al., 2001). However, Ziegler et al. (2003) showed that serial effects were not only present in nonword reading but also in word reading. They investigated length effects in reading of both words and nonwords in English and German dyslexic children. In terms of response times, they found striking length effects in the dyslexics of both languages, which were larger than those exhibited by reading and chronological-age matched controls. Such strong length effects suggest that dyslexic children follow a serial rather than a parallel reading strategy. In terms of error rates, the English but not the German dyslexics showed a length-specific deficit but only when compared to the chronological-age matched controls. They also found no interactions with lexicality, which suggests that the dyslexic children processed both words and nonwords in a serial fashion. It was concluded that it could be the case that both words and nonwords are submitted to a similar serial reading mechanism.

In addition, a discrepant nonword reading performance in dyslexia in the context of equivalent word reading accuracy skills suggests that a selective nonword reading deficit cannot be accounted for by limited experience with written language in comparison with control individuals of the same reading age. Thus, the developmental lag hypothesis seems implausible. This view is also supported by the absence of a significant correlation between nonword reading and print exposure in the dyslexics (refer to Table 1:3 of Chapter 1). In support of this, Barker, Torgesen, & Wagner (1992) also showed that reading experience (as indexed by performance on the Title Recognition Test) did not account for a nonword reading deficit in dyslexia.

5 CONCLUSION

The present study provided evidence that a selective nonword reading deficit in dyslexia cannot be fully explained by a phonological impairment. This was shown by finding a specific nonword reading deficit even in the presence of equivalent sublexical conversion skills, as indexed by an advantage for reading and spelling regular words over irregular words in the dyslexics that was commensurate with that of reading and spelling-age matched control individuals. Further evidence was provided by finding that a nonword reading deficit was not only present in individuals with phonological dyslexia but also in individuals with surface dyslexia. Crucially, this deficit was equally severe in both dyslexic subtypes despite differential functioning of the sublexical route. More importantly, a nonword reading deficit remained beyond poor phonological processing abilities. Our findings point to the conclusion that the difficulties with nonword reading could also be explained by a non-phonological impairment relating to a difficulty encoding the unrelated units within novel letter strings, where a more serial processing strategy needs to be reinforced. Such a conceptualization implicates the selection of the nonword reading method as a direct indicator of phonological coding skills. It has also further implications on the development of special teaching methods and remedial work with respect to the unique difficulty with reading novel words in individuals with developmental dyslexia, which would also focus on the enhancement of more analytic processing abilities.

Chapter 3

Order Encoding, Sequential Processing, Array Matching and Lexical Learning: Contributions to Developmental Dyslexia

1 INTRODUCTION

Our research team (Di Betta & Romani, 2006; Romani, Di Betta, Tsouknida & Olson, 2008) has found that a deficit in written lexical learning accounts for variation in the severity of the orthographic symptoms seen in developmental dyslexia/dysgraphia. We have argued that written learning taps the ability to recombine units of a given visual sequence into a new lexical representation. We have shown that a deficit in written lexical learning is more profound in individuals with developmental surface dyslexia/dysgraphia (for a group study: Di Betta & Romani, 2006; Romani et al., 2008; for a single case study: Romani & Stringer, 1994; Romani, Ward, & Olson, 1999). In their single case study, Romani, Ward, & Olson (1999) have also measured the ability to process multi-element visual sequences (involving both alphabetic and non-alphabetic information) in an adult with surface dysgraphia, AW, by using the following tasks: a) the Hindi and Japanese (H&J) sorting tasks, which involved visual series of briefly presented Hindi characters that appeared one after the other (sequentially) and Japanese characters that appeared both one after the other and altogether in a single line (simultaneously), and b) the array matching tasks, which involved same-different pairs of words and nonwords, consonant letters and familiar symbols, under two conditions: an identity and an order, where the different pairs involved a change in the identity or order of two adjacent units. It was found that AW was impaired in the sequential presentation of the H&J characters and in the order rather than in the identity condition of the same-different array matching tasks suggesting a specific difficulty at encoding the order of visual sequences.

The present study measures different types of visual skills, such as the ability to process visual series and learn and recall visuospatial information, in a group of adults with developmental dyslexia/dysgraphia that showed symptoms of surface dysgraphia as compared to a group of control adults (matched for chronological age, performance IQ and verbal IQ to the dyslexics). To measure the ability to process visual series, we used the original H&J sorting tasks (which involved four Hindi or five Japanese characters) and same-different array matching tasks (which involved pairs of eight consonants or symbols). In addition to the study of Romani et al. (1999), we included a simultaneous presentation for the Hindi characters. To measure visuospatial abilities, we used a number of visuospatial tasks involving different types of information (i.e. paired associates of nonsense figures and colours, abstract shapes, different kinds of doors and H&J characters following both simultaneous and sequential presentations).

To date, a number of studies have linked reading impairments to a deficit in processing multi-element visual arrays (Mason, 1975, 1980; Manis & Morrison, 1982; Enns, Bryson, & Roes, 1995; Valdois 1996; Romani et al., 1999; Valdois, Bosse, Carbonnel et al., 2003; Valdois, Bosse, & Tanturier, 2004; Pammer, Lavis, Hansen, & Cornelissen, 2004; Pammer, Lavis, Cooper, Hansen, & Cornelissen, 2005; Hawelka & Wimmer, 2005; Hawelka, Huber, & Wimmer, 2006; Bosse, Tainturier, & Valdois, 2007; Prado, Dubois, & Valdois, 2007; Jones, Branigan, & Kelly, 2008; Lassus-Sangosse, N'guyen-Morel, & Valdois, 2008). Most of the evidence has been obtained by means of 'whole report' tasks, where subjects are asked to verbally report the identities of briefly presented (for 100 or 200ms) multi-element visual arrays (usually consisting of five consonant letters), irrespective of their positions, and 'partial report' tasks, where subjects are asked to verbally report the identity of a single visual element within the array in response to a post-stimulus position cue. The design of these tasks was inspired from the original method developed by Averbach and colleagues (Averbach & Coriell, 1961; Averbach & Sperling, 1968) in order to study the processing of letter information perceived during a single fixation. Since then, a number of researchers have used the same tasks (or variants) to measure both control and impaired visual attentional abilities (for control: Mewhort, Campbell et al., 1981; Hagenaar & Van Der Heijden, 1995; Dixon, Gordon et al., 1997; Giesbrecht & Dixon, 1999; for impaired: Rapp & Caramazza, 1991; Arguin & Bub, 1993; Duncan et al., 1999; Habekost & Bundesen, 2003).

In these studies, a 'multi-element string processing deficit' has been operationally defined by poor performance on the whole and/or partial report tasks. However, the nature of this deficit remains largely unclear, as the two tasks do not seem to tap the same abilities. The partial report tasks are more taxing of position encoding rather than simultaneous processing. In addition, both report tasks induce naming and verbal STM abilities, known to be impaired in the dyslexics. Thus, a difficulty in processing the visual strings might reflect a problem with verbal coding. To avoid the involvement of verbal processes and to make interpretation of results less trivial, we used more visually based tasks, which do not require the verbal report of the names of the visual elements. In the case of the nameable stimuli included (consonants and familiar symbols), our tasks required the detection/comparison of same-different visual sequences by the push of a button. In the case of the non-nameable stimuli (unfamiliar Hindi & Japanese characters), our tasks required the reproduction of the order of the visual sequences by sorting tiles of cards with the corresponding characters (passed to the subjects immediately after the string presentation). In addition, we measured both the simultaneous and the sequential processing of series of H&J characters, differently from a small number of studies that have measured the simultaneous and the sequential processing of single visual configurations in general (Ben Yehudah, Sackett, Malchi-Ginzberg, & Ahissar, 2001; Ben-Yehudah & Ahissar, 2004; Ram-Tsur, Faust, & Zivotofsky, 2006, 2008). Finally, we measured both processing accuracy and speed of the consonant and symbol strings. The aim of the present study is to assess the contribution of a deficit in processing series of independent visual units to the orthographic symptoms seen in developmental dyslexia, beyond the significant contribution of the strong phonological deficit. We also aimed at investigating the relation between a deficit in processing visual sequences on one side, and phonological, lexical learning and orthographic deficits on the other.

1.1 Review of evidence for a visual processing deficit in developmental dyslexia

Morgan (1896) and Hinshelwood (1917) have first introduced the hypothesis of a deficiency in visual processing as the cause of developmental dyslexia. This hypothesis came back at the core of the debate with the magnocellular hypothesis, a deficit in low-level visual processing.

1.1.1 The magnocellular deficit hypothesis

Since the mid 1970s, the visual processing deficits in developmental dyslexia have been linked to functional anomalies in the 'visual magnocellular pathway[27]' (Breitmeyer & Ganz, 1976; Lovegrove, Martin, & Slaghuis, 1986; Lehmkuhle, Garzia et al., 1993; Eden et al., 1996; Stein & Walsh, 1997; Cornelissen, Hansen et al., 1998; Demb, Boynton, & Heeger, 1998; Stein, 2001; Pammer & Wheatly, 2001; Stein, 2003, for a review). Lesion studies in monkeys have shown that the magnocellular (M) visual system is responsible for the perception of movement and the detection of stimuli of low luminance, low spatial resolution and high temporal frequency (Merigan & Maunsell, 1990; Merigan et al., 1991a). Therefore, a dysfunctioning M visual pathway should result in poor detection of visual stimuli that are briefly presented, flicker or drift along the screen ('transient' stimuli). Autopsies of dyslexic brains and psychophysical or electrophysiological techniques have found specific visual abnormalities in the magnocellular lateral geniculate nucleus (mLGN) of the thalamus (Lovegrove et al., 1980; Lemkuhle, Garzia et al., 1993; Merigan & Maunsell, 1993; Brannan & Williams, 1988; Livingstone, Rosen, Drislane, & Galaburda, 1991; Lehmkuhle, 1993; Cornelissen, Richardson et al., 1995; Stein & Walsh, 1997). Indeed, Livingstone et al. (1991) found that the ventral layers of the

[27] In both macaques and humans, the primate visual system consists of three pathways that run parallel from the retinal ganglion cells, through the lateral geniculate nucleus (LGN), and hence to the primary visual cortex (V1). These pathways are characterised by three principal types of cells: the magnocellular, the parvocellural and the koniocellular that can be distinguished from each other based upon laminar location, morphology, connections and neurochemistry. The different cell types respond preferentially to different stimulus characteristics. The M-cells are more sensitive to moving targets, flicker lights of high temporal frequency, low intensity, contrast and spatial frequency. The P-cells are more sensitive to colour, high spatial frequency and contrast. The K-cells have been very limited studied. They have been suggested to possibly play role in motion processing (Livingstone & Hubel, 1988; Merigan & Maunsell, 1993; Xu, Ichida, Allison, Boyd, & Bonds, 2001; Sincich, Park et al., 2004). Some degree of segregation between the M and the P-system is maintained in the higher cortical areas with the former being more prominent in the dorsal stream (associated with object locations and motion) and the latter being more prominent in the ventral stream (associated with object recognition and form representation).

mLGN of the dyslexic brains consisted of fewer, smaller cells than the control brains, whereas the cell of the parvocellular lateral geniculate nucleus (pLGN) did not differ in size between the dyslexic and control brains. However, failure to replicate these psychophysical findings has yielded considerable criticism (Hulme, 1988; Gross-Glen et al., 1995; Hadyuk et al., 1996; Spinelli et al., 1997; Vanni, Uusitalo, Kiesila, & Hari, 1997; Skottun, 2000, 2005; Ramus et al., 2003; Williams, Stuart, Castles, & Mc-Anally, 2003; Hutzler, Kronbichler, Jacobs, & Wimmer, 2006). Criticism of the magnocellular theory also focuses on the failure to replicate findings of visual deficits specific to the M system (Johanes, Kussmaul et al., 1996; Ben-Yehudah, Sackett et al., 2001; Ben-Yehudah & Ahissar, 2004; Ram-Tsur, Faust, & Zivotofsky, 2006, 2008) and on the findings that visual deficits occur across a wide range of stimuli, not just those perceived by the M system (Farrag, Khedr, & Able-Naser, 2002; Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Skottun, 2000, for a critical review).

While a large number of dyslexic studies have reported deficits in the M visual pathway, manifesting themselves by impaired spatial contrast sensitivity (Lovegrove et al., 1980, 1986, 1990; Livingstone et al. 1991; Stein & Fowler, 1993; Stein, 2003), an equally impressive number of other dyslexic studies have reported negative or inconsistent results (for a critical review, see Skottun, 2000). The methodology of the different paradigms used to measure spatial contrast sensitivity and the degree to which they have equally evaluated the functions of the M and the P systems has also been repeatedly questioned (Cornelissen et al., 1995; Greatrex & Drasdo, 1995; Hadyuk et al., 1996; Demb et al., 1998; Sperling, Lu et al., 2003). Livingstone et al. (1991) used visually evoked potentials (VEP) and found that dyslexics had reduced amplitudes to low contrast stimuli at high temporal frequencies. Numerous other studies have found that dyslexics showed a reduced temporal contrast sensitivity to transient stimuli of low spatial frequencies (Martin & Lovegrove, 1987; May, Lovergrove et al., 1991; Cornelissen, 1993; Borsting et al., 1996; Ridder et al., 1997). In contrast, other studies have found no reductions (Victor et al., 1993; Gross-Glenn et al., 1995; Spinelli et al., 1997; Ben Yehudah et al., 2001). Furthermore, Evans et al. (1994) and Williams, Stuart et al. (2003) showed that not only there is not an evidence that magnocellular impairments are associated with the different types of dyslexia, but that unfortunately there is evidence that perceptual discrimination deficits in the dyslexics are not specific, but occur across a range of spatial and temporal frequencies as well as with stationary (sustained) stimuli. This is true even for dyslexics, who were found consistently poor in low-level visual processing tasks induced by a magnocellular dysfunction (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002). On the other hand, Sperling, Lu et al. (2005) found that contrast thresholds for letter identification of both low and high-frequency gratings in noise did not differ between dyslexic and non-dyslexic individuals. In addition, in their review paper, Stuart, McAnally, & Castles (2001) suggested that dyslexics suffer from no perceptual deficits at all, but that orthographic disorders might be the result of unsystematic attentional lapses which might be more common amongst individuals with dyslexia given the high co-morbidity with the Attention Deficit Hyperactivity Disorder (ADHD).

Reports of deficits in detecting coherent motion or in judging speed of motion have probably been more consistent in the dyslexia literature (Cornelissen et al., 1995; Eden et al., 1996; Demb, Boynton, & Heeger, 1998; Slaghuis & Ryan, 1999; Talcott, Hansen, Assoku, & Stein, 2000; Talcott, Witton, Hebb et al., 2002; Wilmer, Richardson, Chen, & Stein, 2004). Experimental fMRI findings, have provided evidence for reduced activation to coherent motion in the medial temporal area in individuals with dyslexia (Eden et al., 1996; Demb et al., 1998). However, a number of other studies have found that dyslexics had no difficulty in detecting coherent motion suggesting intact magnocellular function (Hansen, Stein et al., 2001; Amitay, Ben-Yehudah et al., 2002; Kronbichler, Hutzler, & Wimmer, 2002; Hawelka & Wimmer, 2005). Yet, the reasons why such deficits could have an impact on orthographic performance are far from clear. However, Cornelissen & Hansen (1998) and Cornelissen, Hansen et al. (1998) found that deficits in motion detection are associated with orthographic problems as shown by positional letter inaccuracies (i.e. letters been missed out, duplicated or unsuccessfully bound together leading to scrambled or nonsense versions) in anagram and lexical decision tasks. An alternative suggestion comes from Stein (2003) who claimed that an inadequately functioning motion system could result in orthographic problems. The author has proposed that the M system is also related to the ability to stabilise print on the paper. Despite the constant wandering of the retina as a result of unintentional eye drifts, our percept remains stable because of inputs from the motion system. Thus, impairments in the motion system could lead to less stable percept and hence to difficulties with processing written speech.

Moreover, performance on magnocellular low-level visual processing tasks has been associated with pseudoword reading (Talcott, Hansen et al., 1998; Witton et al., 1998) and phonological disorders (Slaghuis, Lovegrove, & Davidson, 1993; Witton et al., 1998; Van Ingelghem, Van Wieringen et al., 2001). To account for the co-occurrence of low-level visual deficits and a phonological impairment, Stein and colleagues proposed a more general version of the magnocellular theory (Stein & Walsh, 1997; Stein & Talcott, 1999; Stein, 1991, 2001, 2003). Their theory postulates that magnocellular temporal processing deficits could result not only in visual but also in auditory processing deficits (McAnally & Stein, 1996; Witton et al., 1998; Talcott et al., 2000; Laasonen, Service, & Virsu, 2001; Renvall & Hari, 2002). In both modalities, performance was characterised by deficits in the rapid temporal processing (Tallal, 1980; Stein & Walsh, 1997; Breznitz & Meyler, 2003). Low-level visual and auditory deficits would involve problems with the phonological analysis, thus, impairing orthographic performance. However, findings relating magnocellular deficits and orthographic performance have not been consistently replicated, nor are they found on multiple task comparisons (Evans, Drasdo, & Richards, 1994; Walther-Muller, 1995). The causal link between the M system deficits and the phonological and orthographic difficulties associated with dyslexia has been heavily challenged (Stanovich, 1988; Hulme, 1988; Greatrex & Drasdo, 1995; Hadyuk, Bruck & Cavanagh, 1996). This relationship has also received much criticism because of the great variability between and within the dyslexic individuals (Borsting et al., 1996; Amitay, Ben-Yehudah et al., 2002; Ramus, 2003; Sperling, Lu et al., 2005) and the degree of orthographic transparency between the different languages (for Italian: Spinelli et al., 1997; for Hebrew: Shovman & Ahissar, 2006). Moreover, attempts to relate cued visual-search performance with more standardised measures of magnocellular functioning (i.e. global dot motion: Cornelissen et al., 1998) failed to demonstrate at least a relationship between these tasks. In summary, there is no evidence showing that low-level visual deficits make unique contributions to orthographic disorders.

1.1.2 The cerebellar deficit hypothesis

The cerebellum is a large structure at the back of the brain, also known as the 'hind-brain' (Holmes, 1939), containing 50% of the total brain neurons. It was primarily known to be directly involved in motor control and coordination (Holmes, 1917, 1939; Eccles, Ito, & Szentagothai, 1967; Ito, 1986, 1993; Marr, 1969; Albus, 1971; Stein & Glickstein, 1992) and is generally considered to be centrally involved in skill automatisation[28] and adaptive learning control (Ito, 1984, 1990; Jenkings, Brooks et al., 1994; Lang & Bastian, 2002). More recent research has highlighted its contributing role to linguistic and other cognitive activity relating to receptive language and language dexterity (Fiez & Raichle, 1997; Justus, 2004; Leiner, Leiner & Dow, 1989, 1991, 1993), speech perception (Mathiak, Hetrich et al., 2002) and visual stimulus sequencing (Ivry & Spencer, 2004). It was then proposed that the cerebellum is involved in any skill, whether motor or cognitive.

The 'cerebellar deficit hypothesis' suggests that abnormalities in cerebellar structure for dyslexic children lead to some problems in automatising language-related skills, and thus lead to the behavioural symptoms seen in dyslexia (Nicolson & Fawcett, 1990, 1994; Fawcett & Nicolson, 1999). Nicolson & Fawcett (1999) presented an over fifteen-year of research review from the Sheffield Research Programme, which provided evidence for the cerebellar deficit of dyslexia. Their longstanding research programme has led to a distinctive 'twin level' framework that proposes, first, that the core deficits are well described in terms of poor skill automaticity ('cognitive level' analysis) and second, that these 'cognitive level' symptoms are attributed to abnormal cerebellar function, ('brain level' analysis). The 'automatisation deficit hypothesis' of dyslexia (ADH) (Nicolson & Fawcett, 1990) predicts difficulties during the initial stages of the acquisition of any learned skill. Nicolson & Fawcett (1990) tested this hypothesis on children with dyslexia and controls across the variety of fine and gross motor skills. The most notable results were found on measures of balance, particularly when subjects were required to complete a task secondary to the initial balance task. The secondary task involved counting or choice reaction task; either would require a degree of higher order cognitive function. Whereas most control subjects improved on the secondary tasks,

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[28] The process by which, after long practice, skills become so fluent that they no longer need conscious control.

presumably through practice effects (Nicolson & Fawcett, 1999), 22/23 children with dyslexia showed balance problems. The authors interpreted these findings as reflecting evidence of an automitisation deficit that is revealed when a secondary task imposes load on the postural control system causing the 'conscious compensation' process, a strategy that they suggest is typically employed in dyslexia to achieve normal performance, to break down (Nicolson & Fawcett, 1990, p.3).

The next phase of this research programme examined the performance of these groups of children with dyslexia, aged 8, 12 and 16 years, on measures of phonological ability, working memory, information processing speed and primitive motor skills. Performance was compared with that of the CA and RA control children. This second level of comparison was undertaken to establish whether differences between groups could be attributed to a simple developmental delay or to a developmental deviance. The authors concluded that children with dyslexia presented a general 'automitisation deficit' across all primitive skills that was not observed in the RA group. This suggested that the difficulties were associated with a general performance deviance rather than a delay in normal development. This was most likely due to a fundamental problem underpinning all skill learning, including acquisition and execution stages, which lead the authors to speculate about the possibility of cerebellar impairment in dyslexia (Nicolson & Fawcett, 1995, 1999).

The third phase of this programme examined evidence for a 'neurological' deficit in dyslexia using clinical measures of cerebellar function (Fawcett, Nicolson, & Dean, 1996; Fawcett & Nicolson, 1999). A total of 14 tasks were used (described in Dow & Morruzzi, 1958). Tasks fell into three types of assessments: a) posture and muscle tone, b) hypotonia of the upper limbs and c) complex voluntary movement. The dyslexic children, aged 10, 14 and 18, performed worse than their CA controls (on all 14 tasks) and their RA controls (on 11 tasks). Deficits were found on all tasks but one, with several of the cerebellar tasks showing deficits larger than reading. These results were replicated by a much larger group of dyslexic children aged 8-16 years old. The authors concluded that this profile of performance corresponded with that predicted by an impairment of cerebellar function (Fawcett, Nicolson, & Dean, 1996).

Within this 'twin level' framework (automatisation/cerebellar), the authors then proposed an ontogenetic causal chain that links cerebellar impairment at birth, via problems in articulation and working memory, to the known phonological, speed and literacy difficulties seen in dyslexia (see Figure 3).

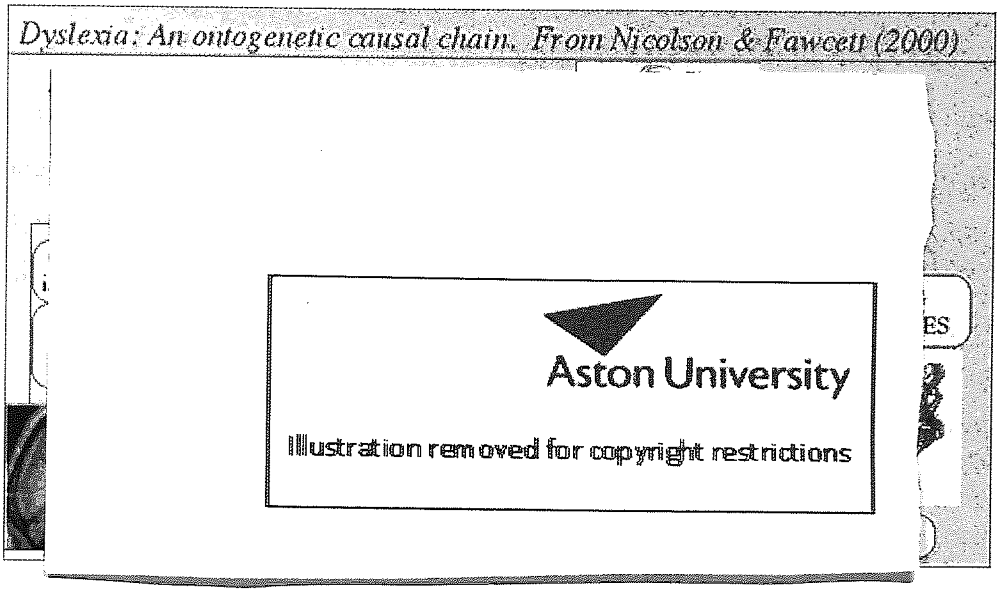

Figure 3. Ontogenetic causal chain of developmental dyslexia from birth to eight years.

The main causal influence of dyslexia, within the ontogenetic model, is weak implicit learning as a direct consequence of cerebellar impairment (Nicolson, Fawcett, & Dean, 2001). The model directly relates cerebellar abnormality to motor impairment and consequently writing skills. It also directly relates cerebellar impairment to constrained articulatory skill. This constraint has two indirect effects: a) more conscious resources are required for articulation therefore fewer remain for processing sensory feedback from articulation, b) speed of articulation is reduced. These indirect effects lead to difficulties not only in language acquisition and dexterity but also lowered sensitivity to the temporal and spatial structure of language. Ivry & Justus (2001) have also related motor articulation with the ability to read and form phonological representations ('motor theory of speech perception', Liberman & Mattingly, 1985; Scott et al., 2001). Nicolson, Fawcett, & Dean (2001) claim that in dyslexia, direct and indirect effects of cerebellar abnormality on articulation can explain the core phonological deficit. The cerebellar deficit hypothesis is thus presented as a biological explanation of the co-occurrence of cognitive phonological deficits and low-level motor impairments in developmental dyslexia.

Furthermore, the cerebellum helps to control eye movements during reading. It has been shown to regulate eye movements responses to visual motion signals in maintaining fixation and adjusting eye movements during reading saccades (Stein, 2001). Right side cerebellar lesions in children have also been associated with language and literacy problems (Scott et al., 2001), although speech and literacy problems are infrequently observed in cerebellar lesions in adults (Ivry & Justus, 2001). Cerebellar abnormalities in dyslexia have been demonstrated in several neuroimaging studies for measures of brain biochemistry (Rae et al., 1998), neural morphology (Rae et al., 2002) and functional activity related to motor learning (Nicolson et al., 1999).

Although the cerebellar deficit hypothesis provides a parsimonious account of the reading and motor control deficits encountered in the broad phenotype of dyslexia, the causal nature of the link between cerebellar dysfunctions and reading disorders associated with dyslexia has been highly called into questions (Wimmer, Mayringer, & Landerl, 1998; Wimmer, Mayringer, & Raberger, 1999; Ramus, Pidgeon, & Frith, 2003). In addition, several other findings from neurophysiological dyslexic studies debated the specificity of the cerebellar dysfunction. For example, Zeffiro & Eden (2001) accept that development of cerebellar function may be impaired in dyslexia. However, they suggest that this may be a consequence of neuropathology elsewhere within the cerebellar-cortical neural networks that give rise to a simulation of cerebellar disease. They cite evidence of circuitry between the cerebellum, the thalamus and the perisylvian neocortical regions associated with phonological dysfunction and the cortical-pontine projections to the cerebellum via the pontine-tegmentum (e.g. Eden & Zeffiro, 1998). They also speculate that impaired sensory information would also impair sensorimotor integration and cerebellar function. This prediction is supported by evidence from a structural MRI study that identified abnormalities within the cerebellar-frontal cortical circuitry that were associated with the double-deficit of phonological and temporal processing subtype of dyslexia (Eckert et al., 2003). In addition, Ivry and Justus (2001) further suggest that cerebellar impairment may be only one of numerous neural anomalies that underpin the range of behavioural deficits observed in dyslexia. Moreover, Bishop (2002) argues that cerebellar impairment may equally arise from avoidance of the tasks that typically aid cerebellar development[29]. Cerebellar impairment may therefore arise as a consequence rather than a cause of motor difficulty because typical development improvement though practice is avoided. Finally, although the cerebellar deficit hypothesis appears to provide both cognitive (automaticity) and biological (cerebellar dysfunction) accounts of the multiple behavioural manifestations associated with the broader phenotype of dyslexia, the conceptualisation of this hypothesis within Frith's (2001) framework, does not demonstrate how the symptoms of cerebellar dysfunction are interrelated, unless they are viewed as discrete symptoms of co-morbid disorders with a shared biological cause as demonstrated in Figure 4.

Figure 4. The cerebellar deficit hypothesis (taken from Frith, 1997).

1.1.3 Parallel vs. sequential visual processing deficits

A number of recent studies have provided evidence for a 'multi-element processing deficit' in developmental dyslexia by using mainly two types of paradigms. One paradigm involves the brief presentation of series of *alphanumeric characters* (i.e. consonant letters or digits), where subjects are asked to report the full set of characters in any order, known as 'whole report' tasks, or a single item in

[29] For instance, a child who frequently experiences failure in ball skills during team games is more likely to avoid further failure by selecting a different activity in which he or she may perform well.

response to a position-cue, known as 'partial report' tasks (for consonant letters: Valdois, Bosse, & Tainturier, 2004; Hawelka, Huber, & Wimmer, 2006; Bosse, Tainturier, & Valdois, 2007; Lassus-Sangosse, N'guyen-Morel, & Valdois, 2008; for digits: Hawelka & Wimmer, 2005; Hawelka, Huber, & Wimmer, 2006; for older studies using variations of this paradigm: Bakker, 1972; Bryden, 1972; Noelker & Schumsky, 1973; Corkin, 1974; Mason, Katz, & Wicklund, 1975; Mason, 1975, 1980; Done & Miles, 1978; Holmes & McKeever, 1979; Mason, Pilkington, & Brandau, 1981; Manis & Morrison, 1982; Williams & Bologna, 1985; Lovergrove, Martin, & Slaghuis, 1986; Enns, Bryson, & Rose, 1995). A second paradigm involves the brief presentation of series of *non-alphanumeric characters* (i.e. abstract geometric forms), where participants are presented with a target visual string, followed by a mask, followed by two visual strings (one target and one distractor, displayed one above the other and differing in the order of two adjacent or non-adjacent units) and are asked to report which string was originally presented, known as 'visual target detection' tasks (Pammer, Lavis, Hansen, & Cornelissen, 2004; Jones, Branigan, & Kelly, 2008).

A multi-element processing deficit has been found consistent across different types of populations and languages. Both children and adults with developmental dyslexia perform worse than chronological-age matched controls (for children, see for *French*: Valdois et al., 2004; Bosse et al., 2007; Lassus-Sangosse et al., 2008; for *English*: Pammer et al., 2004; Bosse et al., 2007; for *German*: Hawelka & Wimmer, 2005; for adults, see for *English*: Jones et al., 2008; for *German*: Hawelka et al., 2006). Performance on the whole and partial report tasks correlates with orthographic performance both in control and dyslexic readers (for control adult readers: Pammer, Lavis, Cooper, Hansen, & Cornelissen, 2005; for dyslexic children: Bosse et al., 2007; Hawelka & Wimmer, 2005; for mixed control and dyslexic groups: Jones et al., 2008). Crucially, some studies found that this association remains even after phonological skills were controlled (Pammer et al., 2004; Hawelka and Wimmer, 2005; Bosse et al., 2007; Lassus-Sangosse et al., 2008).

Following Valdois, Bosse, & Tainturier (2004), a difficulty in processing multi-element visual arrays in individuals with developmental dyslexia might reflect a limitation in the amount of distinct visual elements that can be processed simultaneously from a brief visual display. This deficit was later called by Bosse, Tainturier, & Valdois (2007) as the 'visual attentional span deficit' or the 'reduced visual attentional window' hypothesis. In their study, Valdois and colleagues measured phonological and visual attentional abilities in French and English children compared to those of the CA controls. All subjects were administered measures of verbal or nonverbal IQ (the French children were submitted to verbal or non-verbal IQ tests, whereas the English children were submitted to non-verbal IQ tests), reading (of regular and exception words and pseudowords), phonological awareness and visuo-attentional processing. Visual attentional abilities were assessed by bar probe tasks which required the verbal report of the full set of letters (*whole report*) or single letter (*partial report*) of briefly presented multi-element visual strings. In the 'whole report' condition, a central fixation point presented (for 1000ms), followed by a blank screen (for 500ms). Immediately thereafter, a letter string presented in the middle of the screen (for 200ms). The letter string consisted of five consonants (in the uppercase) that were presented in parallel. Participants were asked to name as many letters as possible in any order. In the 'partial report' condition, the same procedure was followed, but the participants were asked to name a single letter in response to a cue (vertical bar) that was briefly presented (for 50 ms) at the offset of the letter string and indicated the position of the letter to be reported.

The French population consisted of 68 dyslexic children, who showed a mean reading delay of 42 months on the Alouette Reading Test (Lefavrais, 1967) and 55 control children matched for chronological age. Results from the French study showed that the dyslexic children performed poorly on both conditions. The visuo-attentional (VA) span deficit hypothesis, as indexed by poor performance on the whole and partial report tasks, is really based on the 'connectionist multi-trace model of polysyllabic word reading[30]' developed by Ans, Carbonell, & Valdois, 1998

[30] According to this, there are two types of reading procedures: a global and an analytic. Global reading always proceeds first, whereas analytic reading takes place when global processing has failed. The two procedures differ in the size of the visual attentional window (VAW) involved, through which information from the sequence of the letter strings is extracted. In global reading, the VAW extends over the whole sequence of the orthographic input. When shifting to analytic reading, the VAW narrows down to focus attention on the different parts of the letter sequence (VA span larger than a single letter). Letters which fall within the VAW (focal sequence) are maximally activated and processed in parallel, whereas letters which fall outside the VAW are only minimally activated or not at all. In the analytic mode, a pronunciation is generated for each focal sequence, and this process is sequentially repeated until the VAW has reached the end of the orthographic input. The two procedures

(ACV98). Crucially, Valdois and colleagues found that this deficit made significant independent contributions to reading accuracy (of both exception words and pseudowords) even after age and phonological processing abilities were controlled. Phonological deficits made also significant independent contributions to reading accuracy (of both exception words and pseudowords), independently of age and visuo-attentional abilities. A distribution analysis of the phonological and VA factorial coefficients revealed that most of the French dyslexic children (63%) appeared to suffer from a single phonological or visuo-attentional impairment (19% showed a selective phonological deficit and 44% showed a selective visuo-attentional deficit).

The results of the French study were replicated by those of the English study (Bosse et al., 2007), which consisted of 29 younger English dyslexic and 23 control children matched for chronological age (and differed marginally in scores of non-verbal IQ). Participants were included in the control group if they scored above the 40th percentile on the reading task of the WRAT test (Wilkinson, 1993), while the dyslexics scored at the 13th percentile on both reading and spelling tasks of the WRAT test. The English subjects were submitted to additional control tests measuring semantic fluency, receptive vocabulary knowledge and letter-identification[31] skills (in addition to non-verbal IQ). Results from the English study showed also an impaired performance on both whole and partial report conditions. This deficit made independent contributions to reading (of exception words in terms of both speed and accuracy, and pseudowords, in terms of speed) even after the control variables and phonological processing abilities were partialed out. Phonological deficits also explained significant variance in reading (of exception words and pseudowords in terms of both speed and accuracy) independently of the control variables and visuo-attentional abilities. As with the French study, most of the English dyslexic children

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also differ in the kind of phonological processing involved. In global processing, the full pronunciation of the letter string is produced in a single step given that the orthographic output is identical to the orthographic input. When it is not, the pronunciation is inhibited and shifts to the analytic mode, where pronunciations corresponding to each focal sequence are successively produced and have to be maintained in the STM in order to remain available at the end of processing.

[31] In this task, participants viewed a single consonant, which appeared at the centre of the display screen at various presentation durations, and were asked to name each letter immediately after presentation. Stimuli were the same with those used in the visual attentional tasks.

(69%) appeared to suffer from a single phonological or visuo-attentional impairment (34.5% showed a selective phonological deficit and 34.5% showed a selective visuo-attentional deficit). When regressing out the impact of letter identification, results showed that some of the English dyslexics (23.1%) persisted in exhibiting a single visuo-attentional deficit.

A dissociation between phonological and visual attentional abilities was also shown by two single case studies of French dyslexics (Valdois, Bosse, Carbonnel, Zorman, David, & Pellat, 2003): Laurent, a teenager with phonological dyslexia and impaired phonological skills, and Nicolas, a teenager with surface dyslexia and excellent phonological skills. The authors found that Laurent performed well within the normal range on both whole and partial letter report tasks, whereas Nicolas was impaired on both tasks. Therefore, Valdois, Bosse et al. (2003) concluded that phonological and visuo-attentional skills can dissociate and that deficits in these skills might contribute independently to reading acquisition disorders. However, the normal performance of the phonological dyslexic on both report tasks does not agree with the results of the French and the English group studies, where dyslexics had also impaired phonological skills.

The hypothesis of a 'reduced visuo-attentional window', at least with respect to letter strings, has received support from studies which have shown: a) a substantially increased number of fixations during text reading in poor readers due to short eye movements in the reading direction (De Luca, Di Pace et al., 1999; De Luca, Borelli et al., 2002; Hutzler & Wimmer, 2004) and b) enhanced word length effects (in terms of speed) in reading in poor readers (Ziegler, Perry et al., 2003; Spinelli et al., 2005).

Deficits in processing multi-element visual arrays have also been found in German-speaking dyslexics. Hawelka & Wimmer (2005) investigated slow readers and poor spellers attending Grade 9, using a partial report task which involved strings of two, four and six digits (rather than letters, as dyslexics might be less frequently exposed to letter strings than control readers). Subjects were asked to name a single digit (by typing their response into the keyboard) in response to a position-cue that followed masked briefly presented strings of digits (for 200ms). It was found that the dyslexics exhibited higher recognition time thresholds than the controls (who were, however, slightly younger than the dyslexics), but that this impairment was limited to the longer strings (of four and six digits). Presentation time thresholds for the longer digit strings were also related to the number of eye movements during (word and pseudoword) reading. A deficit in processing multi-digit visual arrays contributed to slow serial reading and remained significant, even after phonological awareness and rapid automatised naming (RAN) were partialed out. However, we must highlight here that phonological and RAN were first assessed at the age of school entrance and had not been re-assessed since.

In their later study, Hawelka, Huber, & Wimmer (2006) measured the performance of older German slow readers on partial report tasks which involved five-element strings consisting of digits and consonant letters. The procedure of the task was the same with that of the task used in their earlier study, but the array presentation time was briefer (100ms). It was found that the dyslexic readers exhibited enhanced recognition time thresholds for both the digit and the letter strings. An estimation of the presentation thresholds for each position separately was also provided. It was found that the majority of the dyslexic readers showed reduced thresholds for the initial and middle positions for both the digit and the letter strings and additional reduced thresholds for the final positions for the letter strings (M-shape). The positional profiles of the dyslexics on both tasks were similar to those of the control readers but at much higher levels.

However, the nature of a multi-element processing deficit in the dyslexics, as indexed by poor performance on the whole and/or partial report tasks including alphanumeric visual information remains largely unclear, as one could argue that the locus of this impairment might not be visual but verbal. This means that a difficulty in processing nameable visual strings might be the result of a problem with access, retrieval and short-term retention of the names of the constituent visual units. In addition, one could further argue that the partial report task taps more position encoding rather than parallel processing. As Averbach & Sperling (1968) originally pointed out, the partial report method, differently from the whole report method, measures primarily early stages of visual processing. This criticism could also hold for the validity of the 'VA span deficit' hypothesis put forward by Valdois and colleagues, as this was operationally defined by poor performance on both the whole and the partial report tasks.

To avoid the involvement of verbal processes, Pammer, Lavis, Hansen, & Cornelissen (2004) have used strings of non-alphanumeric characters. Following their studies on control adult readers (Pammer, Lavis, Hansen, & Cornelissen, 2004; Pammer, Lavis, Cooper, Hansen, & Cornelissen, 2005), Pammer et al. (2004) measured position encoding abilities in English reading disabled children by using a novel 'symbol-string' task consisting of five simple geometric forms. Participants viewed the predefined target string (for 100ms), followed by a mask (for 100ms), followed by the simultaneous presentation of two five-element visual strings, one being the target and the other being a distractor, presenting one above the other and differing in the order of two adjacent and non-adjacent symbols (position swaps: 2/3, 3/4, and 2/4). The task required the report of the symbol string that was originally presented. Results showed that poor readers made more incorrect reports (irrespective of position swaps, with the non-adjacent swaps being the hardest to detect) than the controls (matched for age, verbal and non-verbal IQ to the dyslexics). Regression analysis on, however, just the control data revealed that performance on the symbol-string task accounted for text reading accuracy (as indexed by the NARA), independently of phonological skills (as indexed by phoneme deletion and digit span). It was assumed that visual processing skills may also contribute to explain variation in children's reading difficulties, independently of phonological skills.

In addition, Jones et al. (2008) measured position encoding abilities in dyslexic and control adults, by using the same 'symbol-string' task with that of Pammer et al. (2004). They found that the dyslexics performed worse than the controls (matched for age, gender and performance IQ to the dyslexics). Performance on the symbol-string task made a significant unique contribution to nonword reading differences (but not to exception word reading differences), suggesting a common causal link between position encoding and phonological decoding.

In contrast, Hawelka & Wimmer (2008) found absolutely no problems with processing multi-element visual arrays of non-alphanumeric stimuli in German slow reading adults. The authors utilised a 'visual target detection' task (introduced by Mason, 1982) which involved strings of non-nameable pseudoletters. Participants viewed the predefined target (probe pseudoletter) which was briefly presented (for 600 ms) above the mid-position of upcoming five-element strings which were briefly presented (for 2200ms). Participants were asked to press the space bar in the case that the target was included in the string and not to respond otherwise. On this task, the dyslexic readers performed as well as the control readers (matched for age and IQ to the dyslexic readers). An estimation of the detection time thresholds for each position separately was also provided. It was found that the dyslexics were slower at detecting the first and the final position than the interior positions (U shape). The same positional profile was exhibited by the controls. The findings of this study did not correspond to those of the earlier studies of Hawelka and colleagues (Hawelka & Wimmer, 2005; Hawelka et al., 2006), where partial report tasks of nameable five-element visual arrays were used. The authors suggested that their findings, as a whole, are more consistent with a naming speed deficit than with a reduced visuo-attentional span deficit. They finally concluded that slow reading speed in their German dyslexic readers cannot be traced to deficient visual processing of letter strings.

Normal simultaneous visual processing of multi-element non-alphanumeric strings was also found by Shovman & Ahissar (2006). The authors have measured single letter identification abilities in Hebrew-speaking adult poor readers by using a subset of the Georgian alphabet (whose letters did not resemble Hebrew or English scripts, but their graphical complexity was similar). Participants viewed a symbol or a string of three symbols (for 200ms), followed by a mask (for 500ms) consisting of a scatter of random Georgian symbols, followed by four symbols presenting in a circle on the full computer screen. They were then asked to indicate the one that matched the stimulus symbol (being either the single symbol or the middle symbol in the case of the triplet) by pressing the corresponding key. Three test conditions were used which involved visual manipulations, such as reducing letter size, increasing letter crowding[32] and adding white noise. Results showed that poor readers performed as

[32] i.e. adding distracting letters (flankers).

well as the control readers (matched for age, verbal and non-verbal IQ to the poor readers) on all test conditions.

The hypothesis of Valdois and colleagues about a 'reduced VAW' contradicts to the hypothesis of Facoetti and colleagues about 'diffuse attention' in the dyslexics (Facoetti, Paganoni, & Lorusso, 2000; Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Facoetti & Molteni, 2001). That is, dyslexic people show slower capture of attention (Facoetti et al., 2003), which reflects a problem in narrowing their attentional focus. To investigate space-based components of attention, Facoetti and colleagues have used 'cue-target' visual paradigms which require an attentional shifting from the fixation point to the cued location. Results showed a defective covert orienting (Facoetti, Paganoni, Turatto et al., 2000; Facoetti et al., 2001, 2003), a slow and difficult attentional focalization resulting in impaired filtering of irrelevant elements (Facoetti, Paganoni, Turatto et al., 2000; Facoetti et al., 2003) and a sluggish and asymmetric attentional allocation (Facoetti & Turatto, 2000; Facoetti, Paganoni, & Lorusso, 2000; Facoetti & Molteni, 2001; Facoetti et al., 2003, 2005; Lorusso, Facoetti et al., 2004). Facoetti, Paganoni, Turatto et al. (2000) also found that dyslexics showed less benefit from cuing (see also Roach & Hogben, 2004). This was true even when they controlled for abnormal eye movements (using a single-fixation search) and measured performance as threshold discriminations for differences in orientation between the target stimuli and the distractors (thus, controlling for the generally higher RTs of the dyslexics).

In addition, Hari & Renvall (2001) have talked about a 'sluggish attentional shifting' (in time and space) in the dyslexics. According to the SAS theory, the dyslexics have troubles disengaging attention from one stimulus to another due to a protracted 'cognitive integration window' (also called 'prolonged time' or 'input chunks'). Once their attention is engaged it cannot easily disengage and vice versa (Hari, Valta, & Uutela, 1999). Following Greenlee et al.'s (2000) imaging findings that sequential spatial frequency discrimination (where attention is shifted between visual sequences) activates parietal areas, Hari and colleagues found that Finnish dyslexic adults had a difficulty processing rapidly stimulus sequences (Hari & Renvall, 2001; Hari, Renvall, & Tanskanen, 2001). This was shown by using 'visual precedence detection' tasks (i.e. temporal order judgement tasks), where the subjects were asked to indicate verbally whether a visual bar in the left or right hemifield preceded a similar bar on the opposite side, and 'line motion illusion' tasks, where the subjects illusorily perceive a line growing from a site when a cue stimulus has been presented slightly earlier. It was argued that the sluggish attentional capture, which arises from a prolonged 'short-term buffer' (associated with increased attentional dwell time), inhibits flexible allocation of attention impairing representation of order. More specifically, Hari and colleagues found that the dyslexics were slower at processing the visual sequences that appeared in the left rather than in the right visual hemifield. It was suggested that this was due to a 'left mini-neglect' that can be caused by minor parietal lobe dysfunction in dyslexics.

An asymmetric distribution of attentional resources across the two visual fields has also been shown by other researchers, who have found a mild left-sided neglect and an increased sensitivity in the right visual field (Brannan & Williams, 1988; Stein & Walsh, 1997; Facoetti, Paganoni, & Lorusso, 2000; Facoetti & Turatto; 2000; Facoetti & Molteni, 2001; Facoetti, Turrato, Lorusso, & Mascetti, 2001; Amitay, Ben-Yehudah et al., 2002; Facoetti, Lorusso, Paganoni et al., 2003; Facoetti, Lorusso, Cattaneo et al. 2005). Geiger, Lettvin, & Zegarra-Moran (1992) have also found that their dyslexic children showed a right attentional advantage in processing eccentrically located letters indicating a difficulty at inhibiting peripheral information in the direction of reading (see also Rayner, Murphy, Henderson, & Pollatsek, 1989). However, in their single French case studies of developmental phonological and surface dyslexia, Valdois et al. (2003) have found exactly the opposite results. When looked at the positional effects on the whole and partial report tasks, Valdois et al. (2003) found that their phonological dyslexic patient showed no particular positional preference in either of the tasks, whereas their surface dyslexic patient showed a particular difficulty in reporting the last two letters on both tasks (same pattern with his word reading). These results are not in accordance with those earlier found by the same author (Valdois, Gerard, Vanault, & Dugas, 1995) for a French 10 year-old visual dyslexic, who showed a preferential processing (of rapidly presented pseudowords) in the right and not in the left visual field. Moreover, in their German group study, Hawelka & Wimmer (2005) have reported no attentional preference on their visual precedence detection task, where subjects were asked to judge which of the two bars (appearing one to the left and one to the right of a centred fixation cross) preceded the other by pressing the corresponding key. The authors found normal recognition thresholds for both visual hemifields for both dyslexics and controls.

Very few studies have attempted to compare simultaneous with sequential visual processing in the dyslexics. The distinction between parallel and sequential visual processing is fundamental as both abilities crucially differ in the predicted dynamics of deploying and redirecting attention. As Bundesen & Habekost (2005) have quoted "a typical serial model assumes that attention focuses on one object in the visual field at a time, moving about at a high speed. In contrast, a typical parallel model assumes a broad distribution of processing resources over the visual field, shifting slowly, but comprising many objects simultaneously" (p. 112). These studies have challenged the hypotheses of the visuo-attentional span deficit and the magnocellular deficit by claiming that individuals with reading disabilities show a visual impairment that may be due to a limited ability to retain and compare perceptual traces across brief time intervals. These studies used 'visual discrimination' tasks that required the simultaneous and sequential comparisons of more general rapidly presented visual stimuli (i.e. flickering or drifting patches of vertical and horizontal lines).

For example, Ben-Yehudah, Sackett, Malchi-Ginzberg, & Ahissar (2001) have measured temporal and spatial contrast sensitivity (often used to demonstrate a magnocellular deficit in dyslexia) in Hebrew-speaking reading disabled adults by using two flickering or drifting patches (containing horizontal or vertical sinusoidal gratings) presenting sequentially (temporal forced choice paradigm, T-FC) and simultaneously (spatial forced choice task, S-FC). The sequential stimuli were presented in the middle of the screen (for 1000ms, with an ISI[33] of 500ms), while the simultaneous stimuli were presented in the upper or lower half of the screen (for 500ms). Subjects were asked to compare the two sequential or simultaneous displays ('retain-and-compare'). Results showed poorer contrast sensitivity compared to the CA controls when the stimuli to be compared were presented sequentially but not simultaneously (poor temporal but good spatial contrast sensitivity). This deficit was

[33] Interstimulus interval.

true for both the flickering and the drifting stimuli. These results suggest that a difficulty in detecting temporally modulated gratings is specific to the sequential presentation of the stimuli and occurs across different types of visual stimuli. This study was later replicated by a follow-up study by Ben-Yehudah and colleagues on Hebrew-speaking reading disabled adults (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002).

In their later study, Ben-Yehudah & Ahissar (2004) examined the dyslexics' spatial frequency discrimination under a simultaneous and a sequential condition, which is important for letter identification (Solomon & Pelli, 1994). The stimuli were presented for 250ms in the simultaneous condition and at SOAs[34] of 500, 750 and 2250ms in the sequential condition. Results were similar to those found in their previous studies. The dyslexics performed as well as the controls in the simultaneous condition but worse than the controls in the sequential condition. The sequential deficit was consistent for all SOAs, although less severe for the longest SOA. One could argue that these findings are probably specific to the Hebrew language. However, when dyslexics of different languages were compared for underlying perceptual mechanisms using exactly the same paradigms, no difference was found whether behavioural techniques (Ben-Yehudah et al., 2001) or imaging techniques (Paulesu et al., 2001) were used.

Ahissar and colleagues have argued that a deficit with sequential visual detection is attributed to 'visual working memory deficits'. Dyslexics will have difficulties in comparing displays across a delay because of fading perceptual memory for the first display. However, this hypothesis predicts that dyslexics will show increasing difficulties with increasing SOAs, which is, however, not what Ben-Yehudah & Ahissar (2004) found. It also argues against the 'sluggish attentional shifting' hypothesis, which predicts exactly the opposite: better sequential processing performance with increasing SOAs.

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[34] Stimulus onset asynchronies.

Similarly, Ram-Tsur, Faust, & Zivotofsky (2006) measured contrast detection thresholds of Hebrew-speaking reading disabled adults, by using a 'temporal' task and a 'spatial' task involving the sequential and simultaneous presentation of two flickering Gabor patches of different orientations, respectively. In both tasks, subjects were asked to indicate whether the two patches were same or different by pressing the corresponding key. In the 'temporal' task, the Gabor patches were presented for 500ms with increasing ISIs of 30, 500, 1000 and 1500ms. In the 'spatial' task, the two Gabor patches were presented for 500, 1000 and 2500ms. Ram-Tsur et al. (2006) found that the dyslexics showed significantly higher thresholds than the CA controls in the sequential but not in the simultaneous condition. The poor visual discrimination during sequential presentation was independent of the size of the ISI. The results of this study are in line with the sequential spatial discrimination deficits found by Ben-Yehudah & Ahissar (2004).

In their more recent study, Ram-Tsur, Faust, & Zivotofsky (2008) investigated the performance of Hebrew-speaking reading disabled adults in an 'order judgement' task (long temporal accuracy task) consisting of three rather than two sequential flicker Gabor patches of different orientations. The Gabor stimuli were presented one after the other in the middle of the screen for 500ms over a range of ISIs of 30, 500, 1000 and 1500ms. Participants were asked to press the corresponding button if the one of the three stimuli had a different orientation and another button if all three stimuli had the same orientation. The authors found that the dyslexics were worse than the CA controls at making sequential visual comparisons even when three stimuli were included. This deficit was also unrelated to the size of the ISIs. The authors attributed the impaired sequential processing to attentional problems as a result of a sluggish attentional shifting or working memory deficits that stem from a cerebellar dysfunction. However, these possible explanations do not seem true, as: a) the 'sluggish attentional shifting' hypothesis predicts better sequential processing at longer ISIs, which is not what it was found and b) the 'working memory deficit' hypothesis predicts increasing difficulties with increasing ISIs, which is not what it was found.

Evidence for deficits in the temporal (sequential) tasks, as opposed to spatial (simultaneous) tasks in English reading disabled children was also reported by an older study by Eden, Stein, Wood, & Wood (1995a). Deficits in sequential processing has also been found in the auditory domain (Tallal, 1980; Temple et al., 2000; Tallal, Miller, & Fitch, 1993, for a review, Talcott et al., 1999; De Martino et al., 2001; Renvall & Hari, 2002; Facoetti, Lorusso et al., 2005; Boets, Wouters et al., 2006; Boets, Ghesquière et al., 2007). It was since concluded that dyslexics suffer from a more general sequential processing disorder (Ben-Yehudah et al., 2001; Amitay et al., 2002, Ben-Yehudah & Ahissar, 2004; Conlon, Sanders, & Zapart, 2004; Ram-Tsur et al., 2006, 2008).

Valdois and colleagues have also examined parallel vs. sequential visual abilities in French dyslexic children by using 'visual search' tasks requiring the search for a target symbol among close distractors and 'global report' and 'sequential report' tasks requiring the verbal report of multi-letter visual strings. In their study, Marendaz, Valdois, & Walch (1996) tested 10 French dyslexic children and 20 French control children, 10 matched for chronological age and 10 for reading age. They found that the dyslexics performed as well as the CA controls in the parallel/automatic condition but worse than both the CA and the RA controls in the serial/attentional condition. The authors proposed that an attentional visual processing deficit could result either from a perceptive grouping dysfunction (reducing the number of items simultaneously processed during serial search) or from a problem in the shifting of attention (Valdois et al., 2004). Poor performance in the serial visual search task was also found by Valdois in her earlier single case study, Clement, a French 10 year-old surface dyslexic boy with no phonological problems (Valdois, 1999).

More recently, Lassus-Sangosse, N'guyen-Morel, & Valdois (2008) examined parallel and serial processing of multi-letter strings in two groups of French children with poor reading skills and impaired or normal phonological skills by using 'global report' and 'sequential report' tasks. In contrast to the above studies, Lassus-Sangosse et al. (2008) found exactly the opposite results. The reading abilities of the French subjects were assessed by performance on the Alouette Reading Test (Lefavrais, 1967) and reading tests of words (regular and irregular) and pseudowords. Children were included in the dyslexic group, if their reading age was at least 18 months lower than that expected for their chronological age and if they scored below the 10^{th} percentile on the tests of either word or pseudoword reading in terms of either speed or accuracy. Phonological abilities were assessed by performance on three phonological awareness tasks (phoneme deletion, phoneme segmentation and acronym). Dyslexics were assigned to the phonological group if they scored at the 10^{th} percentile or below on at least one of the phonological awareness tasks. Dyslexics were assigned to the non-phonological group if they scored above the 10^{th} percentile on each of the phonological awareness tasks. Each group consisted of 13 dyslexics compared to 13 chronological-age matched controls. Both dyslexic groups were severely impaired in reading tasks of both words and pseudowords in terms of both accuracy and speed. Instead, one would expect that the non-phonological children would exhibit at least a less severe impairment at reading pseudowords than the phonological children. The global and sequential report tasks used in this study required the verbal report of strings of five consonant letters (in the uppercase) presented in simultaneous and sequential modes, respectively. In the 'global report' task, the procedure followed was identical to that described for the whole report condition of the bar probe task used by Bosse et al., 2007 (with the difference that the blank screen following the fixation point was displayed for 50ms instead of 500ms). In the 'sequential report' task, the letters were presented one after the other for 200ms. In both tasks, participants were asked to name as many letters as possible irrespective of their order. Performance was measured in number of correctly reported letters.

Results from the French study showed that both dyslexic groups with and without phonological difficulties exhibited a simultaneous processing deficit but normal sequential processing skills. A simultaneous visual processing deficit was, however, more severe for the non-phonological dyslexics than for the phonological dyslexics. This deficit made a significant contribution to reading speed and accuracy, even after age and sequential processing were controlled.

Uniquely, our study (as well as that by Romani et al., 1999) measured directly order encoding abilities of simultaneous vs. sequential multi-element visual strings involving non-alphanumeric stimuli (i.e. unfamiliar Hindi & Japanese characters) by using sorting tasks. In these tasks, subjects were asked to reproduce the order of briefly presented visual characters by arranging the corresponding cards passed to the subjects immediately after the string presentation to avoid the involvement of STM recall abilities. As we show later, we found a difficulty in encoding order in the sequential but not in the simultaneous condition.

Deficits in the rapid sequential processing of visual information is not in line with the hypothesis that dyslexics have difficulties in processing multi-element visual arrays due to a 'narrowed visuo-attentional window' and that they can only process smaller visual chunks at a time (Farrah & Wallace, 1991). An alternative possibility is that a selective sequential deficit is part of a more general problem with encoding serial order. This difficulty might not have to do with the ability to remember visual information per se but rather with the ability to link a single visual unit with an ordering or temporal vector which indicates at what point in time or sequence of events a particular stimulus has been presented. This becomes particularly crucial when the same visual stimuli are presented over and over again. This hypothesis would predict that the dyslexics will perform poorly when asked to remember the order of sequentially presented visual strings, but will have no difficulties at remembering the identities of the visual units.

2 METHOD

2.1 Participants

We investigated two study groups: one large and one smaller. The large group consisted of the original 44 dyslexics and 40 controls matched for chronological age, gender, education, performance IQ and verbal IQ. All participants were submitted to additional measures of the ability to process visual series, such as the Hindi and Japanese sorting task, and the ability to learn and recall visuospatial information, such as the Visual Memory of the WMS-R, the Shapes Test and Doors Test of the Doors and People, and the Hindi and Japanese recognition task. The smaller group derived from the large group and consisted of 25 dyslexics (15 with a prior diagnosis of dyslexia and 10 self-referred for suspected dyslexia) and 21 controls matched for age, gender, education, performance IQ and verbal IQ (the demographic characteristics and cognitive performance of the large and smaller groups are included in Table 3:1 and 3:2, respectively). The smaller group was submitted to an additional measure of the ability to process visual series, the same-different array matching task.

2.2 Materials (procedure & scoring)

2.2.1 Processing of visual series

To measure the ability to process multi-element visual arrays of different types of information (i.e. alphabetic and non-alphabetic), we administered the following tasks:

a) ***Hindi and Japanese (H&J) sorting*** (computerised). This task involved the reproduction of the order of sequences of four Hindi or five Japanese characters presenting one at a time in the middle of the computer screen. The Hindi task was administered first. The two tasks were carried out in separate sessions, each lasting 25-30 minutes. Both tasks were carried out under two modes of presentation: a) a simultaneous, where the Hindi or Japanese characters were presented altogether (2cm apart from each other) in a single horizontal line for 1700ms and 2200 ms, respectively, and b) a sequential, where the Hindi or Japanese characters were presented one after the other at the centre of the computer screen for 200 ms (mean duration of fixation during reading, long enough for an extended glimpse, yet too short for an intentional eye movement) with an ISI of 300ms. A fixation cross in the middle of the screen preceded the presentation of each string. Immediately after presentation of each string, participants were given a set of tiles (arranged in a random order) with the corresponding characters (in their original size) and were asked to sort them into the original order of presentation. In total, subjects viewed 40 Hindi and 50 Japanese characters equally distributed between the simultaneous and the sequential conditions. In both Hindi and Japanese tasks, the subjects were seated at a viewing distance of approximately 60cm from the computer screen (with the four Hindi characters subtending 11.5° of visual angle; 12cm long, and the five Japanese characters subtending 15.3° of visual angle; 16 cm long, for the simultaneous condition, and with each Hindi and Japanese character subtending 1.4° of visual angle; 1.5 cm, for the sequential condition). There was no time limit to respond, but a response was produced within a few seconds. Both tasks consisted of four testing blocks, each including five sequences of each type of stimulus. Conditions were alternated and counterbalanced (from simultaneous to sequential and from sequential to simultaneous). The first pair of testing blocks consisted of the same set of characters presented in a different order. The second pair of testing blocks consisted from a set of new characters also presented in a different order. No character was repeated within the same testing block. Participants were familiarised with the stimuli by a practice trial which preceded each pair of blocks. A recognition task followed immediately after each block of sequences including an equivalent number of previously seen characters and distractors (see section 2.2.c, for a detailed description of the recognition task). Each character recalled in the correct order received one point. Performance is reported in percentage of errors made in each condition. A sample of the Hindi and Japanese characters is presented in Appendix 26.

b) ***Same-different array matching*** (computerised). This task involved the comparison of two visual strings consisting of eight consonants or symbols that presented side by side at the centre of the computer screen. The consonant task was administered first. Both consonant and symbol tasks were carried out under two conditions: a) an identity, where the different pairs were formed by substituting two adjacent units within the seven different positions in one of two otherwise identical strings, and b) an order, where the different pairs were formed by reversing the positions of two adjacent units within the seven different positions in one of two otherwise identical strings. Each pair of adjacent characters were changed an equal number of times (seven pairs changing six times each). Participants were asked to decide whether the two strings were same or different as quickly and as accurately as possible, by pressing the 'Yes' button (of the voice key machine) if the two strings were the same or the 'No' button if the two strings were not the same. A practice trial preceded each task. A fixation cross in the middle of the screen preceded the presentation of each pair of strings. Stimuli remained on the screen until a decision was made. In both consonant and symbol tasks, subjects were seated at a viewing distance of approximately 60cm from the computer screen (with the pairs of strings subtending 20.4° of visual angle; 21.4cm long or each pair of string subtending 6.7° of visual angle; 7cm long). In total, subjects viewed 84 pairs of each type of stimulus (42 same and 42 different pairs). Stimuli appeared in a 20-point Courier New boldface and were presented one next to another. The two strings were separated by eight character spaces. We used lowercase for the letters as this is more frequently encountered in reading. The ***consonant order*** task comprised the following letter sequences in various random combinations: c d j p f s l v. The ***consonant identity*** task was analogous to the consonant order task, except that it used the remaining thirteen English consonants to replace the two adjacent letters included in one of the two strings. No letter was repeated within the same string. The consonant strings never matched the skeleton of a real English word (i.e. cmprhnsv). The ***symbol order*** task used the following set of symbols in various random combinations: # \ £ ! @ * % <. The ***symbol identity*** task was analogous to the symbol order task, except that it used the following thirteen symbols to replace the two adjacent symbols included in one of the two strings: Ã·(¹¥°$~Æ-¢´¦. No symbol was repeated within the same string. The tasks were carried out in four separate sessions (with the identity condition being administered first), each lasting around 10 minutes. Each correct judgement received one point. Performance is reported in number of errors made in each condition. Reaction times for the correct responses were also measured (those more than 2SDs from each participant's mean and those corresponding to techniqual errors were removed from the analysis). Stimuli items are presented in Appendix 27.

2.2.2 Learning and recall of visuospatial information

To measure the ability to remember and retain different kinds of visual information (i.e. nonsense configurations, paired associates of nonsense drawings and colours, different kinds of doors and novel non-alphabetic characters), we used the following tasks:

a) ***WMS-R Visual Memory*** (Wechsler, 1987). We administered all the visual subtests included:

   i) *Figural Memory*. This task required the recognition of visual configurations, such as nonsense matrices containing combinations of rectangles of various sizes (in dark and bright shades of grey). At first, participants viewed a design for 5 seconds and were asked to remember it. A second page including the first design (target) and two more (distractors) was then displayed. Participants were asked to point to the figure they had originally seen. A different page with three new designs was then displayed for 15 seconds and participants were asked to remember them. Another page including the three designs and six more was then presented and participants were asked to point to the three targets they had just seen. A maximum of 30 seconds were allowed to respond. Two last design pages including three new figures were presented in the same manner. Distractors were all close approximations to the targets. Each design identified correctly received one point.

   ii) *Visual Paired Associates*. This task required the learning of visual pairs. Participants viewed 6 nonsense drawings, each paired with a different colour and were asked to learn the associations. After this, the same figures were presented (in a different order) alone, one at a time, and participants were asked to point to the matching colour in a card (5 minutes were allowed to respond). The test was discontinued if all six pairs were answered correctly on the third trial. If not, they were shown again. A total of six trials were allowed. Each correct association received one point.

iii) *Visual Reproduction*. This task required the learning of geometric drawings. Participants viewed 4 drawings presented one at a time for 10 seconds and were asked to draw them from memory as closely as possible. The drawings were scored according to the criteria of the manual.

The subtests were administered according to the standardised instructions. Performance is reported in the visual memory weighted raw score sum according to the standardised instructions.

b) ***Doors and People (D&P)*** (Baddeley, Emslie, & Nimmo-Smith, 1994). This task contrasts visual and verbal tests of recall and recognition abilities. For the purposes of this study, we administered only the visual subtests:

i) *The Shapes Test*. This test required the immediate and delayed learning and recall of simple shapes. In the ***immediate learning*** task, participants viewed 4 line drawings of crosses presented one at a time for 5 seconds. First, they were asked to copy down each of the drawings being left in front of them. After all four shapes were copied, participants were asked to draw all four of them again from memory (in any order). If all four drawings were not recalled the first learning trial ended (either when they said they could not remember anymore or after they had drawn nothing for 15 seconds). Unless all drawings were recalled correctly, a second learning trial was given in which the four drawings were presented again sequentially for 3 seconds each. The subject was then asked to draw all four shapes again from memory. A total of three learning trials were allowed. In the ***delayed recall*** task, participants had to draw as many of the shapes as possible from memory. Each correct recall received 3 points. Administration and scoring of the drawings were carried out according to the standardised instructions. Performance is reported in percentage of incorrect recalls.

ii) *The Doors Test*. This test required the recognition of different kinds of doors (i.e. front, stable, shed, pub doors, etc). Participants viewed coloured photographs of 24 doors presented one at a time in two separate sets (of 12 doors each) for 3 seconds. The experimenter provided a verbal label for each door presented (so that each label would not allow the target to be discriminated from the three distractors, hence forcing the subject to rely on visual rather than on verbal memory). Participants were then shown pages of different doors including one door they had seen before and three more on each page. They were asked to pick the door they recognised. It was explained to them that the second set of photographs was more difficult than the first one in that the four doors that the subjects had to choose from were more similar than they were in the first set. Thus, subjects were advised to look at each of the photos quite carefully. The type of visual memory resources needed for this task is less clear. However, this task contrasts to the other tasks in that good performance depends on veridical memory for detail (especially for the second set of doors). Each correct recall received one point. This subtest was administered according to the standardised instructions. Performance is reported in percentage of incorrect recalls.

c) ***Hindi & Japanese (H&J) recognition*** (computerised). This task involved the recognition of Hindi and Japanese characters. Participants were asked to identify Hindi and Japanese characters that presented in the middle of the computer screen by simply pressing the 'Yes' button for the characters they had seen in the previous sorting task or the 'No' button for the characters they had not seen in the previous sorting task. Stimuli remained on the screen until a decision was made. There was no time limit to respond. However, a response was produced within a few seconds. No character was repeated within the same recognition task. Each correct judgement received one point. Performance is reported in percentage of errors made in the tasks that followed the simultaneous or the sequential conditions.

3 RESULTS

3.1 Overview of the participants' performance

Tables 3:1 and 3:2 present the demographic data and general performance of the large and smaller groups, respectively, on tasks measuring performance IQ, verbal IQ (as indexed by scores on the Vocabulary and Similarities subtests of the WAIS-R), orthographic skills of different types (i.e. reading comprehension, reading of text, reading and spelling of single words and nonwords), and sublexical phonology (i.e. phonological STM and phonological awareness). The dyslexic z-scores (from the control mean performance) representing highly significant results (***, for $p \leq .001$, **, for $p \leq .01$) are highlighted in boldface yellow, while those representing less significant results (*, for $p \leq .05$) are highlighted in boldface green. Marginal results (for $p \leq .09$) are in italics and not significant results (for $p \geq .10$) are marked as n.s.

Table 3:1. Demographic and defining characteristics of the 44 dyslexics and 40 controls (for text comprehension: 43 dyslexics and 38 controls; for text reading speed and accuracy: 40 dyslexics and 40 controls). 'Impaired' is defined as 2SDs from the control mean.

		DYSLEXICS				CONTROLS		COMPARISON	
LARGE GROUP		Mean	SD	z-score	% impaired	Mean	SD	value	p
Age	years	**27.7**	10.6	0.2	9.1	**25.5**	10.5	F=0.9	n.s
Sex	male : female	**15:29**				**8:32**		χ^2=1.4	n.s
Education	university : secondary	**33:11**				**31:9**		χ^2=0.0	n.s
Performance IQ	scaled score	**107.0**	12.1	-0.1	0.0	**108.8**	13.8	F=0.4	n.s
Vocabulary	scaled score	**10.6**	2.3	-0.1	4.5	**10.7**	2.4	F=0.1	n.s
Similarities	scaled score	**12.8**	2.7	0.3	0.0	**11.9**	3	F=2.1	n.s
Reading text									
Comprehension	N err	**4.7**	2.1	0.6	11.4	**3.6**	1.9	F=2.1	**
(out of 9 questions)								F=6.5	
Speed	ms	**242.5**	99.7	1.8	29.5	**178.6**	35.7	F=14.6	***
Accuracy	N err	**12.9**	11.6	2.5	38.6	**3.6**	3.7	F=23.2	***
(out of 466 words)									
Reading									
Words	RT	**660.9**	231.0	2.1	36.3	**526.3**	63.1	F=12.7	***
	% err	**5.9**	3.4	3.3	65.9	**2.2**	1.1	F=42.1	***
Nonwords	RT	**1048.2**	672	3.4	40.9	**657.7**	114	F=13.1	***
	% err	**27.8**	13.2	5.6	86.4	**7.2**	3.7	F=90.4	***
Spelling									
Words	% err	**23.0**	11.7	4.8	77.2	**8.1**	3.1	F=61.2	***
Nonwords	% err	**25.5**	17	2.3	47.7	**9.7**	6.8	F=30.0	***

(continued)

		DYSLEXICS				CONTROLS		COMPARISON	
LARGE GROUP		**Mean**	**SD**	**z-score**	**% impaired**	**Mean**	**SD**	**value**	**p**
Phonological STM									
Digit span	raw score	**5.7**	0.8	**-1.5**	29.5	**6.8**	0.7	F=38.9	***
Nonword serial recall	% err	**34.1**	14.1	**1.0**	22.7	**23.9**	10.5	F=13.8	***
Word serial recall	% err	**37.8**	10.8	**1.0**	18.2	**27.9**	10.1	F=19	***
Phonological Awareness									
Phoneme counting	% err	**18.8**	16.4	**0.9**	22.7	**9.8**	10.3	F=9.0	***
Spoonerisms	% err	**22.0**	20.2	**3.0**	54.5	**5.4**	5.6	F=25.2	***

Table 3:2. Demographic and defining characteristics of the 25 dyslexics and 21 controls.

SMALLER GROUP		DYSLEXICS				CONTROLS		COMPARISON	
		Mean	SD	z-score	% impaired	Mean	SD	value	p
Age	years	**23.1**	6.3	0.5	12.0	**20.7**	4.7	F=2.1	n.s
Sex	male : female	**7:18**				**3:18**		χ^2=0.6	n.s
Education	university : secondary	**22:3**				**20:1**		χ^2=0.1	n.s
Performance IQ	scaled score	**107.5**	12.3	-0.4	4.0	**112.4**	12.9	F=1.7	n.s
Vocabulary	scaled score	**11.2**	2.3	-0.2	0.0	**11.7**	2.6	F=0.5	n.s
Similarities	scaled score	**13.2**	2.4	0	0.0	**13.4**	3.1	F=0.07	n.s
Reading text									
Comprehension (out of 9 questions)	N err	**4.5**	2.2	0.8	20.0	**3.3**	1.6	F=4.1	*
Speed	ms	**207.3**	35.1	0.4	4.0	**190.2**	41.2	F=2.3	n.s
Accuracy (out of 466 words)	N err	**8.9**	6.1	**2.5**	48.0	**2.6**	2.5	F=20.2	***
Reading									
Words	RT	**600.0**	117.4	**1.9**	52.0	**504.7**	50.2	F=12.0	***
	% err	**5.6**	2.5	**3.2**	68.0	**2.4**	1.0	F=28.4	***
Nonwords	RT	**877.7**	331.6	**2.2**	48.0	**638.8**	107	F=10.0	***
	% err	**24.7**	9.1	**6.2**	88.0	**7.4**	2.7	F=70.6	***
Spelling									
Words	% err	**19.7**	6.7	**3.6**	76.0	**8.2**	3.2	F=51.6	***
Nonwords	% err	**20.8**	11.3	**1.4**	44.0	**11.9**	6.5	F=10.2	***

(continued)

		DYSLEXICS				CONTROLS		COMPARISON	
SMALLER GROUP		**Mean**	**SD**	**z-score**	**% impaired**	**Mean**	**SD**	**value**	**p**
Phonological STM									
Digit span	raw score	**5.8**	0.9	**-1.8**	48.0	**6.9**	0.6	F=23.4	***
Nonword serial recall	% err	**30.6**	11.5	**1.3**	32.0	**19.4**	8.6	F=13.4	***
Word serial recall	% err	**36.0**	11.1	**0.8**	12.0	**28.1**	9.8	F=6.5	*
Phonological Awareness									
Phoneme counting	% err	**17.5**	15.4	**1.3**	36.0	**6.1**	8.4	F=9.1	***
Spoonerisms	% err	**20.0**	16.8	**3.6**	64.0	**2.9**	4.9	F=20.4	***

The smaller group of dyslexics showed the same characteristics with the large group of dyslexics (see section 3.1 of Chapter 1, for a description). That is, they did not differ from the controls in age, gender, education, performance IQ and verbal IQ (in either the Vocabulary or the Similarities subtests). Consistently with the characteristics of other groups with developmental dyslexia reported in the literature, they made more errors at spelling words and nonwords and were both slower and more error prone at reading words and nonwords compared to the matched controls. In reading comprehension, they were less significantly impaired. In text reading, they made more errors than the controls but were as fast as them. However, in this particular task, the large group of dyslexics was impaired in terms of both accuracy and speed. In terms of phonological abilities, the smaller group of dyslexics was also impaired on all phonological STM and phonological awareness tasks. Difficulties in the sublexical phonology tasks were of medium severity with the exception of an exceptionally poor performance on the Spoonerisms task. Individual z-scores of the smaller group of dyslexics on all types of orthographic tasks are presented in Appendix 28, while those on the sublexical phonology tasks are presented in Appendix 29.

Likewise the original dyslexic population, the profile of the smaller dyslexic group is more consistent with surface than with phonological dysgraphia. As shown in Table 3:2, word spelling is more impaired than nonword spelling. However, in reading, the pattern is reversed. Nonword reading is more impaired than word reading in terms of both speed and accuracy. Since performance in nonword spelling indicates relatively good sublexical conversion skills, the severely impaired performance in nonword reading has to be attributed to a different source of impairment. One of the aims of our experimental investigation is, in fact, to assess whether the ability to process series of independent visual units is an alternative source.

3.2 Learning and recall of visuospatial information

In line with the literature around intact visuospatial skills in the dyslexics, we expect to find normal performance on the visuospatial learning and recall tasks (Swanson, 1984, 1987; McDougall, Hulme, Ellis, & Monk, 1994; Romani, Ward & Olson, 1999; Di Betta & Romani, 2006). Results for both the large and the smaller groups are presented in Tables 3:3 and 3:4, respectively. Individual dyslexic z-scores are presented in Appendices 30 and 31, respectively.

Table 3:3. Performance of the 44 dyslexics and 41 controls on the visuospatial tasks (for WMS-R: 42 dyslexics and 39 controls; for D&P: 37 dyslexics and 37 controls).

		DYSLEXICS				CONTROLS		COMPARISON	
LARGE GROUP		**Mean**	**SD**	**z-score**	**% impaired**	**Mean**	**SD**	**F**	**p**
Visuospatial Tasks									
WMS-R									
Visual memory	weighted raw score	**60.7**	5.0	*-0.4*	4.5	**63.0**	5.5	3.9	*n.s*
D&P									
Learning-immediate	% err	**1.9**	5.4	-0.2	2.3	**3.6**	7.0	1.4	n.s
Learning-delayed	% err	**4.1**	8.1	-0.1	2.3	**4.5**	8.5	0.06	n.s
Recognition	% err	**22.4**	15.1	0.4	9.1	**17.8**	11.7	2.2	n.s
H&J									
Recognition	% err	**25.1**	5.6	0.0	2.3	**24.8**	6.5	0.04	n.s

Table 3:4. Performance of the 25 dyslexics and 21 controls on the visuospatial tasks (for WMS-R: 25 dyslexics and 20 controls; for D&P: 23 dyslexics and 20 controls).

		DYSLEXICS				CONTROLS		COMPARISON	
SMALLER GROUP		**Mean**	**SD**	**z-score**	**% impaired**	**Mean**	**SD**	**F**	**p**
Visuospatial Tasks									
WMS-R									
Visual memory	weighted raw score	**61.9**	5.3	*-0.06*	12.0	**64.6**	4.7	3.1	*n.s*
D&P									
Learning-immediate	% err	**1.8**	6.4	0.0	8.0	**1.7**	4.7	0.01	n.s
Learning-delayed	% err	**2.2**	5.7	-0.1	12.0	**2.9**	6.2	0.2	n.s
Recognition	% err	**26.4**	16.3	0.3	8.0	**22.9**	12.5	0.6	n.s
H&J									
Recognition	%err	**24.2**	5.7	0.2	4.0	**23.1**	5.4	0.4	n.s

As expected, our dyslexic groups showed no significant impairments in any of the visuospatial tasks administered.

3.3 Processing of visual series

In line with the studies finding a difficulty in processing briefly presented multi-element visual arrays in individuals with developmental dyslexia (as reviewed in the Introduction), we expect to find poor performance on at least some of the tasks used to measure processing of visual sequences of both linguistic (consonant letters) and non-linguistic information (simple or more complex symbols).

Tables 3:5 and 3:6 show the scores of the large and the smaller groups, respectively, on the simultaneous and sequential conditions of the Hindi and Japanese sorting and recognition tasks. Individual dyslexic z-scores are presented in Appendix 32, for the large group, and in Appendix 33, for the smaller group.

Table 3:5. Performance of the 44 dyslexics and 40 controls on the sorting and recognition tasks of the Hindi and Japanese tasks. Results are all in percentage of errors.

	DYSLEXICS				CONTROLS		COMPARISON	
LARGE GROUP	Mean	SD	z-score	% impaired	Mean	SD	F	p
Sorting Simultaneous								
Hindi	**34.4**	13.6	0.2	4.5	**32.0**	11.8	0.7	n.s
Japanese	**45.5**	10.3	0.2	0.0	**42.4**	15.0	1.2	n.s
Total	**40.5**	9.4	0.2	0.0	**37.8**	11.5	1.5	n.s
Sorting Sequential								
Hindi	**28.1**	14.2	**0.9**	13.6	**16.0**	14.1	15.4	***
Japanese	**28.5**	14.1	**0.8**	18.2	**18.0**	13.0	12.7	***
Total	**28.4**	12.7	**0.9**	15.9	**17.1**	12.2	17.2	***
Recognition from Simultaneous								
Hindi	**28.5**	6.7	0.1	2.3	**27.5**	8.1	0.4	n.s
Japanese	**26.9**	7.1	-0.2	0.0	**28.6**	7.0	1.2	n.s
Total	**27.6**	6.0	-0.1	0.0	**28.1**	6.9	0.1	n.s
Recognition from Sequential								
Hindi	**24.6**	6.3	0.3	2.3	**22.5**	7.7	2.0	n.s
Japanese	**20.8**	7.5	0.0	2.3	**20.7**	7.5	0.0	n.s
Total	**23.6**	6.0	0.1	0.0	**21.5**	6.7	0.6	n.s

Table 3:6. Performance of the 25 dyslexics and 21 controls on the sorting and recognition tasks of the Hindi and Japanese tasks. Results are all in percentage of errors.

	DYSLEXICS				CONTROLS		COMPARISON	
SMALLER GROUP	**Mean**	**SD**	**z-score**	**% impaired**	**Mean**	**SD**	**F**	**p**
Sorting Simultaneous								
Hindi	**34.4**	14.1	0.5	8.0	**29.5**	10.6	1.7	n.s
Japanese	**42.7**	10.1	0.3	0.0	**38.5**	14.3	1.4	n.s
Total	**39.0**	9.9	0.4	0.0	**34.5**	10.8	2.2	n.s
Sorting Sequential								
Hindi	**24.7**	13.6	**1.6**	4.0	**11.8**	8.3	14.3	***
Japanese	**24.3**	14.7	**0.9**	4.0	**14.2**	11.4	6.6	***
Total	**24.5**	13.0	**1.4**	4.0	**13.1**	8.3	11.9	***
Recognition from Simultaneous								
Hindi	**28.0**	6.6	0.2	4.0	**26.7**	7.8	0.3	n.s
Japanese	**26.2**	7.4	0.0	0.0	**26.0**	5.0	0.0	n.s
Total	**27.0**	6.2	0.1	0.0	**26.3**	6.0	0.1	n.s
Recognition from Sequential								
Hindi	**23.2**	6.0	0.3	4.0	**21.6**	5.8	0.8	n.s
Japanese	**20.1**	8.1	0.2	4.0	**18.6**	6.7	0.5	n.s
Total	**21.4**	6.0	0.3	0.0	**19.9**	5.2	0.8	n.s

The pattern of the Hindi and Japanese versions of the sorting and recognition tasks is the same across groups. Results from performance on the sorting tasks revealed an impairment in the sequential condition but normal performance in the simultaneous condition. This suggests that the dyslexics showed a significant difficulty in encoding the order of briefly presented multi-element visual arrays. However, this deficit was limited to the sequential presentation of the visual arrays (where information is being processed in an analytic/serial mode). It might have been the case that the normal performance in the simultaneous presentation of the multi-element visual arrays (where information is being processed as single/whole visual configurations) was the result of normal visuospatial abilities. Results from the recognition tasks showed absolutely no difficulties in identifying the visual characters following the simultaneous or the sequential presentation.

To assess group differences in the simultaneous and sequential conditions of the averaged H&J tasks, we carried out two-way mixed-model ANOVAs, one for the sorting and one for the recognition tasks. The within-subjects factor was 'condition' (i.e. simultaneous vs. sequential) and the between-subjects factor was 'group' (i.e. dyslexics vs. controls). For the ***sorting tasks***, results showed significant main effects of condition, $F(1,82)=238.5$, $p<.001$, $MSE=47.3$, with the sequential condition being easier than the simultaneous condition, and group, $F(1,82)=9.5$, $p=.003$, $MSE=215.9$, with the dyslexics making more errors than the controls. We also found an interaction between condition and group, $F(1,82)=15.9$, $p<.001$), suggesting that the difference in performance in the simultaneous from the sequential condition was smaller for the dyslexics compared to the controls. As shown in Tables 3:6 and 3:7, the dyslexics performed worse than the matched controls in the sequential condition, but as well as them in the simultaneous condition. The sequential condition was, however, easier for both groups (dyslexics: $F(1,43)=58.9$, $p<.001$, $MSE=55.3$; controls: $F(1,39)=221.5$, $p<.001$, $MSE=38.5$). The results obtained from the sorting tasks are interesting because they indicate that a deficit in encoding the order of sequentially presented visual characters is not an artefact of the sequential condition being more difficult than the simultaneous condition. For the ***recognition tasks***, results showed a different pattern. There was no significant effect of group, $F(1,82)=0.04$, $p=.84$, $MSE=73.5$, with the dyslexics performing as well as the controls, but a significant main effect of condition, F(1,82)=184.0, p<.001, MSE=7.9, with the characters following the sequential presentation being easier to identify than the characters following the simultaneous presentation. We also found no significant interaction between condition and group, F(1,82)=3.0, p=.08, reflecting that the difference in performance following the simultaneous from the sequential presentation was of similar size in the dyslexics and controls. As shown in Tables 3:6 and 3:7, the dyslexics performed as well as the controls on both recognition tasks.

Our results replicate those by Romani et al. (1999) for the case of AW, who showed an impairment in the sequential but not in the simultaneous condition of the sorting tasks and no problems in the recognition tasks. A deficit in the sequential condition is consistent with a deficit in encoding serial order. This was not shown in the simultaneous condition because the dyslexics might have used alternative encoding strategies in order to process the visual arrays, such as processing the string as a single visual configuration. The pattern of results obtained does not support alternative hypotheses of visual impairments. The normal performance in the recognition tasks does not fit within the hypothesis of 'poor visual working memory'. The impairment in the sequential presentation of multi-element visual arrays is also not in line with the hypothesis of a 'reduced visual attentional span' supported by Valdois and colleagues. Instead, this hypothesis predicts an impairment in the simultaneous condition, which is the opposite of what we found. Our results are also not in line with those from Lassus-Sangosee, N-guen-Morel, & Valdois (2008), who found impaired simultaneous but preserved sequential visual processing in a subgroup of French dyslexic children with phonological problems. Finally, the normal performance in the recognition tasks following a sequential presentation does not agree with the hypothesis of 'sluggish attentional shifting' supported by Hari & Renvall (2001), which predicts worse performance with sequential than with the simultaneous presentation across tasks.

Table 3:7 presents the scores of the dyslexics and matched controls on the same-different array matching tasks of consonants and symbols. Individual dyslexic z-scores are presented in Appendix 34.

Table 3:7. Performance of the 25 dyslexics and 21 controls on the identity and order conditions of the same-different array matching tasks of consonants and symbols.

	DYSLEXICS				CONTROLS		COMPARISON	
	Mean	**SD**	**z-score**	**% impaired**	**Mean**	**SD**	**F**	**p**
Consonant Identity								
RT	**2572**	641	**1.3**	24.0	**2064**	381	10.2	***
% err	**7.6**	5.1	**1.0**	24.0	**3.9**	3.3	5.9	*
Consonant Order								
RT	**3219**	849	0.4	8.0	**2964**	680	1.2	n.s
% err	**13.7**	7.3	**1.2**	0.0	**6.8**	4.8	9.7	***
Symbol identity								
RT	**2613**	468	0.0	4.0	**2632**	655	0.0	n.s
% err	**8.1**	4.9	0.5	8.0	**5.5**	4.9	2.4	n.s
Symbol Order								
RT	**3324**	781	0.1	8.0	**3277**	625	0.1	n.s
% err	**14.9**	8.0	**1.2**	40.0	**7.6**	4.9	9.1	***

Results from performance on the 'same-different' trials showed that the dyslexics were impaired in the order condition of both consonant and symbol string tasks in terms of accuracy but not in terms of speed. They were also impaired in the identity condition of the consonant but not the symbol string tasks in terms of both accuracy and speed. In other words, in detecting possible changes in the order of adjacent visual units, the dyslexics were less accurate than the controls but as fast as them. This was true for both letters and symbols. In detecting possible changes in the identity of adjacent visual units, the dyslexics were both less accurate and slower than the controls. This was limited to letters.

We then measured performance on the separate 'same' and 'different' trials of the consonant and symbol string tasks in terms of both speed and accuracy. Results are presented in Table 3:8. Individual dyslexic z-scores are presented in Appendix 35.

Table 3:8. Performance of the 25 dyslexics and 21 controls on the identity and order conditions of the 'same' and 'different' trials of the array matching tasks of consonants and symbols.

CONSONANTS	DYSLEXICS				CONTROLS		COMPARISON	
	Mean	SD	z-score	% impaired	Mean	SD	F	p
Identity								
Same								
RT	**2798**	707	**1.0**	20.0	**2293**	520	7.3	**
% err	**3.1**	1.4	0.0	4.0	**3.1**	1.7	0.0	n.s
Different								
RT	**2334**	601	**1.7**	32.0	**1843**	288	12.2	***
% err	**12.4**	4.8	**1.3**	32.0	**4.8**	2.5	7.9	***
Order								
Same								
RT	**3418**	898	0.2	4.0	**3278**	905	0.3	n.s
% err	**2.4**	1.5	0.1	3.0	**1.9**	1.1	0.2	n.s
Different								
RT	**2966**	734	*0.6*	16.0	**2630**	540	3.0	*n.s*
% err	**25.0**	7.1	**1.2**	36.0	**11.7**	4.5	9.9	***

(continued)

SYMBOLS	DYSLEXICS				CONTROLS		COMPARISON	
	Mean	SD	z-score	% impaired	Mean	SD	F	p
Identity								
Same								
RT	**2865**	590	-0.1	0.0	**2948**	780	0.2	n.s
% err	**1.4**	0.7	-0.3	0.0	**2.6**	1.6	2.1	n.s
Different								
RT	**2347**	400	0.0	4.0	**2320**	556	0.0	n.s
% err	**14.8**	4.9	0.7	20.0	**8.1**	4.0	4.3	*
Order								
Same								
RT	**3614**	885	-0.1	8.0	**3722**	741	0.2	n.s
% err	**2.6**	0.9	0.3	0.0	**1.7**	1.1	1.6	n.s
Different								
RT	**2984**	711	0.3	8.0	**2798**	552	0.9	n.s
% err	**27.9**	7.6	1.6	44.0	**11.9**	4.3	12.5	***

Results from performance on the 'same' trials showed that the dyslexics performed normally in the order condition of both consonant and symbol string tasks in terms of both speed and accuracy. In contrast, they performed poorly in the identity condition of the consonant string tasks in terms of speed but not in terms of accuracy. No problems were found in the identity condition of the symbol string tasks in terms of either speed or accuracy. In other words, in matching the order of identical adjacent visual units, the dyslexics were both as fast and accurate as the controls with both letters and symbols. In matching the identity of identical adjacent visual units, the dyslexics were as accurate as the controls with both letters and symbols but slower than the controls with letters only.

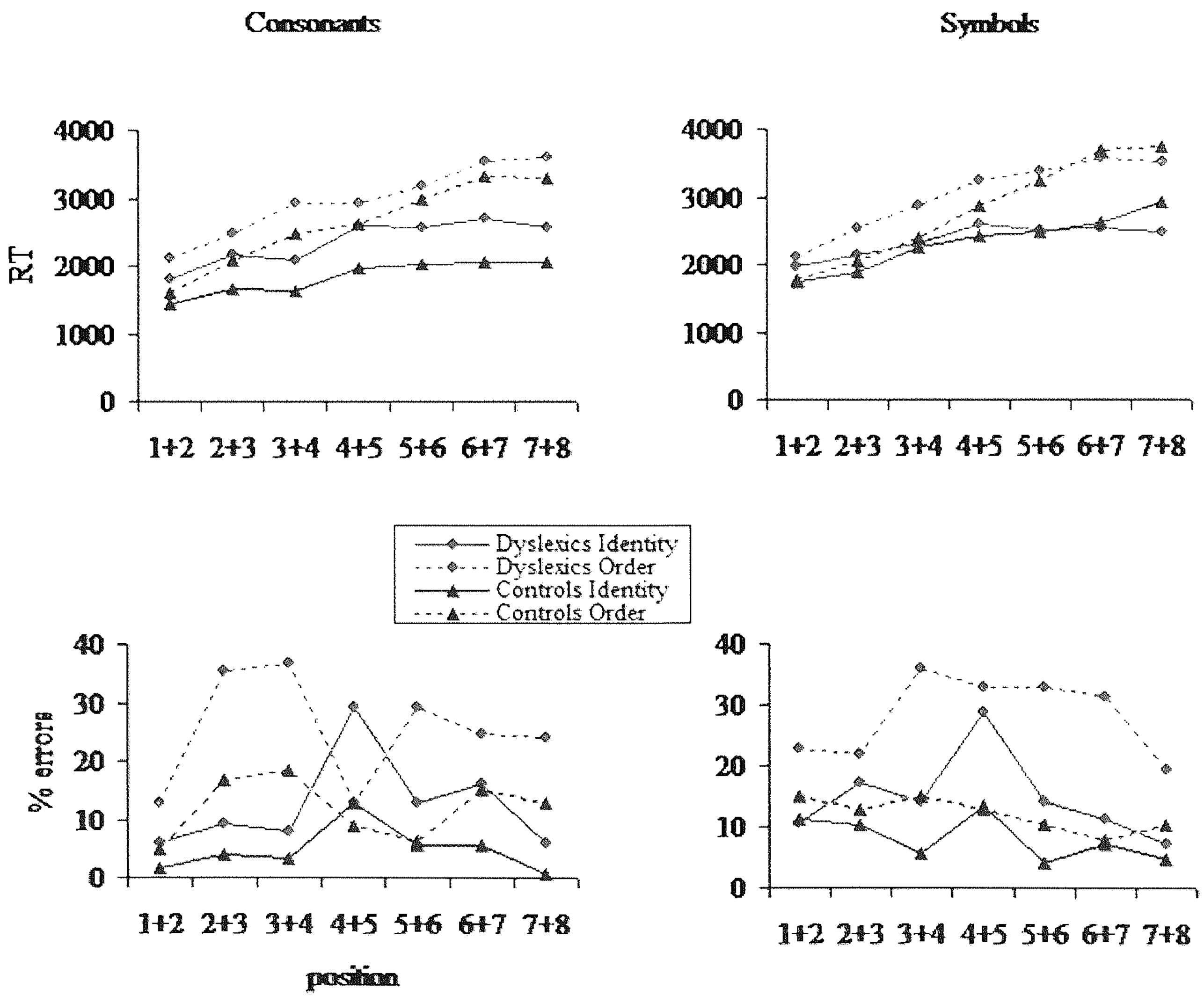
Results from performance on the 'different' trials showed that the dyslexics performed poorly in the order condition of both consonant and symbol string tasks in terms of accuracy and slightly poorly in the same condition of the consonant but not the symbol string tasks in terms of speed. They also performed poorly in the identity condition of both consonant and symbol sting tasks in terms of accuracy and in the same condition of the consonant but not the symbol string tasks in terms of speed. In other words, in detecting changes in the order of different adjacent visual units, the dyslexics were less accurate than the controls with both letters and symbols. They were also mildly slower than the controls with letters but normal with symbols. In detecting changes in the identity of different adjacent visual units, the dyslexics were less accurate than the controls with both letters and symbols. They were also significantly slower than the controls but only with letters.

To assess group differences in the identity and order conditions and same and different trials of the array matching tasks, we carried out three-way mixed-model ANOVAs, one for the consonant and one for the symbol matching tasks, with correct RT and error rate data as separate dependent variables. The within-subjects factors were 'condition' (i.e. identity vs. order) and 'trial' (i.e. same vs. different) and the between-subjects factor was 'group' (i.e. dyslexics vs. controls). We found more significant effects for accuracy rather than for speed for both tasks. For the ***consonant matching tasks***, results showed a significant main effect of <u>condition</u> with the order condition being harder than the identity condition for both accuracy, $F(1,44)=23.7$, $p<.001$, $MSE=6.5$, and speed, $F(1,44)=65.4$, $p<.001$, $MSE=396660.1$. There were also significant main effects of <u>group</u> with the dyslexics being both less accurate, F(1,44)=10.4, p=.002, MSE=22.4, and slower than the controls, F(1,44)=4.8, p=.03, MSE=1309276, and <u>trial</u> with the 'same' trials being matched slower than the 'different' trials, F(1,44)=97.6, p<.001, MSE=117304.2, and the 'different' trials being matched less accurately than the 'same' trials, F(1,44)=44.1, p<.001, MSE=21.6. There was no interaction between condition and group for either accuracy, F(1,44)=2.7, p=.11, or speed, F (1,44)=2.0, p=.16. However, there were interactions between <u>trial and group</u> for accuracy, F(1,44)=9.9, p=.003, but not for speed, F(1,44)=0.9, p=.35, and <u>condition and trial</u> for accuracy, F(1,44)=44.9, p<.001, but not for speed, F(1,44)=2.3, p=.13. There was no three-way interaction between condition and trial and group for either accuracy, F(1,44)=2.8, p=.10, MSE=5.2, or speed, F(1,44)=2.4, p=.12, MSE=46545.2. For the ***symbol matching tasks***, results showed a significant main effect of <u>condition</u> with the order condition being harder than the identity condition for both accuracy, F(1,44)=15.5, p<.001, MSE=9.3, and speed, F(1,44)=76.6, p<.001, MSE=259399.4. There were also significant main effects of <u>group</u> with the dyslexics being less accurate than the controls, F(1,44)=9.9, p=.003, MSE=24.8, but as fast as them, F(1,44)=.001, p=.97, MSE=1374997.9, and <u>trial</u> with the 'same' trials being matched slower than the 'different' trials, F(1,44)=176.8, p<.001, MSE=117740.0, and the 'different' trials being matched less accurately than the 'same' trials, F(1,44)=74.6, p<.001, MSE=19.8. There were also interactions between <u>condition and group</u> for accuracy, F(1,44)=6.9, p=.01, but not for speed, F(1,44)=0.2, p=.66, <u>trial and group</u> for both accuracy, F(1,44)=13.1, p=.001, and speed, F(1,44)=3.9, p=.05, and <u>condition and trial</u> for both accuracy, F(1,44)=16.1, p<.001, and speed, F(1,44)=14.5, p<.001. There was no three-way interaction between condition and trial and group for either accuracy, F(1,44)=2.9, p=.10, MSE=8.9, or speed, F(1,44)=2.9, p=.09, MSE=32916.9.

3.3.1 Serial position effects and group differences

The positional profiles of the dyslexics and controls in the 'different' trials of the consonant and symbol string tasks for both RTs and errors are plotted in Figure 5.

Figure 5. Positional profiles of the 25 dyslexics and 21 controls on the ‘different’ trials of the array matching tasks of consonants and symbols.



In terms of speed, RTs increased almost progressively from the left to the right of the visual strings, for both the dyslexics and the controls. This was true for both letter and symbol strings. However, with respect to *order changes*, the dyslexics performed worse than the controls when changes occurred in the beginning positions. This was true for both letter and symbol strings (consonants: positions 1+2: $F(1,45)=9.7$, $p=.003$; positions 2+3: $F(1,45)=4.4$, $p=.04$; symbols: positions 1+2: $F(1,45)=4.2$, $p=.05$). With respect to *identity changes*, the dyslexics performed worse than the controls when changes occurred in any of the seven positions. This was limited to letter strings (positions 1+2: $F(1,45)=5.1$, $p=.03$; positions 2+3: $F(1,45)=6.3$, $p=.02$; positions 3+4: $F(1,45)=10.4$, $p=.002$; positions 4+5: $F(1,45)=12.8$, $p=.001$; positions 5+6: $F(1,45)=10.1$, $p=.003$; positions 6+7: $F(1,45)=12.8$, $p=.001$; positions 7+8: $F(1,45)=6.7$, $p=.01$).

In terms of accuracy, the serial position curves were relatively ragged for both the dyslexics and the controls. However, the dyslexic profile in the various positions was similar to the control profile, but at much higher levels. This was true for both consonant and symbol tasks. In the ***consonant matching tasks***, with respect to *order changes*, the dyslexics made fewer errors when changes occurred in the first and final positions (ends advantage) or the very middle points (positions 4+5) rather than when changes occurred in the intermediate positions. M-shaped serial position curves have also been found by Hawelka, Huber & Wimmer (2006) and previously by Mason (1982) who have, however, used briefly presented single visual arrays consisting of five letters. This pattern was the same for the controls, with the exception that the controls showed also reduced errors for the positions immediately after the fixated middle (positions 5+6). The dyslexics' performance in the fixated middle was normal, whereas that in both adjacent positions to the fixated middle (positions 3+4 and 5+6), which still contained the medial letters (4 and 5), was poor (positions 3+4: $F(1,45)=6.0$, $p=.02$; positions 5+6: $F(1,45)=11.4$, $p=.002$). In addition, the dyslexics performed worse than the controls when changes occurred in the positions immediately after the start of the strings (positions 2+3: $F(1,45)=5.7$, $p=.02$). With respect to *identity changes*, the dyslexics made fewer errors when changes occurred in the first or second halves of the strings rather than when changes occurred in the very middle of the strings. The least errors were observed at the ends of the strings, while the most errors were observed in the very middle of the strings. This pattern was the same for the controls. In addition, the dyslexics performed as well as the controls in all positions, but the fixated middle (positions 4+5: $F(1,45)=5.0$, $p=.03$) and the positions just before the final positions (positions 6+7: $F(1,45)=4.0$, $p=.05$). In the ***symbol matching tasks***, with respect to *order changes*, the dyslexics made fewer errors when changes occurred in the beginning (positions 1+2 and 2+3) and final positions rather than when changes occurred in the intermediate positions. The controls showed a flatter pattern compared to the dyslexics. The dyslexics performed worse than the controls in all positions, but the beginning and the final (positions 3+4: $F(1,45)=6.2$, $p=.02$; positions 4+5: $F(1,45)=9.4$, $p=.004$; positions 5+6: $F(1,45)=11.3$, $p=.002$; positions 6+7: $F(1,45)=12.7$, $p=.001$). With respect to *identity changes*, both the dyslexics and the controls made more errors when changes occurred in the fixated middle rather than when changes occurred in the first and second halves of the strings. Finally, the dyslexics performed worse than the controls when changes occurred in the fixated middle (positions 4+5: $F(1,45)=4.1$, $p=.05$), and its both adjacent positions (positions 3+4: : $F(1,45)=5.4$, $p=.03$; positions 5+6: $F(1,45)=6.2$, $p=.02$).

Differently from previous studies, we used longer than five-element visual arrays. In addition, differently from previous studies, we used same-different pairs of visual arrays that remained on the screen until a judgement was made and not single visual arrays that were briefly presented on the screen. In this way, we allowed the detection and comparison of same-different visual pairs by the push of a button and avoided the involvement of verbal recall and naming abilities, known to be impaired in the dyslexics. However, the inclusion of eight-element strings that involved changes in two adjacent elements (in contrast to a single element) within seven different positions (in contrast to five different positions) makes the distinction of the middle positions of the strings less straightforward. For example, the fourth and the fifth units (position 4+5) that represent the very middle units of the strings mix also with the third and the sixth units, respectively, (positions 3+4 and 5+6). Thus, the conceptualisation of performance in the middle positions of the strings becomes more difficult.

To assess group differences in the identity and order conditions and different serial positions of the array matching tasks, we carried out three-way mixed-model ANOVAs, one for the consonant and one for the symbol matching tasks, with correct

RT and error rate data as separate dependent variables. The within-subjects factors were 'condition' (i.e. identity vs. order) and 'serial position' (i.e. 1+2, 2+3, 3+4, 4+5, 5+6, 6+7, 7+8) and the between-subjects factor was 'group' (i.e. dyslexics vs. controls). We found more significant effects for accuracy rather than for speed for both tasks. For the ***consonant matching tasks***, results showed a significant main effect of condition with the order condition being harder than the identity condition for both accuracy, $F(1,44)=38.1$, $p<.001$, $MSE=1.4$, and speed, $F(1,44)=86.9$, $p<.001$, $MSE=902627.5$. There were also significant main effects of group with the dyslexics being both less accurate, $F(1,44)=10.7$, $p=.002$, $MSE=5.9$, and slower than the controls, $F(1,44)=8.5$, $p=.006$, $MSE=3419215.3$, and serial position for both accuracy $F(1,44)=5.0$, $p<.001$, $MSE=0.9$, and speed, $F(1,44)=77.7$, $p<.001$, $MSE=218365.1$. In particular, speed slowed down progressively from left to right relative to the position of the different item to be detected, while the serial position curves in terms of accuracy were relatively ragged across the two conditions. In general, both groups made more errors when item changes occurred in the middle or adjacent to the middle positions rather than when item changes occurred in the beginning or end positions of the strings. There was no interaction between condition and group for either accuracy, $F(1,44)=3.0$, $p=.09$, or speed $F(1,44)=1.3$, $p=.26$. There was also no interaction between serial position and group for either accuracy, $F(1,44)=.70$, $p=.65$, or speed, $F(1,44)=.15$, $p=.99$. However, there was an interaction between condition and serial position for both accuracy, $F(1,44)=13.3$, $p<.001$, and speed, $F(1,44)=16.5$, $p<.001$. Finally, we found a three-way interaction between condition and serial position and group for accuracy, $F(1,44)=2.9$, $p=.009$, $MSE=0.7$, but not for speed, $F(1,44)=1.3$, $p=.25$, $MSE=167053.7$. For the ***symbol matching tasks***, results showed a significant main effect of condition with the order condition being harder than the identity condition for both accuracy, $F(1,44)=17.1$, $p<.001$, $MSE=2.5$, and speed, $F(1,44)=71.8$, $p<.001$, $MSE=750867.5$. There were also significant main effects of group with the dyslexics being less accurate than the controls, $F(1,44)=12.6$, $p= .001$, $MSE=5.9$, but as fast as them, $F(1,44)=0.7$, $p=.42$, $MSE=3596350.8$, and serial position for both accuracy, $F(1,44)=4.3$, $p<.001$, $MSE=0.9$, and speed, $F(1,44)=62.8$, $p<.001$, $MSE=337283.7$. In particular, speed slowed down progressively from left to right relative to the position of the different item to be detected, while the serial position curves in terms of accuracy were relatively ragged across the two conditions. Both groups made more errors when item changes occurred in the middle or adjacent to the middle positions rather than when item changes occurred in the beginning or end positions of the strings. There were also interactions between condition and group for accuracy, $F(1,44)=5.0$, $p=.03$, but not for speed, $F(1,44)=1.7$, $p=.20$, serial position and group for both accuracy, $F(1,44)=2.7$, $p=.01$, and speed, $F(1,44)=4.7$, $p<.001$, and condition and serial position for speed, $F(1,44)=15.6$, $p<.001$, but not for accuracy, $F(1,44)=2.1$, $p=.06$. Finally, we found no three-way interaction between condition and serial position and group for either accuracy, $F(1,44)=.70$, $p=.65$, $MSE=0.1$, or speed, $F(1,44)=.56$, $p=.76$, $MSE=192005.3$.

3.4 Relations among tasks

Since lexical learning taps the ability to create new representations from a series of unrelated visual units, we would expect to find significant correlations with the tasks measuring the ability to process visual series. This would suggest that the two tasks share a common 'order encoding' mechanism. Order encoding abilities are also important for reading and spelling and for remembering strings of phonological information. We should, therefore, be able to find significant correlations with the orthographic and phonological tasks, respectively (although in a lesser degree for the array matching tasks, which are more visually based tasks than the H&J sorting tasks), as they both involve the ability to process strings of phonological units (i.e. words, nonwords, phonemes of words and nonwords). We also expect to find significant correlations with the visuospatial tasks. However, the kind of associations we expect to find between the simultaneous H&J sorting task, in particular, and the visuospatial tasks is less clear. In explaining AW's good performance in the simultaneous condition of the H&J task, Romani et al. (1999) argued that AW was able to over-rely on his exceptionally good visuospatial memory abilities. If this hypothesis is correct, then, we should expect to find stronger correlations between the simultaneous and the visuospatial tasks in the dyslexics than in the controls. However, despite the dyslexics of the present study performed normally on the visuospatial tasks, their performance was just within average. An alternative possibility could be that the simultaneous presentation of the H&J characters allows the use of different encoding strategies that might rely on visuospatial abilities and/or verbal processes, such as naming and memorization abilities. For example, it could be the case that some of the subjects gave names to the unfamiliar characters to aid their serial encoding. This predicts that significant associations will also co-occur between the H&J sorting and the phonological tasks.

We investigated how performance on the simultaneous and sequential conditions of the H&J sorting tasks among dyslexic and control individuals were related to variations in performance on the visuospatial, phonological, lexical learning and orthographic tasks. We conducted Pearson's 2-tailed correlations (partialing out age) and regression analyses (controlling for age, performance IQ and phonological abilities) in the dyslexics and the controls. Table 3:9 presents the correlation results.

In addition to the phonological factor, we computed a 'visual factor' which derived by running a principal component analysis on the data from the D&P immediate and delayed visual learning and the WMS-R visual memory. This yielded a single factor with an eigenvalue greater than one, which accounted for 59% of variance and received high loadings from all components: D&P immediate learning=.73, D&P delayed learning=.79 and WMS-R visual memory=.79.

Table 3:9. Partial correlations among the simultaneous and sequential conditions of the Hindi and Japanese sorting tasks on one side, and the visuospatial, phonological, lexical learning and orthographic tasks on the other side in the dyslexics and controls (df for all tasks: 41 dyslexics and 37 controls; except for visual factor: 34 dyslexics and 34 controls; D&P visual recognition: 36 dyslexics and 34 controls).

	DYSLEXICS				CONTROLS			
	H&J sorting				H&J sorting			
	simultaneous	p	**sequential**	p	**simultaneous**	p	**sequential**	p
H&J sorting simultaneous	1		**0.53**	.00	1		**0.71**	.00
Visuospatial Tasks								
H&J recognition	**0.37**	.01	**0.50**	.00	**0.58**	.00	**0.60**	.00
Visual factor	0.27	.11	**0.47**	.00	**0.53**	.00	**0.43**	.01
D&P visual recognition	0.09	.59	0.05	.75	*0.29*	.08	0.20	.25
Phonological Ability	**0.49**	.00	**0.32**	.04	**0.36**	.02	*0.29*	.07
Lexical Learning								
Written	**0.34**	.03	**0.40**	.00	**0.31**	.05	*0.29*	.07
Spoken	**0.43**	.00	**0.30**	.05	**0.50**	.00	**0.46**	.00
Russian	**0.62**	.00	**0.42**	.01	**0.34**	.03	0.25	.13
Orthographic Tasks								
Spelling words	**0.32**	.04	0.25	.10	**0.38**	.02	0.11	.49
nonwords	0.25	.10	**0.35**	.02	**0.43**	.01	**0.53**	.00
Reading words RT	0.15	.35	0.12	.45	**0.55**	.00	**0.47**	.00
errors	0.25	.10	0.14	.37	0.27	.10	0.11	.49
nonwords RT	0.16	.31	0.13	.41	0.24	.14	0.24	.15
errors	**0.42**	.01	0.09	.55	0.004	.98	0.01	.93

In both the dyslexics and the controls, the simultaneous and the sequential conditions of the H&J sorting tasks were strongly related to one another. In the dyslexics, the simultaneous and the sequential tasks correlated significantly with phonological and lexical learning tasks (for all, spoken, written and russian). This is consistent with the hypothesis of a common 'order encoding' component in these tasks. The same pattern was also shown for the simultaneous task in the controls. The sequential task showed a marginal correlation with the phonological tasks and a significant correlation with lexical learning (spoken only). What is interesting is that, in the dyslexics, the simultaneous task showed a less strong association with the visuospatial tasks and a stronger association with the phonological tasks, whereas the controls showed the opposite pattern. On the other hand, the sequential task showed a stronger association with the visuospatial tasks and a less strong association with the phonological tasks in both the dyslexics and the controls. These results suggest that the two groups might have used different strategies in order to encode the order of the simultaneously presented H&J characters but the same strategies in order to encode the order of the sequentially presented H&J characters. However, interpretation of results must be made with caution, as the performance of our dyslexics on the visuospatial tasks was just within average. Consistently with the hypothesis of an 'order encoding' component, the H&J sorting tasks also showed a significant relationship with the orthographic tasks. The simultaneous task correlated with word spelling, while the sequential task correlated with nonword spelling in both the dyslexics and the controls. The simultaneous task also correlated with nonword reading accuracy in the dyslexics and nonword spelling in the controls. Both the simultaneous and the sequential tasks were also associated with word reading speed in the controls.

We were then interested in investigating how performance on the identity and order conditions of the same-different array matching tasks (of consonants and symbols) among dyslexic and control individuals were related to variations in performance on the visuospatial, phonological, lexical learning and orthographic tasks. As for the H&J sorting task, we conducted Pearson 2-tailed correlations and regression analyses. Table 3:10 presents the correlation results.

Because the sample size for the array matching tasks was smaller than that of the H&J tasks, we computed new phonological and visual factors, which derived by running principal component analyses on the same data with those of the H&J tasks. A 'phonological factor' with an eigenvalue greater than one was returned, which accounted for 70% of variance and received high loading from all components: digit span=.78, nonword serial recall=.86, phoneme counting=.62, spoonerisms=.56. In addition, a 'visual factor' with an eigenvalue greater than one was returned, which accounted for 57% of variance and received high loading from all components: D&P immediate learning=.52, D&P delayed learning=.56 and WMS-R visual memory=.63.

Table 3:10. Partial correlations among the identity and order conditions of the same-different array matching tasks on one side, and the visuospatial, phonological, lexical learning and orthographic tasks on the other side in the dyslexics and controls (df for all tasks: 29 dyslexics and 19 controls; except for H&J recognition: 29 dyslexics and 18 controls; for visual factor and D&P visual recognition: 26 dyslexics and 17 controls).

CONSONANTS	**DYSLEXICS**				**CONTROLS**			
	Identity	**p**	**Order**	**p**	**Identity**	**p**	**Order**	**p**
Consonants								
Order	**0.45**	.01	1		**0.52**	.02	1	
Symbols								
Identity	**0.47**	.01	*0.31*	.09	0.30	.18	**0.49**	.00
Order	**0.41**	.02	**0.41**	.02	**0.49**	.02	**0.60**	.00
Visuospatial Tasks								
H&J recognition	-0.04	.85	0.08	.69	-0.08	.75	0.02	.95
Visual factor	0.21	.29	-0.09	.65	**0.46**	.05	0.19	.43
D&P visual recognition	0.11	.57	**0.46**	.01	0.09	.72	-0.07	.78
Phonological Ability	0.12	.53	0.26	.16	0.08	.74	0.26	.25
Lexical Learning								
Written	0.20	.27	0.09	.63	0.01	.96	-0.20	.38
Spoken	-0.03	.86	0.01	.95	0.13	.59	-0.05	.82
Russian	0.08	.67	0.13	.48	0.06	.80	0.11	.64
Orthographic Tasks								
Spelling words	**0.41**	.02	0.26	.16	0.22	.33	0.06	.81
nonwords	-0.19	.32	-0.17	.36	0.18	.43	0.24	.29
Reading words RT	*0.32*	.08	0.09	.64	0.16	.49	0.15	.51
errors	0.19	.30	-0.08	.68	0.09	.68	0.35	.12
nonwords RT	**0.38**	.04	0.10	.58	0.20	.39	-0.05	.84
errors	0.30	.10	-0.07	.73	**0.48**	.03	0.19	.41

(continued)

SYMBOLS	DYSLEXICS				CONTROLS			
	Identity	**p**	**Order**	**p**	**Identity**	**p**	**Order**	**p**
Symbols								
Order	**0.78**	.00	1		**0.50**	.02	1	
Visuospatial Tasks								
H&J recognition	0.21	.26	0.14	.46	0.30	.21	0.02	.92
Visual factor	0.16	.41	0.22	.26	0.23	.35	0.25	.30
D&P visual recognition	-0.17	.38	-0.11	.58	0.21	.38	0.01	.98
Phonological Ability	0.27	.14	**0.38**	.04	0.23	.31	0.16	.49
Lexical Learning								
Written	0.17	.36	0.07	.72	0.05	.81	0.15	.52
Spoken	0.07	.70	0.03	.89	-0.04	.88	0.17	.46
Russian	**0.40**	.03	0.23	.21	0.15	.53	0.34	.14
Orthographic Tasks								
Spelling words	**0.44**	.01	*0.33*	*.07*	0.10	.66	0.06	.80
nonwords	0.02	.91	-0.10	.60	-0.03	.90	0.02	.93
Reading words RT	**0.38**	.03	0.28	.12	*0.38*	.09	0.28	.22
errors	**0.35**	.05	0.20	.28	0.17	.47	0.31	.18
nonwords RT	**0.40**	.03	0.27	.13	-0.20	.39	-0.04	.88
errors	*0.33*	.07	0.12	.52	0.08	.73	0.16	.48

In the consonant tasks, the identity and the order condition were significantly related to one another in both the dyslexics and the controls. The identity condition related also significantly to the order condition of the symbol tasks, while the order condition related also significantly to the respective condition of the symbol tasks in both the dyslexics and the controls. In addition, in the dyslexics, the identity conditions of both consonant and symbol tasks were also significantly related to one another, while, in the controls, the order condition of the consonant task was also significantly associated with the identity condition of the symbol task. We found no significant correlations with the phonological and lexical learning tasks for either the identity or the order tasks (of consonants) in the dyslexics or the controls. However, we found significant associations with the visuospatial tasks in both dyslexics and controls. In the dyslexics, the order task correlated with D&P visual recognition. In the controls, the identity task correlated with the visual factor. We also found significant associations with the orthographic tasks in both the dyslexics and the controls. In the dyslexics, the identity task correlated with word spelling and nonword reading speed. In the controls the identity task correlated with nonword reading accuracy.

In the symbol tasks, the identity and the order condition were significantly related to one another in both the dyslexics and the controls (more strongly for the dyslexics). Differently from the consonants tasks, we found no significant correlations with the visuospatial tasks for either the identity or the order tasks in the dyslexics or the controls. However, we found significant associations with the phonological and the lexical learning tasks but only in the dyslexics. The order task correlated with phonological ability, while the identity task correlated with russian lexical learning. We also found significant associations with the orthographic tasks but only in the dyslexics. The identity task correlated with word spelling and word reading accuracy as well as with word and nonword reading speed.

3.5 Predicting Reading and Spelling

A further question was whether performance on the tasks measuring the ability to process visual series (H&J sorting and same-different array matching tasks) predicted performance on the orthographic tasks independently of phonological processing, age and performance IQ. To determine this, we computed a series of stepwise regression analyses in the dyslexics and the controls. We used performance on the orthographic tasks as 'dependent variables' and performance on the tasks measuring the ability to process visual series as 'independent variables'. Age and performance IQ were entered at the first step and the phonological factor and the H&J sorting tasks (simultaneous and sequential) or same-different array matching tasks (identity and order) were entered alternately at the second step. Results for both the dyslexics and the controls are presented in Table 3:11, for the H&J sorting tasks, and in Table 3:12, for the same-different array matching tasks.

Table 3:11. Regression equations showing the contribution of the H&J sorting tasks to orthographic skills in the dyslexics and controls after age, performance IQ and phonological skills have been controlled.

		Spelling				**Reading Speed**				**Reading Accuracy**			
		words		**nonwords**		**words**		**nonwords**		**words**		**nonwords**	
DYSLEXICS	df	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p
1 Age+Performance IQ	2,41	**19.4**	0.01	**14.7**	0.04	**20.9**	0.01	**17.2**	0.02	6.2	0.27	6.8	0.23
2 Phonological factor	1,40	*5.9*	0.08	**22.9**	0.00	**13.3**	0.01	**24.2**	0.00	0.8	0.57	**17.4**	0.00
3 Simultaneous	1,39	1.0	0.46	0.6	0.53	0.7	0.53	1.4	0.34	1.4	0.43	4.0	0.15
3 Sequential	1,39	0.4	0.65	1.5	0.34	0.1	0.81	0.2	0.75	0.0	0.91	1.1	0.46
2 Simultaneous	1,40	3.6	0.18	1.3	0.43	0.5	0.62	0.8	0.55	2.1	0.35	**12.2**	0.02
3 Phonological factor	1,39	3.3	0.19	**22.2**	0.00	**13.5**	0.01	**24.9**	0.00	0.1	0.83	**9.2**	0.03
2 Sequential	1,40	1.1	0.46	4.2	0.16	0.1	0.81	0.2	0.74	0.0	0.99	0.1	0.86
3 Phonological factor	1,39	5.2	0.11	**20.2**	0.00	**13.3**	0.01	**24.1**	0.00	0.8	0.56	**18.4**	0.00
CONTROLS													
1 Age+Performance IQ	2,37	**15.4**	0.05	**30.0**	0.00	10.6	0.12	3.2	0.55	**38.5**	0.00	**18.1**	0.02
2 Phonological factor	1,36	4.2	0.18	1.1	0.44	5.4	0.14	3.1	0.28	2.4	0.23	**10.8**	0.02
3 Simultaneous	1,35	*7.6*	0.06	**7.2**	0.05	**17.7**	0.00	2.4	0.37	1.3	0.38	4.7	0.12
3 Sequential	1,35	0.1	0.87	**14.9**	0.00	**11.6**	0.02	2.5	0.33	0.0	0.92	1.2	0.43
2 Simultaneous	1,36	**8.7**	0.05	**7.7**	0.04	**19.5**	0.00	2.9	0.30	1.7	0.32	3.3	0.22
3 Phonological factor	1,35	3.1	0.23	0.6	0.56	3.6	0.18	2.5	0.33	2.1	0.27	**12.2**	0.02
2 Sequential	1,36	0.3	0.73	**15.8**	0.00	**13.7**	0.02	3.3	0.27	0.1	0.79	0.4	0.67
3 Phonological factor	1,35	3.9	0.20	0.3	0.68	3.4	0.21	2.3	0.35	2.3	0.25	**11.6**	0.02

In the dyslexics, age and performance IQ accounted for a significant amount of variance in the prediction of word and nonword spelling and word and nonword reading speed. The phonological factor predicted mainly nonword processing. This was true when entered both second and last. The simultaneous H&J task predicted nonword reading accuracy. This was, however, true when it was entered second. The sequential H&J task did not make a unique contribution to orthographic performance when it was entered either second or last.

In the controls, age and performance IQ accounted for a significant amount of variance in the prediction of word and nonword spelling and word and nonword reading accuracy. The phonological factor explained a significant additional amount of variance in nonword reading accuracy. This was true when it was entered both second and last. Both the simultaneous and the sequential H&J tasks made unique contributions to nonword spelling and word reading speed even when both H&J tasks were entered after the phonological factor. However, the simultaneous H&J task was a stronger predictor of word reading speed than the sequential H&J task, while the sequential H&J task was a stronger predictor of nonword spelling than the simultaneous H&J task (even when entered after the phonological factor). In addition, the simultaneous H&J task was also a less strong predictor of word spelling. This was, however, true when entered second (a contribution was marginal when entered last).

Table 3:12. Regression equations showing the contribution of the same-different array matching tasks to orthographic skills in the dyslexics and controls after age, performance IQ and phonological skills have been controlled.

		Spelling				**Reading Speed**				**Reading Accuracy**			
		words		**nonwords**		**words**		**nonwords**		**words**		**nonwords**	
DYSLEXICS	df	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p	% R^2 change	p
1 Age+Performance IQ	2,29	**26.3**	.01	*17.5*	.06	**20.9**	.03	*18.0*	.06	4.4	.52	3.3	.62
2 Phonological Factor	1,28	2.9	.30	*8.0*	.09	*8.4*	.08	**16.2**	.01	0.2	.80	**13.2**	.04
3 Consonant Identity	1,27	**12.0**	.03	4.8	.18	6.4	.11	**8.9**	.05	3.3	.34	6.5	.14
3 Consonant Order	1,27	3.8	.23	6.5	.12	0.2	.97	0.1	.88	0.9	.61	3.2	.31
3 Symbol Identity	1,27	*9.0*	.06	1.1	.53	*9.1*	.06	**9.0**	.05	8.9	.11	5.9	.16
3 Symbol Order	1,27	3.2	.27	7.2	.10	3.0	.28	1.7	.40	1.9	.46	0.1	.88
2 Consonant Identity	1,28	**13.2**	.02	3.5	.27	*8.0*	.09	**11.6**	.04	3.4	.32	8.6	.11
3 Phonogical factor	1,27	1.7	.39	*9.3*	.07	6.8	.10	**13.5**	.02	0.1	.88	*11.1*	.06
2 Consonant Order	1,28	5.5	.14	2.6	.34	0.6	.65	0.9	.59	0.6	.68	0.4	.73
3 Phonological factor	1,27	1.1	.51	**11.8**	.04	7.8	.10	**15.4**	.02	0.5	.70	**16.0**	.03
2 Symbol Identity	1,28	**10.5**	.04	0.3	.74	**11.9**	.03	**13.1**	.03	9.1	.10	8.9	.10
3 Phonological factor	1,27	1.4	.44	*8.8*	.08	5.6	.13	**12.1**	.02	0.0	.99	*10.2*	.07
2 Symbol Order	1,28	4.9	.17	2.9	.32	6.4	.13	6.1	.15	2.2	.43	0.7	.65
3 Phonological factor	1,27	1.2	.50	**12.2**	.04	5.0	.17	**11.9**	.03	0.0	.98	**12.6**	.05

(continued)

		Spelling				Reading Speed				Reading Accuracy			
		words		nonwords		words		nonwords		words		nonwords	
CONTROLS													
1 Age+Performance IQ	2,19	**35.4**	.02	*22.3*	.09	**33.6**	.02	11.5	.31	*24.6*	.07	12.8	.27
2 Phonological Factor	1,18	0.7	.65	7.4	.19	2.4	.42	0.1	.87	0.3	.79	10.1	.14
3 Consonant Identity	1,17	0.9	.63	1.5	.56	0.1	.89	1.5	.59	0.0	.96	**19.3**	.03
3 Consonant Order	1,17	2.8	.39	1.2	.59	0.8	.64	3.5	.42	3.6	.37	1.0	.64
3 Symbol Identity	1,17	1.9	.48	2.5	.44	2.1	.46	12.9	.11	0.1	.92	0.0	.99
3 Symbol Order	1,17	2.1	.46	0.5	.72	0.6	.69	2.5	.49	2.3	.47	1.2	.62
2 Consonant Identity	1,18	0.8	.63	1.3	.59	0.1	.90	1.5	.58	0.0	.96	**18.6**	.04
3 Phonological factor	1,17	0.8	.65	7.6	.19	2.4	.43	0.2	.86	0.3	.80	*10.8*	.09
2 Consonant Order	1,18	2.4	.41	2.1	.49	0.5	.72	3.2	.42	3.8	.34	2.0	.53
3 Phonological factor	1,17	1.1	.58	6.5	.22	2.8	.40	0.4	.79	0.1	.88	9.1	.17

Note: In the controls, no regression analyses were conducted for the symbol string tasks (identity and order) as there were no significant correlations with orthographic performance (refer to Table 3:10).

In the dyslexics, the consonant and symbol identity tasks accounted for unique variance in nonword reading speed. This was true even when entered after the phonological factor. Both tasks made also a unique contribution to word spelling. In the case of the consonant task, this was true even when entered after the phonological factor. In the case of the symbol task, this was true only when entered before the phonological factor (a contribution was marginal when entered last).

In the controls, the consonant identity task made a significant and independent contribution to nonword reading accuracy. This was true even when entered after the phonological factor.

4 GENERAL DISCUSSION

The aim of the present study was to assess the contribution of a deficit in processing visual sequences to the orthographic disorders seen in developmental dyslexia, independently of the significant contribution of the strong phonological deficit. To date, most of the evidence for a 'multi-element string processing deficit' in developmental dyslexia has been obtained by means of 'whole report' tasks (requiring the verbal report of the identities of briefly presented multi-element visual arrays independent of their order) and 'partial report' tasks (requiring the verbal report of a single visual unit within the array in response to a position cue). A multi-element string processing deficit has been operationally defined by poor performance on both or either of these tasks. However, a significant disadvantage is that these tasks involve naming and verbal STM abilities, known to be impaired in dyslexics. Therefore, a deficit in processing visual strings could reflect a problem with verbal coding and recall. In addition, the partial report task seems to be more taxing of order encoding than simultaneous processing abilities. To make interpretations of results less trivial, we used a sorting task which required the reconstruction of the order of briefly presented series of non-linguistic characters (i.e. Hindi and Japanese) that were presented both simultaneously and sequentially. We also used an array matching task which required the comparison of same-different visual strings of both linguistic and non-linguistic information (i.e. consonants and familiar symbols) that were presented simultaneously and remained on the screen until a judgement was made. We investigated the level of performance on these tasks in a group of adults with developmental dyslexia/dysgraphia as compared to a group of control adults (matched for chronological age, performance IQ and verbal IQ to the dyslexics). We also assessed the relationship between performance on these tasks and performance on the phonological, lexical learning and orthographic tasks, where dyslexics are impaired.

Our results showed that the dyslexics performed poorly on the sorting task, but only when the visual characters were presented sequentially. A crucial finding is that a deficit in encoding the order of sequentially presented visual strings was not the consequence of the sequential task being harder than the simultaneous task. The differential results obtained from performance between the two tasks indicate that the dyslexics were able to divide attention over whole visual strings (because they could probably use their visuospatial skills) but unable to distribute attention across the separate elements making up a visual string.

We also found significant correlations between the sequential sorting and both the phonological and the lexical learning tasks, which suggests that these tasks involve an order encoding ability. There were also significant correlations with the orthographic tasks. In the dyslexic individuals, the sequential task correlated with nonword spelling and the simultaneous task correlated with word spelling and nonword reading accuracy. In the control individuals, correlations with the orthographic tasks were even more extensive and stronger. The sequential task correlated with nonword spelling and word reading speed. The simultaneous task correlated with word and nonword spelling and word reading speed. These results are consistent with an 'order encoding deficit' in dyslexia. However, after controlling for phonological processing skills, the contributions of the sorting tasks to orthographic performance remained significant only in the controls. In the dyslexics, the sorting tasks made no unique contributions. However, the simultaneous task made a unique contribution to nonword reading accuracy problems but not after controlling for phonological ability. These results point to a particular kind of order encoding deficit that has limited implications for the long-term outcome of dyslexia.

The first question to address is whether the 'order encoding deficit' hypothesis relates to alternative hypotheses put forward in the dyslexia literature. A number of hypotheses can be put aside. Poor performance on the sequential sorting task cannot be accounted for by 'poor visuospatial memory' 'perceptual deficits', 'limited visual working memory' or 'sluggish attentional shifting'. Our dyslexics, in fact, performed normally on a range of visuospatial tasks and showed no difficulties in identifying visual characters that followed a simultaneous or a sequential presentation. In addition, our sorting task minimised the impact of the 'reduced visual attentional window' hypothesis. This is particularly clear in the sequential condition, where characters were presented one at a time. It is even clear in the case of the simultaneous condition, where characters were presented for more than one second which allows for eye movements. Our sorting task taxes different resources than a visual attentional span task. This is demonstrated by the opposite results found when the sequential and simultaneous presentations were contrasted across the two tasks.

With a visual attentional span task, dyslexics are impaired with the simultaneous but not with the sequential presentation (Valdois et al., 2004; Bosse et al., 2007; Lassus-Sangosse et al., 2008), which is the opposite of what we found with our sorting task. However, the normal performance with the sequential presentation in the visual-attentional span task is not surprising since in Valdois and colleagues' experiment participants were asked to recall the visual letters irrespective of their order. Thus, in their experiment, the task used did not require either order encoding or visual attentional span resources.

Recently, Hawelka and Wimmer (2008) reported normal performance with sequences of non-alphanumeric characters but poor performance with sequences of digits and consonant letters (as used in their earlier study Hawelka, Huber, & Wimmer, 2006) in German dyslexic adults. The authors concluded that the deficits found are the consequence of a naming deficit. The non-verbal task used by Hawelka and Wimmer (2008) required only the identification of a single visual character embedded in a series of other characters. Thus, their results indicate normal visual memory in dyslexia, which is consistent with our results, but do not speak of order encoding difficulties. Still, naming difficulties could perhaps explain the specific impairment shown in the sequential condition of our sorting task. The verbal coding of the characters may help their serial recall. The sequential condition may be harder because reduced naming speed is more detrimental in a condition where each character is presented for a very short time. Although plausible, this explanation seems unlikely for a number of reasons. First of all, assigning names to characters in the sequential condition is very difficult for anybody. Thus, if anything, one could expect to see a larger impact of naming difficulties in the simultaneous condition where naming is easier. Consistent with this explanation, phonological tasks show, if anything, a smaller correlation with the sequential than with the simultaneous task, in both the dyslexics and the controls. Secondly, a similar dissociation between an impaired performance in the sequential condition and normal performance in the simultaneous condition was also shown in our single case study, AW, who had no naming difficulties at all. Finally, the hypothesis that naming difficulties could account for the dissociation of performance in the sequential and the simultaneous condition would consider coincidental similar dissociations found with flickering stimuli (originally devised to test the 'magnocellular deficit' hypothesis of dyslexia).

Naming abilities have little place in judging the left vs. right orientation of flickering lines.

We have seen how a number of studies have reported that groups of dyslexic adults perform poorly when they are asked to compare more general visual stimuli (not visual strings) across displays (sequential presentations), but not when these stimuli are presented simultaneously (Ben-Yehudah et al, 2001; Ben-Yehudah & Ahissar, 2004; Ram-Tsur, Faust, & Zivotofsky, 2006, 2008). Rather than explaining this dissociation with a deficit of visual memory, as suggested by the authors, an alternative possibility is to assume that both types of tasks involve a form of order encoding, which allows linking visual stimuli to different points in a time continuum. To perform the tasks with the flickering displays, one has to remember exactly which display has been presented at which particular point in time. Similarly, our sequential sorting task can be carried out by linking each of the characters to a time signal. This will guarantee reconstruction of order at a later point in time. The fact that, in the dyslexics, the sequential task is selectively related to nonword spelling supports this interpretation. The ability to spell a nonword requires holding on to a phonological representation in the working memory and, then, keeping track of the order of the individual letters to be transcribed. Again, this requires a precise association between a time signal and different parts of a representation.

The pattern of associations shown by the sequential and simultaneous sorting tasks with phonological, lexical learning and orthographic tasks also supports the hypothesis that these tasks tap an order encoding component, which is an important component in reading and spelling. The significant association found between the simultaneous sorting task and the nonword reading task also suggests that nonword reading involves also orthographic coding abilities related to serial order (consistent with the view supported in Chapter 2). Replicating our previous results, in the dyslexics, nonword processing is strongly associated with phonological skills, while word processing is strongly associated with lexical learning. The sorting tasks are associated less strongly with both word and nonword processing but they do not make a unique contribution to orthographic problems. These results indicate that phonological, lexical learning and sorting tasks tap partially independent resources and that order encoding abilities are less important than phonological abilities and lexical learning in predicting severity of dyslexia.

One reason why the sorting tasks may not make independent contributions to orthographic performance in the dyslexics is because the dyslexics are less severely impaired in the sorting than in the phonological and lexical learning tasks. In addition, the dyslexics show no impairments at all in the simultaneous sorting task. Another reason is that deficits in order encoding may be more easily compensated. Both nonword reading and nonword spelling require keeping active a phonological representation. We have argued that especially nonword spelling requires an explicit representation of order which allows one to know at exactly what point in time one is in the process of phoneme-grapheme conversions. A representation of order, however, is implicit in a phonological representation. Thus, the quality and distinctiveness of this representation may go a great length to ameliorate (or hamper) any difficulties with order encoding. Similarly, in the case of word processing, one may argue that, in adult dyslexics, the quality of representations in the orthographic lexicon is linked more to a specific ability to form and store, in a permanent (or semi-permanent) fashion, new representations than to the quality of phonological representations. Good lexical learning abilities may compensate for these more peripheral impairments, whereas the opposite would be more difficult.

The influence of order encoding abilities may emerge more clearly in the control individuals because phonological and lexical learning skills are more plentiful. We found that, in the control individuals, phonological skills account only for nonword reading accuracy. Nonword spelling, instead, is more strongly accounted for by the sequential sorting task and word reading speed is more strongly accounted for by the simultaneous sorting task. We have argued that the sequential sorting task is the task which more clearly relates to order encoding. To perform this task, one has to assign temporal-sequential order to a number of distinct stimuli. The simultaneous task, instead, relies more on parallel visual processing and could tap a component similar to the visual attentional span described by Valdois and her colleagues (Valdois et al., 2004, Bosse et al., 2007; Lassus-Sangosse et al., 2008). It seems to us that, even for this task, one should emphasize an ordering component rather than a visual-attentional span capacity component. With studies which have used arrays of non-alphanumeric stimuli, deficits have been shown only with tasks requiring explicit processing of order (Pammer et al., 2004, 2005), but not with tasks which merely required identification of characters embedded in visual arrays (Hawelka & Wimmer, 2008; Shovman & Ahissar, 2004). However, this is probably not very distant from what suggested by Valdois and colleagues who have also conceived this component as specialized in processing sequences of visual characters rather than visuospatial configurations.

We then measured the level of performance on the same-different array matching tasks which required the detection of possible changes in terms of either the order or the identity of adjacent units within multi-element visual strings (of consonants and symbols) in the dyslexics and their matched controls. We also assessed the relationship between performance on these tasks and performance on the phonological, lexical learning and orthographic tasks, where dyslexics are impaired.

Our results showed that the dyslexics were impaired in both the order and the identity same-different tasks in terms of accuracy for the former and both accuracy and speed for the latter. An impairment at detecting possible order changes of adjacent visual units was present for both letters and symbols. An impairment at detecting possible identity changes of adjacent visual units was limited to the letters. These results suggest that dyslexics have a difficulty analyzing multi-element visual strings into their component elements (in terms of either their order or identities) in order to form and match their respective representations. The dyslexics performed normally at matching the order of identical adjacent visual units in terms of both speed and accuracy. Normal performance was present for both letters and symbols. However, they were slower than the controls but as accurate as them at matching the identities of identical adjacent visual units. This deficit was limited to letters. In addition, the dyslexics were more error-prone at detecting both order and identity changes of adjacent visual units. This deficit was present for both letters and symbols. They were also mildly slower at detecting order changes but significantly slower at detecting identity changes. This deficit was limited to the letters. Order changes were more difficult to process than identity changes in terms of both speed and accuracy. In addition, the dyslexics took more time to match identical adjacent units rather than to detect changes, while they made more errors at detecting changes than matching identical adjacent units. These results were true for both letters and symbols. Our results are reminiscent of those by Pammer et al. (2004) and Jones et al. (2008) who found increased error rates at distinguishing between pairs of simultaneously presented units of geometric forms, which differed in the order of two (adjacent and non-adjacent) units and which stayed in full view with no time limit.

We have also provided a comparison of the positional profiles of the dyslexics and controls on their ability to detect order and identity changes in the letter and symbol strings. We found that, in terms of both speed and accuracy, the dyslexic profile was similar to the control profile, but at much higher levels. More specifically, in terms of speed, both the dyslexics and the controls followed a serial analytic strategy in detecting identity and order changes of both letters and symbols, with RTs increasing almost progressively from the left to the right of the visual strings. The dyslexics were slower than the controls at detecting order changes occurring in the first two positions. This deficit was true for both letter and symbol strings. They were also slower than the controls at detecting identity changes occurring in any positions. This deficit was limited to letter strings. In terms of accuracy, results were more complicated. When asked to detect order letter changes, both the dyslexics and the controls showed an advantage for the first, final and fixated middle positions. The dyslexics made more errors than the controls at detecting order letter changes that occurred in the adjacent to the fixated middle positions (that also contained the medial letters) as well as in the second positions. When asked to detect order symbol changes, the dyslexics also showed an advantage for the first two and the final positions. On the other hand, the controls performed similarly in all positions. The dyslexics were as accurate as the controls at detecting order symbol changes that occurred in the first two and final positions but not in the intermediate positions. When asked to detect identity changes of both letters and symbols, both the dyslexics and the controls showed an advantage for all positions but the fixated middle. With respect to letters, the dyslexics were as accurate as the controls at detecting identity changes that occurred in all positions but the fixated middle and those before the final positions. With respect to the symbol tasks, the dyslexics were as accurate as the controls at detecting identity changes that occurred in all positions but the fixated middle and both its adjacent positions.

We also examined correlations between the same-different array matching tasks and other tasks. Correlations were generally weaker than those shown by the sorting tasks probably because the latter are more taxing of order encoding abilities. With respect to the consonant tasks, we found no significant associations with the phonological or the lexical learning tasks in either the dyslexics or the controls. However, we found significant associations with the orthographic tasks in both the dyslexics and the controls. In the dyslexics, the identity task correlated with word spelling and nonword reading speed. In the controls, the identity task correlated significantly with nonword reading accuracy. What is interesting is that contributions remained significant in both the dyslexics and the controls, even after controlling for phonological processing skills. These results are consistent with the hypothesis that order encoding is important for spelling and reading. With respect to the symbol tasks, we found significant associations but only in the dyslexics. There were significant correlations with both the phonological and the lexical learning tasks. The order task correlated with the phonological tasks, while the identity task correlated with the lexical learning tasks. This might indicate that the dyslexics have used different strategies in order to process the positions and the identities of the symbolic sequences. There were also significant correlations with the orthographic tasks. The identity task correlated with word spelling and word reading accuracy as well as with word and nonword reading speed. When controlling for phonological processing skills, a contribution to nonword reading speed remained significant, while the contributions to word spelling, word reading speed and accuracy fell just outside significance.

5 CONCLUSION

The present study assessed the ability to process the order of visual sequences of either a linguistic or a non-linguistic nature by using a sorting task involving unfamiliar ideographs presented under a simultaneous and a sequential condition and a same-different array matching task involving pairs of consonant letters and simple symbols presented under an identity and an order condition. We found a deficit in encoding order as indexed by poor performance in the sequential presentation of multi-element visual arrays and in the detection of both order and identity changes of adjacent units within multi-element visual arrays. This deficit involved both linguistic and non-linguistic information. Consistently with the hypothesis that order encoding is important for spelling and reading, we found significant contributions to orthographic skills, even after age, performance IQ and phonological processing skills were controlled. In particular, the sequential task was a significant predictor of nonword spelling, while the simultaneous task was a significant predictor of word reading speed. Furthermore, the identity consonant task was a significant predictor of word spelling and nonword reading speed in the dyslexics and nonword reading accuracy in the controls, while the identity symbol task was a significant predictor of nonword reading speed in the dyslexics.

APPENDICES

APPENDIX 1. Consent f forms for dyslexics and controls.

ASTON UNIVERSITY

REG/00/175

HUMAN SCIENCE ETHICS COMMITTEE

CONSENT FORM

For volunteers who report a history of reading/spelling difficulties

Aston University

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ASTON UNIVERSITY REG/00/175

HUMAN SCIENCE ETHICS COMMITTEE

CONSENT FORM

For volunteers who do NOT report any history of reading spelling difficulties

APPENDIX 2. General information questionnaire.

Name ______________________________

Gender Male ☐ Female ☐

Age at testing ______________________________

Date of testing ______________________________

Date of Birth ______________________________

Education ______________________________

Occupation ______________________________

Address ______________________________

____

Tel. **Home** ________________________

Work ________________________

Mobile ________________________

E-mail. ________________________

Handedness	Right ☐	Left ☐
Hearing problems	Yes ☐	No ☐
Colour-blind	Yes ☐	No ☐
Glasses to read	Yes ☐	No ☐

Self-reported current reading and spelling difficulties:

____

____

____

____

____

____

____

____

Self-reported other current or past problems:

____

____

____

____

____

Pre-school and school history

- Any long absences from school (especially in the first three grades)?

- Any changes of schools or teachers mid-year?

Problems occurring prenatally, at birth, or in the early developmental years

- Any serious injuries?

- Any hospitalisation (especially before 3 years of age)?

- Measles? What age? High temperatures and/or convulsions?

- Chickenpox? What age? Severely?

- Any difficulties your mother faced with delivery or pregnancy? (especially delay in breathing or difficulty of feeding)

- Was your mother taking any medication during pregnancy (including tablets for morning sickness)?

- Any allergies she might have had during pregnancy or you might have?

Problems in developmental stages (crawling, general activity level, speech development, laterality)

- Did you crawl (creep) on hands and knees? If not, how, or was the crawling stage very brief?

- Did you begin to talk (three word sentences) early, average or late?

- Was your preschool speech clear, or did you lisp, stutter or jumble up words?

- Was your coordination at preschool age good, average, or poor (e.g. throwing and catching balls)?

- Were you a 'climber' (a child who climbs everything in reach)?

- Are you ambidextrous?

Family history

- Is there any left handedness or ambidexterity in your family or either parent's family?

____

- Is there any family history of reading or spelling difficulties?

____

Parental attitudes and methods of managing problems

- Describe how your father deals or has dealt with the difficulties you are facing

____
____
____
____

- Describe how your mother deals or has dealt with the difficulties you are facing

____
____
____
____

Additional information about your interests, personal and social adjustment

- What would you do by choice on the weekends and holidays?

____
____
____
____

- Do you eat well? Sleep well?

____

- What was your relationship as a child with the other children? How is it now with other people?

____
____
____
____

How would you judge your spelling abilities? (1=very poor and 5=very good)

1 2 3 4 5

How would you judge your reading abilities? (1=very poor and 5=very good)

1 2 3 4 5

How would you judge your reading habits? (1=read very rarely and 5=avid reader)

1 2 3 4 5

Previous Assessment Yes ☐ No ☐

If yes, when? ______________________________

Current Assessment Yes ☐ No ☐

If yes, when? ______________________________

Report copy given Yes ☐ No ☐

Remedial help received Yes ☐ No ☐

Familiality Yes ☐ No ☐

If yes, report who ______________________________

____

Foreign Languages ______________________________

____

Other Comments ______________________________

APPENDIX 3. Single word spelling tasks.

List 1 (Schonell, 1985)

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List 2 (Holmes & Ng, 1993)

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List 3 (Romani & Ward, unpublished)

APPENDIX 4. Single nonword spelling task (Kay, Lesser & Coltheart, 1992; PALPA, subtest 45).

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APPENDIX 5. Single word and nonword reading tasks (computerised).

List 1 (Seidenberg, Waters, Barnes, & Tanenhaus, 1984, Experiment 3)

List 2 (Seidenberg, Waters, Barnes, & Tanenhaus, 1984, Experiment 4)

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List 3 (Kay, Lesser & Coltheart, 1992: PALPA, subtest 31)

Words

APPENDIX 6. Reading comprehension task (from the scholastic book "How to prepare for the SAT I", Green & Wolf, 1997, 19th Edition, Barron's Educational Series, Inc) and multiple choice questions.

APPENDIX 7. Text reading task (from the scholastic book "How to prepare for the SAT I", Green & Wolf, 1997, 19th Edition, Barron's Educational Series, Inc) and multiple choice questions.

APPENDIX 8. Phonological STM tasks.

a) Digit span

Trial	L=3	L=4	L=5	L=6	L=7	L=8
1	580	0851	15902	028513	3521804	40812536
2	142	2417	24173	731425	5437120	01273548
3	739	9376	67391	193762	2796315	51369720
4	658	8560	06584	485609	9680542	24508697
5	041	4103	30145	541032	2043158	85134027
6	239	9327	72396	206734	5297364	46379251
7	760	0673	37602	739640	4703621	12630745
8	693	3964	46937	824716	0634978	87943602
9	724	2471	17428	908173	6721485	58412760
10	180	0817	71809	693275	3107892	29870136
Score						

Digit span=..........

Scoring: Each sequence recalled correctly=0.1 point (10 correct sequences =1 point). The span is the sum of the scores obtained for each length. If all sequences are recalled correctly for L=4, start the score from 4.

Example:

L=4 > 10/10 correct > score=4.0

L=5 > 5/10 correct > score=0.5

L=6 > 2/10 correct > score=0.2

Digit span =4.7

b) Nonword serial recall

Lists of 3 nonwords

1 syllable

1.	bip	bise	lig
2.	prip	fune	speat
3.	meap	vome	prore
4.	rab	jaf	proom
5.	kobe	mab	fosh
6.	balb	pratch	dant
7.	mise	snick	loat
8.	grile	bish	lek
9.	blap	nust	jost
10.	sleg	pral	zeer

2 syllables

1.	renda	monor	porut
2.	criet	lerbik	tratex
3.	rasbil	rethom	anash
4.	traggen	kiper	espim
5.	foorly	cawell	vamuth
6.	ponnal	wealing	cajin
7.	fazzum	lobble	gudin
8.	whopple	orclab	mopon
9.	velly	laper	nimack
10.	teldom	putcher	delet

3 syllables

1.	willabon	malican	marlinize
2.	pefferone	stantepest	imbercline
3.	seeperel	mecreton	codderal
4.	tigulate	inchilton	elaptic
5.	vecular	noppion	rigumate
6.	janester	sipperil	anaptic
7.	rendooly	recliptic	biduking
8.	jutterese	corsitive	severtell
9.	narlisage	defitcher	wobucky
10.	probanty	bubbery	petabone

c) <u>Word serial recall</u>

Lists of 5 words

1 syllable

1.	lapse	shaft	debt	lake	myth
2.	pause	taste	brake	coal	blank
3.	elk	scope	throne	noise	skill
4.	ice	beach	fame	screen	flag
5.	roof	spice	peer	grief	cloud
6.	claim	mood	cone	scheme	cork
7.	phrase	thorn	veil	edge	scene
8.	dawn	tongue	dust	port	path
9.	vent	cage	dwarf	hole	fern
10.	sage	mint	dance	bib	grade

2 syllables

1.	jewel	sedan	burden	jacket	portion
2.	tennis	widow	coral	budget	egret
3.	secret	hammer	muzzle	velvet	ideal
4.	peril	flavour	promise	falcon	novel
5.	walrus	planet	bracket	council	kitten
6.	collar	cradle	title	conflict	pension
7.	tango	vapour	April	support	duchess
8.	scholar	easel	debate	author	lumber
9.	closet	purpose	honour	fever	pedal
10.	moral	devil	balloon	index	dragon

3 syllables

1.	kaleidoscope	prejudice	panorama	apology	refinement
2.	suggestion	territory	symphony	continent	boundary
3.	electricity	violence	paradise	mystery	scaffolding
4.	illusion	library	fellowship	republic	February
5.	percentage	valentine	fraternity	refrigerator	colony
6.	conference	horoscope	comedy	occupation	crocodile
7.	profession	gentleman	telegram	exercise	temperature
8.	dandelion	carpenter	dynamite	discipline	investment
9.	bifocals	chandelier	conversation	discovery	galaxy
10.	saxophone	medicine	factory	cardinal	orchestra

APPENDIX 9. Phonological awareness tasks.

a) Phoneme counting

	Words		Nonwords
2 phonemes			
	ache	am	ap
	itch	it	ip
	knee	go	ni
3 phonemes			
	knock	mud	mub
	cough	kin	kig
	vague	vet	vep
	guide	gap	gak
	wreck	rod	rop
	debt	dot	dop
4 phonemes			
	scheme	skid	skib
	autumn	atom	apom
	ocean	omen	oren
	ghost	gust	geest
5 phonemes			
	caution	cabin	cadim
	receipt	rebut	rebit
	session	solid	folid

b) <u>Spoonerisms</u>

Swaps resulting in two words

1.	bad	sin	sad	bin
2.	seal	deem	deal	seem
3.	bed	rent	red	bent
4.	fair	port	pear	fort
5.	chain	pat	pain	chat
6.	jet	mist	met	gist
7.	bear	chat	chair	bat
8.	ghost	mere	most	gear
9.	hare	band	bare	hand
10.	share	mop	mare	shop
11.	green	toss	teen	gross
12.	jacket	ram	racket	jam

Swaps resulting in two nonwords

1.	dare	night	nare	dight
2.	seem	pond	peem	sond
3.	tame	pet	pame	tet
4.	fog	ram	rog	fam
5.	hare	gin	gare	hin
6.	share	lest	lare	shest
7.	power	lime	lower*	pime
8.	down	band	bown	dand
9.	jacket	led	lacket	jed
10.	dull	foot	full*	doot
11.	room	mad	moom	rad
12.	vase	port	pase	vort

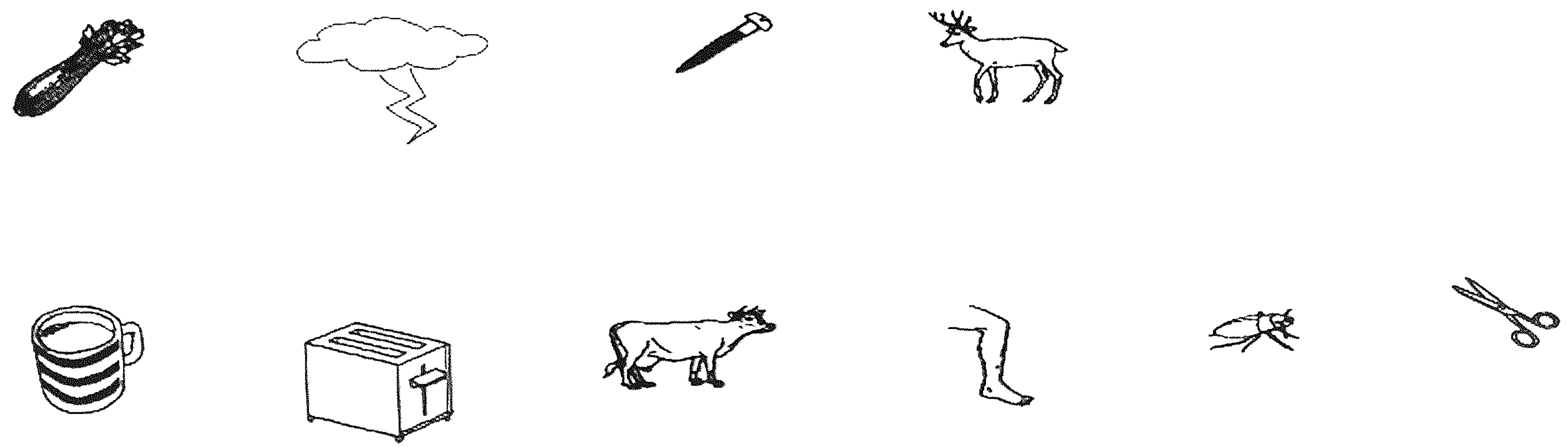
Swaps resulting in one word and one nonword

1.	dear	lamp	lear	damp
2.	tooth	moss	mooth	toss
3.	gold	mist	mould	ghist
4.	got	chest	chot	guest
5.	dog	gem	jog	dem
6.	mill	tooth	till	mooth
7.	mat	dear	dat	mere
8.	fare	cute	care	fute
9.	clove	starch	stove	clarch
10.	bond	chair	chond	bear
11.	met	coast	ket	most
12.	nest	met	mest	net

APPENDIX 10. Lexical learning tasks.

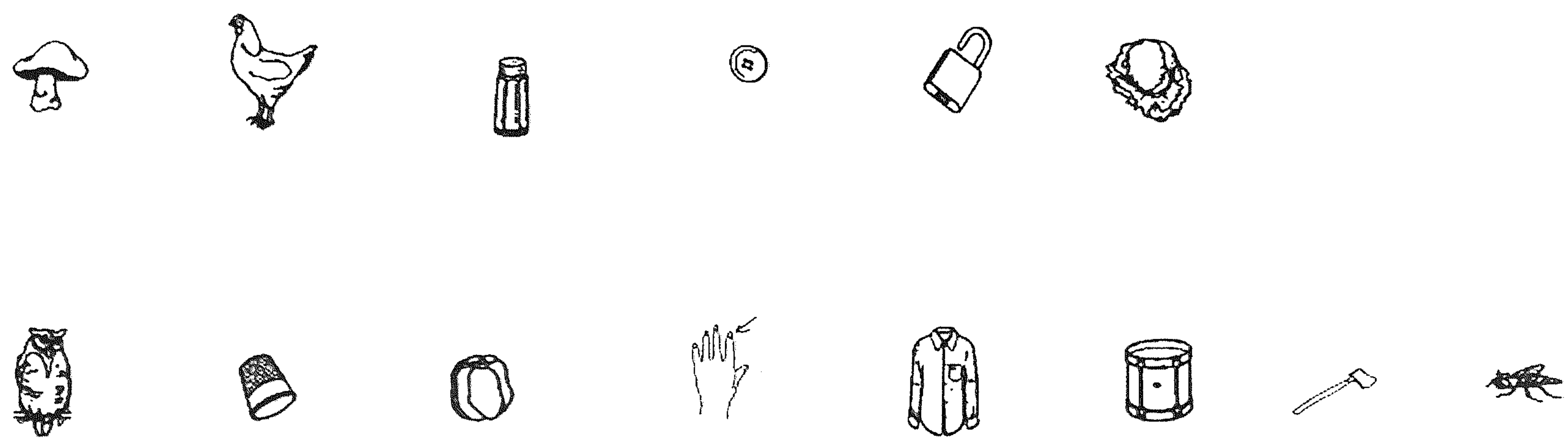
a) Spoken English nonwords paired with pictures

Item	Pronunciation	Picture
freet	freet	celery
lome	L0m	bolt
bepend	bIpend	mug
pilty	pILtI	toaster
teddle	tedL	screw
koodum	kudVm	deer
maltaf	m-Lt-f	cow
notten	n0ten	leg
sellocud	seL0kVd	beetle
zaledrok	zaLedr0k	scissors



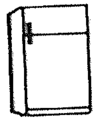
b) Spoken Dutch words paired with pictures

Item	Pronunciation	Picture
paddestoel	p-destuL	mushroom
kip	kep	chicken
uil	eL	owl
vingerhoed	vingerhUd	thimble
zoutvat	zutv-t	salt-pot
knoop	knup	button
paprika	paprIka	pepper
nagel	nigl	nail
slot	sL0t	padlock
kool	kuL	cabbage
hemb	hemd	shirt
trammel	tr0mel	drum
bijl	beeL	axe
vlieg	vLeeg	fly



Note: Words are coded according to the Oxford Psycholinguistic Database phonetic codes.

c) Written English nonwords paired with pictures


coset


clead

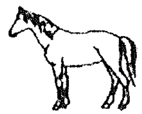

rownik


jotib


spulken

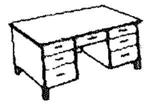

bimper


fimple


slish

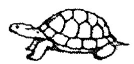

dolibish

d) Written Dutch words paired with pictures

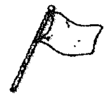


TAPEL

EEKHOORN

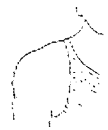


SCHILDPAD



VLAG

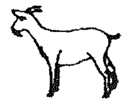
BORSTEL



SCHOUDER

HOED

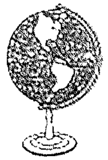
PARAPLU



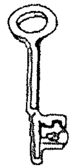
GEIT

ZWAAN

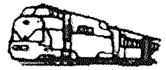
VARKEN



WERELDBOL



SLEUTEL



TREIN

SCHOEN

MUIS

BOEK

ZEEMEERMIN

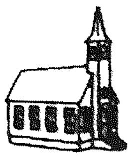
PIJP

KLOK

KNIE

TIJGER

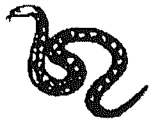
KETEL



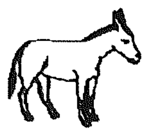
KERK

e) <u>Written Russian words paired with pictures</u>

руки



змея



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APPENDIX 11. Rey Auditory Verbal Learning Test, RAVLT (Rey, 1964).

APPENDIX 12. Verbal paired associates of the WMS-R (Wechsler, 1987).

APPENDIX 13. Author Recognition Test (ART) (Clark-Carter, 1997).

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APPENDIX 14. Individual z-scores (from the control mean) of the 44 dyslexics on all types of orthographic tasks.

		Spelling		Reading Speed		Reading Accuracy		Reading Comprehension	Text Reading	
N	**name**	**words**	**nonwords**	**words**	**nonwords**	**words**	**nonwords**	**words**	**speed**	**accuracy**
1	AQ	6.4	1.0	1.5	1.7	0.0	2.8	1.8	1.3	0.1
2	AUD	6.0	0.4	0.1	6.6	0.2	6.5	2.8	1.3	2.8
3	BH	6.8	2.3	1.6	7.8	2.7	6.5	0.2	2.2	4.7
4	CE	2.2	0.4	0.2	1.3	0.2	-0.3	-0.8	--	--
5	CH	1.4	-0.2	-0.1	0.5	-0.6	3.1	0.2	--	--
6	CMD	15.4	4.7	3.1	11.9	6.5	13.6	-0.8	1.3	3.4
7	DS	4.7	1.6	1.8	0.5	4.9	3.1	-0.3	-0.5	0.4
8	GB	6.6	7.8	8.9	1.7	14.6	6.8	2.3	3.8	6.9
9	HI	0.9	1.6	1.4	-0.4	0.9	4.1	1.3	2.3	0.6
10	HR	2.5	0.4	-1.5	0.1	-0.8	0.8	-0.8	-0.1	-0.2
11	IM	4.5	1.6	2.1	5.8	5.8	4.8	0.7	2.0	3.9
12	JC	3.3	-1.4	1.0	0.9	3.6	3.8	0.2	0.8	0.1
13	KO	5.9	1.6	3.1	7.8	3.0	7.2	0.2	0.3	0.1
14	LF	1.0	3.5	0.4	2.1	0.2	6.8	1.8	0.7	1.7
15	LL	5.0	1.0	0.7	2.1	0.3	8.2	0.2	0.7	0.4
16	LM	2.3	2.3	-0.8	1.7	-0.3	3.8	0.7	-1.1	0.9
17	MAN	0.2	2.3	-1.3	2.5	-1.4	6.2	1.8	0.0	1.2
18	MAR	2.2	3.5	-0.4	2.5	-0.7	1.4	-0.3	0.6	-1.0
19	MB	1.5	2.3	-0.5	3.3	0.9	2.4	-1.4	0.2	0.1
20	MD	4.2	5.9	0.7	0.5	1.2	5.5	1.3	0.7	1.7
21	MP	11.8	4.7	16.5	11.5	19.8	14.9	1.3	15.1	11.7
22	NAH	0.9	-0.8	4.3	-0.8	4.4	3.8	0.7	0.0	-0.7
23	NEI	4.1	-0.2	-0.2	1.3	-0.6	4.1	1.3	0.9	0.6
24	NH	12.0	7.2	8.5	4.1	19.7	8.5	2.3	6.8	4.7
25	NL	4.6	1.0	2.9	3.3	1.3	5.5	1.3	2.5	3.9
26	NR	3.0	0.4	0.1	1.7	-0.2	0.8	-0.8	0.9	0.1

27	PR	13.7	10.8	10.1	5.4	21.4	13.6	1.3	6.0	9.0
28	PRI	3.4	1.6	-0.8	2.5	-0.7	3.1	-1.4	1.7	3.6
29	RB	13.7	0.4	10.1	10.7	13.4	6.8	1.3	6.3	13.1
30	RFM	8.8	0.4	1.8	3.3	2.2	4.1	-0.8	0.2	0.6
31	RK	1.8	2.3	-0.7	2.9	-0.9	0.4	-0.3	-0.2	1.7
32	RKI	6.8	2.9	0.1	2.1	0.4	8.5	--	--	--
33	RL	3.5	7.2	2.8	2.9	6.0	10.6	1.3	--	--
34	RP	5.5	1.0	-1.2	3.7	-0.4	5.8	-1.4	0.2	-0.4
35	RW	9.0	2.9	0.9	7.4	-0.1	8.5	0.2	3.1	4.2
36	SA	1.6	5.3	-1.4	5.4	-1.4	10.2	2.3	1.7	0.9
37	SI	5.5	2.3	1.8	5.0	3.1	9.2	-0.3	2.3	3.9
38	SK	2.9	1.6	1.2	0.5	0.0	2.8	0.2	-0.3	0.9
39	SM	2.4	1.0	-0.8	3.7	-0.7	6.8	0.7	0.5	3.6
40	ST	3.5	-0.8	5.2	2.1	9.1	2.4	-0.3	2.7	2.5
41	TL	5.6	2.3	2.5	3.3	1.7	5.5	2.3	0.7	4.2
42	VS	2.1	0.4	3.8	2.1	3.0	6.5	0.7	1.4	1.2
43	VT	0.6	3.5	0.6	-0.4	0.5	-0.3	1.3	0.4	0.6
44	YO	1.7	2.3	3.4	2.1	8.5	5.5	1.3	2.1	2.3
	Mean	**4.8**	**2.3**	**2.1**	**3.3**	**3.4**	**5.6**	**0.6**	**1.8**	**2.5**
	SD	**3.8**	**2.5**	**3.7**	**3.1**	**5.9**	**3.6**	**1.1**	**2.8**	**3.1**

APPENDIX 15. Individual z-scores (from the control mean) of the 44 dyslexics on the sublexical phonology tasks.

		Phonological STM			Phonological Awareness	
N	**name**	**Digit span**	**Nonword serial recall**	**Word serial recall**	**Phoneme counting**	**Spoonerisms**
1	AQ	-2.6	1.7	1.7	1.7	2.4
2	AUD	-3.4	2.3	2.3	-0.5	3.4
3	BH	-1.0	-0.9	0.7	-0.1	8.7
4	CE	-0.7	0.1	1.1	-0.3	-0.5
5	CH	-2.4	1.4	2.3	-0.1	0.1
6	CMD	-0.9	0.1	0.4	0.5	3.1
7	DS	-2.9	2.3	2.7	3.3	2.1
8	GB	-3.6	2.7	2.2	3.3	9.5
9	HI	-2.3	2.2	1.5	3.5	5.4
10	HR	-1.7	2.0	-0.2	-0.7	-1.0
11	IM	1.4	-0.9	-1.7	-0.3	-0.5
12	JC	-2.3	1.0	1.1	-0.7	6.4
13	KO	-1.9	0.6	1.1	1.5	7.7
14	LF	-1.7	-0.1	0.2	-0.1	-0.7
15	LL	-1.6	1.6	1.7	0.1	-0.2
16	LM	-1.7	1.1	1.2	1.9	3.9
17	MAN	-1.7	-0.5	0.7	0.1	-0.7
18	MAR	-1.3	0.2	0.1	-0.5	0.3
19	MB	0.1	0.5	0.1	1.9	1.1
20	MD	-0.7	1.3	1.3	2.3	4.4
21	MP	-2.0	1.2	1.5	2.9	3.4
22	NAH	0.9	-1.0	0.0	-0.1	1.1
23	NEI	-1.0	-0.2	-0.5	0.1	-0.2
24	NH	-3.1	3.8	2.3	3.5	5.7
25	NL	-0.9	0.6	0.8	0.5	2.1
26	NR	-1.4	-0.9	-0.5	1.5	-1.0

27	PR	-2.3	4.4	2.4	3.9	12.6
28	PRI	1.3	-0.1	-0.5	-1.0	1.1
29	RB	-1.3	3.1	2.3	0.3	12.3
30	RFM	-1.3	0.4	0.7	-0.1	9.5
31	RK	-0.4	-0.9	0.3	-0.7	-1.0
32	RKI	-1.9	1.0	1.9	1.3	2.9
33	RL	-4.0	3.4	1.8	3.3	7.5
34	RP	-1.9	1.9	1.6	-0.1	-1.0
35	RW	-0.7	-1.2	0.3	0.3	-0.7
36	SA	-3.3	2.6	3.2	4.1	2.9
37	SI	-2.7	1.2	-0.9	0.9	1.3
38	SK	0.7	-0.2	0.5	-0.5	1.8
39	SM	-1.6	0.8	1.5	-0.5	3.9
40	ST	-1.3	1.1	0.3	-0.1	3.4
41	TL	-1.4	1.1	1.9	0.7	1.8
42	VS	-1.9	-0.1	0.4	-0.3	-0.5
43	VT	-1.4	0.9	1.8	-1.0	3.0
44	YO	-1.3	1.2	-0.1	4.1	3.6
	Mean	**-1.5**	**1.0**	**1.0**	**0.9**	**3.0**
	SD	**1.2**	**1.3**	**1.1**	**1.6**	**3.6**

APPENDIX 16. Individual z-scores (from the control mean) of the 44 dyslexics on the lexical learning, lexical-semantic learning and print exposure tasks.

		Lexical learning			Lexical-semantic learning				Print exposure
		English nonwords & Dutch words		Russian nonwords	Immediate		Delayed		
N	name	spoken	written	written	WMS-R word pairs	RAVLT	WMS-R word pairs	RAVLT	
1	AQ	2.3	2.7	1.3	2.2	2.4	-0.4	1.5	-1.8
2	AUD	1.9	2.9	1.0	0.9	1.5	-0.4	1.9	1.5
3	BH	2.2	0.9	0.3	-0.5	0.3	-0.4	1.1	1.5
4	CE	2.1	1.9	-0.4	0.2	0.5	-0.4	-0.7	0.1
5	CH	1.2	1.3	1.6	--	1.7	--	1.9	-0.9
6	CMD	2.3	3.6	0.7	-0.5	--	-0.4	--	1.0
7	DS	1.2	1.6	0.5	8.3	0.9	6.3	0.2	-1.8
8	GB	2.3	2.5	0.8	3.6	3.0	1.8	1.9	-0.4
9	HI	1.5	0.2	1.4	3.6	0.0	1.8	0.6	-2.3
10	HR	-1.5	-0.8	-1.1	0.2	-2.0	-0.4	-0.3	0.1
11	IM	1.8	1.1	0.0	2.2	0.3	1.8	1.5	1.5
12	JC	0.3	1.7	0.3	-0.5	-0.5	-0.4	1.5	1.5
13	KO	1.8	0.2	0.7	-1.1	-1.8	-0.4	-0.7	-0.4
14	LF	0.5	1.2	1.1	-1.1	-0.3	-0.4	-1.1	-0.4
15	LL	2.2	1.6	0.8	0.2	0.5	-0.4	1.1	0.1
16	LM	1.3	0.6	1.1	0.2	1.2	-0.4	1.1	0.5
17	MAN	0.8	0.0	0.7	0.2	1.2	-0.4	-0.3	-1.3
18	MAR	0.8	0.8	0.8	2.2	-0.6	-0.4	0.2	0.1
19	MB	1.5	0.7	0.5	-0.5	1.1	-0.4	0.6	-2.3
20	MD	2.5	2.7	0.7	2.2	1.7	-0.4	1.5	-0.4
21	MP	3.4	3.9	1.6	3.6	0.1	4.1	1.1	0.5
22	NAH	0.5	-0.3	-0.9	0.2	0.6	-0.4	-0.3	-0.9
23	NEI	0.5	1.5	0.8	1.5	-0.3	1.8	1.1	0.1
24	NH	1.1	1.9	1.8	2.9	0.6	1.8	-0.3	0.1
25	NL	1.6	2.4	1.4	3.6	1.2	1.8	1.9	1.0
26	NR	1.6	1.6	1.3	1.5	1.1	-0.4	1.1	-0.4

27	PR	2.5	3.1	0.3	0.2	-1.4	-0.4	-0.7	--
28	PRI	0.2	-0.7	0.2	0.2	-0.6	-0.4	-0.3	1.0
29	RB	3.0	4.6	2.1	3.6	-0.5	1.8	-0.3	0.5
30	RFM	2.3	1.8	0.8	-0.5	0.5	-0.4	1.9	-1.8
31	RK	1.0	1.0	-0.9	-1.1	-1.4	-0.4	-0.7	1.5
32	RKI	1.9	1.3	1.4	--	--	--	--	0.5
33	RL	2.8	0.9	0.8	0.9	0.1	-0.4	1.1	--
34	RP	1.7	2.6	1.4	1.5	-0.5	-0.4	-0.7	-0.4
35	RW	2.9	4.8	2.1	4.9	3.2	4.1	3.7	1.9
36	SA	2.2	2.6	1.8	0.9	0.9	1.8	1.1	-2.3
37	SI	-1.1	-0.3	-0.4	-0.5	-1.8	1.8	-0.7	1.5
38	SK	1.7	2.1	0.5	-0.5	1.7	-0.4	1.9	-0.4
39	SM	2.6	2.4	1.4	0.9	0.5	-0.4	0.6	2.4
40	ST	2.1	0.4	0.0	-0.5	-2.1	-0.4	-1.1	0.1
41	TL	1.0	2.0	0.5	0.2	0.9	-0.4	3.2	-0.4
42	VS	-1.1	2.2	1.0	0.9	-1.2	-0.4	-1.1	0.1
43	VT	1.4	2.4	1.3	4.2	3.8	1.8	2.8	1.0
44	YO	0.9	-0.1	-0.8	-0.5	0.5	-0.4	0.2	-1.8
	Mean	**1.5**	**1.6**	**0.7**	**1.2**	**0.4**	**0.5**	**0.7**	**0.0**
	SD	**1.1**	**1.3**	**0.8**	**2.0**	**1.4**	**1.6**	**1.2**	**1.2**

APPENDIX 17. Dyslexic subgroups selected according to the spelling criterion. Results are presented in z-scores (from the control mean).

			Spelling		
N	**Subgroup**	**name**	**irregular**	**nonword**	**discrepancy**
1	surface	RB	12.2	0.4	11.8
2	surface	CMD	13.5	4.7	8.8
3	surface	RFM	7.6	0.4	7.2
4	surface	MP	11.0	4.7	6.3
5	surface	AQ	7.1	1.0	6.1
6	surface	RW	8.7	2.9	5.8
7	surface	AUD	6.0	0.4	5.6
8	surface	NEI	4.5	-0.2	4.7
9	surface	ST	3.8	-0.8	4.6
10	surface	JC	3.1	-1.4	4.5
11	surface	BH	6.6	2.3	4.3
12	surface	RP	5.3	1.0	4.3
13	surface	TL	6.4	2.3	4.1
14	surface	KO	5.6	1.6	4.0
15	surface	LL	4.9	1.0	3.9
		Mean	**7.1**	**1.4**	**5.7**
		SD	**3.1**	**1.8**	**2.2**
1	intermediate	NL	4.9	1.0	3.9
2	intermediate	DS	5.1	1.6	3.5
3	intermediate	RKI	6.4	2.9	3.5
4	intermediate	SI	5.4	2.3	3.1
5	intermediate	IM	4.6	1.6	3.0
6	intermediate	HR	3.0	0.4	2.6

7	intermediate	NR	2.6	0.4	2.2
8	intermediate	NAH	1.3	-0.8	2.1
9	intermediate	NH	9.2	7.2	2.0
10	intermediate	CE	2.4	0.4	2.0
11	intermediate	VS	2.4	0.4	2.0
12	intermediate	CH	1.8	-0.2	2.0
13	intermediate	PRI	3.3	1.6	1.7
14	intermediate	SK	2.9	1.6	1.3
		Mean	**3.9**	**1.5**	**2.5**
		SD	**2.1**	**1.9**	**0.8**
1	phonological	PR	11.2	10.8	0.4
2	phonological	SM	1.4	1.0	0.4
3	phonological	LM	2.3	2.3	0.0
4	phonological	MB	2.1	2.3	-0.2
5	phonological	YO	1.8	2.3	-0.5
6	phonological	HI	0.8	1.6	-0.8
7	phonological	RK	1.2	2.3	-1.1
8	phonological	MAR	2.0	3.5	-1.5
9	phonological	MAN	0.3	2.3	-2.0
10	phonological	MD	3.6	5.9	-2.3
11	phonological	GB	5.4	7.8	-2.4
12	phonological	VT	0.9	3.5	-2.6
13	phonological	LF	0.8	3.5	-2.7
14	phonological	SA	1.3	5.3	-4.0
15	phonological	RL	2.6	7.2	-4.6
		Mean	**2.5**	**4.1**	**-1.6**
		SD	**2.7**	**2.8**	**1.5**

APPENDIX 18. Individual z-scores (from the control mean) of the 15 surface dyslexics and 15 phonological dyslexics on all types of orthographic tasks.

			Spelling		**Reading Speed**		**Reading Accuracy**		**Reading Comprehension**	**Text Reading**	
N	**subgroup**	**name**	**words**	**nonwords**	**words**	**nonwords**	**words**	**nonwords**	**words**	**speed**	**accuracy**
1	surface	AQ	6.4	1.0	1.5	1.7	0.0	2.8	1.8	1.3	0.1
2	surface	AUD	6.0	0.4	0.1	6.6	0.2	6.5	2.8	1.3	2.8
3	surface	BH	6.8	2.3	1.6	7.8	2.7	6.5	0.2	2.2	4.7
4	surface	CMD	15.4	4.7	3.1	11.9	6.5	13.6	-0.8	1.3	3.4
5	surface	JC	3.3	-1.4	1.0	0.9	3.6	3.8	0.2	0.8	0.1
6	surface	KO	5.9	1.6	3.1	7.8	3.0	7.2	0.2	0.3	0.1
7	surface	LL	5.0	1.0	0.7	2.1	0.3	8.2	0.2	0.7	0.4
8	surface	MP	11.8	4.7	16.5	11.5	19.8	14.9	1.3	15.1	11.7
9	surface	NEI	4.1	-0.2	-0.2	1.3	-0.6	4.1	1.3	0.9	0.6
10	surface	RB	13.7	0.4	10.1	10.7	13.4	6.8	1.3	6.3	13.1
11	surface	RFM	8.8	0.4	1.8	3.3	2.2	4.1	-0.8	0.2	0.6
12	surface	RP	5.5	1.0	-1.2	3.7	-0.4	5.8	-1.4	0.2	-0.4
13	surface	RW	9.0	2.9	0.9	7.4	-0.1	8.5	0.2	3.1	4.2
14	surface	ST	3.5	-0.8	5.2	2.1	9.1	2.4	-0.3	2.7	2.5
15	surface	TL	5.6	2.3	2.5	3.3	1.7	5.5	2.3	0.7	4.2
		Mean	**7.4**	**1.4**	**3.1**	**5.5**	**4.1**	**6.7**	**0.6**	**2.5**	**3.2**
		SD	**3.7**	**1.8**	**4.6**	**3.9**	**5.9**	**3.6**	**1.2**	**3.8**	**4.1**
1	phonological	GB	6.6	7.8	8.9	1.7	14.6	6.8	2.3	3.8	6.9
2	phonological	HI	0.9	1.6	1.4	-0.4	0.9	4.1	1.3	2.3	0.6
3	phonological	LF	1.0	3.5	0.4	2.1	0.2	6.8	1.8	0.7	1.7
4	phonological	LM	2.3	2.3	-0.8	1.7	-0.3	3.8	0.7	-1.1	0.9
5	phonological	MAN	0.2	2.3	-1.3	2.5	-1.4	6.2	1.8	0.0	1.2
6	phonological	MAR	2.2	3.5	-0.4	2.5	-0.7	1.4	-0.3	0.6	-1.0

7	phonological	MB	1.5	2.3	-0.5	3.3	0.9	2.4	-1.4	0.2	0.1
8	phonological	MD	4.2	5.9	0.7	0.5	1.2	5.5	1.3	0.7	1.7
9	phonological	PR	13.7	10.8	10.1	5.4	21.4	13.6	1.3	6.0	9.0
10	phonological	RK	1.8	2.3	-0.7	2.9	-0.9	0.4	-0.3	-0.2	1.7
11	phonological	RL	3.5	7.2	2.8	2.9	6.0	10.6	1.3	--	--
12	phonological	SA	1.6	5.3	-1.4	5.4	-1.4	10.2	2.3	1.7	0.9
13	phonological	SM	2.4	1.0	-0.8	3.7	-0.7	6.8	0.7	0.5	3.6
14	phonological	VT	0.6	3.5	0.6	-0.4	0.5	-0.3	1.3	0.4	0.6
15	phonological	YO	1.7	2.3	3.4	2.1	8.5	5.5	1.3	2.1	2.3
		Mean	**2.9**	**4.1**	**1.5**	**2.4**	**3.3**	**5.6**	**1.0**	**1.3**	**2.2**
		SD	**3.4**	**2.8**	**3.5**	**1.7**	**6.7**	**3.9**	**1.0**	**1.8**	**2.7**

APPENDIX 19. Individual z-scores (from the control mean) of the 15 surface dyslexics and 15 phonological dyslexics on the sublexical phonology tasks.

			Phonological STM			Phonological Awareness	
N	subgroup	name	Digit span	Nonword serial recall	Word serial recall	Phoneme counting	Spoonerisms
1	surface	AQ	-2.6	1.7	1.7	1.7	2.4
2	surface	AUD	-3.4	2.3	2.3	-0.5	3.4
3	surface	BH	-1	-0.9	0.7	-0.1	8.7
4	surface	CMD	-0.9	0.1	0.4	0.5	3.1
5	surface	JC	-2.3	1	1.1	-0.7	6.4
6	surface	KO	-1.9	0.6	1.1	1.5	7.7
7	surface	LL	-1.6	1.6	1.7	0.1	-0.2
8	surface	MP	-2	1.2	1.5	2.9	3.4
9	surface	NEI	-1	-0.2	-0.5	0.1	-0.2
10	surface	RB	-1.3	3.1	2.3	0.3	12.3
11	surface	RFM	-1.3	0.4	0.7	-0.1	9.5
12	surface	RP	-1.9	1.9	1.6	-0.1	-1
13	surface	RW	-0.7	-1.2	0.3	0.3	-0.7
14	surface	ST	-1.3	1.1	0.3	-0.1	3.4
15	surface	TL	-1.4	1.1	1.9	0.7	1.8
		Mean	**-1.6**	**0.9**	**1.1**	**0.4**	**4.0**
		SD	**0.7**	**1.2**	**0.8**	**0.9**	**4.1**
1	phonological	GB	-3.6	2.7	2.2	3.3	9.5
2	phonological	HI	-2.3	2.2	1.5	3.5	5.4
3	phonological	LF	-1.7	-0.1	0.2	-0.1	-0.7
4	phonological	LM	-1.7	1.1	1.2	1.9	3.9
5	phonological	MAN	-1.7	-0.5	0.7	0.1	-0.7
6	phonological	MAR	-1.3	0.2	0.1	-0.5	0.3

7	phonological	MB	0.1	0.5	0.1	1.9	1.1
8	phonological	MD	-0.7	1.3	1.3	2.3	4.4
9	phonological	PR	-2.3	4.4	2.4	3.9	12.6
10	phonological	RK	-0.4	-0.9	0.3	-0.7	-1
11	phonological	RL	-4	3.4	1.8	3.3	7.5
12	phonological	SA	-3.3	2.6	3.2	4.1	2.9
13	phonological	SM	-1.6	0.8	1.5	-0.5	3.9
14	phonological	VT	-1.4	0.9	1.8	-1	3
15	phonological	YO	-1.3	1.2	-0.1	4.1	3.6
		Mean	**-1.8**	**1.3**	**1.2**	**1.7**	**3.7**
		SD	**1.1**	**1.5**	**1.0**	**2.0**	**3.9**

APPENDIX 20. Individual z-scores (from the control mean) of the 15 surface dyslexics and 15 phonological dyslexics on the lexical learning, lexical-semantic learning and print exposure tasks.

			Lexical learning			**Lexical-semantic learning**				**Print exposure**
			English nonwords & Dutch words		**Russian words**	**Immediate**		**Delayed**		
N	**subgroup**	**name**	**spoken**	**written**	**written**	**WMS-R word pairs**	**RAVLT**	**WMS-R word pairs**	**RAVLT**	
1	surface	AQ	2.3	2.7	1.3	2.2	2.4	-0.4	1.5	-1.6
2	surface	AUD	1.9	2.9	1.0	0.9	1.5	-0.4	1.9	1.3
3	surface	BH	2.2	0.9	0.3	-0.5	0.3	-0.4	1.1	1.3
4	surface	CMD	2.3	3.6	0.7	-0.5	--	-0.4	--	0.9
5	surface	JC	0.3	1.7	0.3	-0.5	-0.5	-0.4	1.5	1.3
6	surface	KO	1.8	0.2	0.7	-1.1	-1.8	-0.4	-0.7	-0.4
7	surface	LL	2.2	1.6	0.8	0.2	0.5	-0.4	1.1	0.1
8	surface	MP	3.4	3.9	1.6	3.6	0.1	4.1	1.1	0.5
9	surface	NEI	0.5	1.5	0.8	1.5	-0.3	1.8	1.1	0.1
10	surface	RB	3.0	4.6	2.1	3.6	-0.5	1.8	-0.3	0.5
11	surface	RFM	2.3	1.8	0.8	-0.5	0.5	-0.4	1.9	-1.6
12	surface	RP	1.7	2.6	1.4	1.5	-0.5	-0.4	-0.7	-0.4
13	surface	RW	2.9	4.8	2.1	4.9	3.2	4.1	3.7	1.8
14	surface	ST	2.1	0.4	0.0	-0.5	-2.1	-0.4	-1.1	0.1
15	surface	TL	1.0	2.0	0.5	0.2	0.9	-0.4	3.2	-0.4
		Mean	**2.0**	**2.3**	**1.0**	**1.0**	**0.3**	**0.5**	**1.1**	**0.2**
		SD	**0.9**	**1.4**	**0.6**	**1.8**	**1.4**	**1.7**	**1.4**	**1.0**

1	phonological	GB	2.3	2.5	0.8	3.6	3.0	1.8	1.9	-0.4
2	phonological	HI	1.5	0.2	1.4	3.6	0.0	1.8	0.6	-2.0
3	phonological	LF	0.5	1.2	1.1	-1.1	-0.3	-0.4	-1.1	-0.4
4	phonological	LM	1.3	0.6	1.1	0.2	1.2	-0.4	1.1	0.5
5	phonological	MAN	0.8	0	0.7	0.2	1.2	-0.4	-0.3	-1.2
6	phonological	MAR	0.8	0.8	0.8	2.2	-0.6	-0.4	0.2	0.1
7	phonological	MB	1.5	0.7	0.5	-0.5	1.1	-0.4	0.6	-2.0
8	phonological	MD	2.5	2.7	0.7	2.2	1.7	-0.4	1.5	-0.4
9	phonological	PR	2.5	3.1	0.3	0.2	-1.4	-0.4	-0.7	--
10	phonological	RK	1.0	1.0	-0.9	-1.1	-1.4	-0.4	-0.7	1.3
11	phonological	RL	2.8	0.9	0.8	0.9	0.1	-0.4	1.1	--
12	phonological	SA	2.2	2.6	1.8	0.9	0.9	1.8	1.1	-2.0
13	phonological	SM	2.6	2.4	1.4	0.9	0.5	-0.4	0.6	2.2
14	phonological	VT	1.4	2.4	1.3	4.2	3.8	1.8	2.8	0.9
15	phonological	YO	0.9	-0.1	-0.8	-0.5	0.5	-0.4	0.2	-1.6
		Mean	**1.6**	**1.4**	**0.7**	**1.1**	**0.7**	**0.2**	**0.6**	**-0.4**
		SD	**0.8**	**1.1**	**0.8**	**1.7**	**1.4**	**1.0**	**1.1**	**1.4**

APPENDIX 21. Information sheets and consent forms for teachers, parents and children.

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APPENDIX 22. Rhyme Test of the Phonological Assessment Battery (Frederickson, Frith & Reason, 1997).

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APPENDIX 23. Spoonerisms Test of the Phonological Assessment Battery (Frederickson, Frith & Reason, 1997).

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APPENDIX 24. Individual z-scores (from the control children's mean) of the 44 dyslexic adults on the spelling and reading tasks of words and nonwords and the nonword serial recall task.

		Spelling		Reading Speed		Reading Accuracy	
N	name	words	nonwords	words	nonwords	words	nonwords
1	AQ	0.6	-0.3	1.1	0.0	-0.8	-0.1
2	AUD	0.4	-0.7	0.0	0.1	1.2	1.9
3	BH	0.7	0.4	1.2	1.4	1.7	1.9
4	CE	-1.0	-0.7	0.0	0.1	-1.0	-1.7
5	CH	-1.2	-1.1	-0.2	-0.3	-1.3	0.1
6	CMD	3.8	2.0	2.3	3.3	3.4	5.7
7	DS	0.0	0.0	1.4	2.5	-1.3	0.1
8	GB	0.6	3.9	7.1	7.4	-0.8	2.1
9	HI	-1.4	0.0	1.0	0.5	-1.6	0.7
10	HR	-0.9	-0.7	-1.4	-0.4	-1.4	-1.2
11	IM	-0.1	0.0	1.6	2.9	0.9	1.0
12	JC	-0.6	-1.9	0.7	1.8	-1.1	0.5
13	KO	0.4	0.0	2.4	1.5	1.7	2.3
14	LF	-1.4	1.2	0.2	0.1	-0.6	2.1
15	LL	0.0	-0.3	0.4	0.2	-0.6	2.8
16	LM	-0.9	0.4	-0.8	-0.2	-0.8	0.5
17	MAN	-1.7	0.4	-1.2	-0.7	-0.4	1.7
18	MAR	-1.0	1.2	-0.5	-0.4	-0.4	-0.8
19	MB	-1.2	0.4	-0.5	0.5	-0.1	-0.2
20	MD	-0.2	2.7	0.5	0.6	-1.3	1.4
21	MP	2.6	2.0	13.2	10.0	3.2	6.4
22	NAH	-1.4	-1.5	3.3	2.2	-1.8	0.5
23	NEI	-0.3	-1.1	-0.3	-0.3	-1.0	0.7
24	NH	2.6	3.5	6.7	10.0	0.2	3.0
25	NL	-0.1	-0.3	2.2	0.7	-0.1	1.4
26	NR	-0.7	-0.7	-0.1	-0.1	-0.8	-1.2

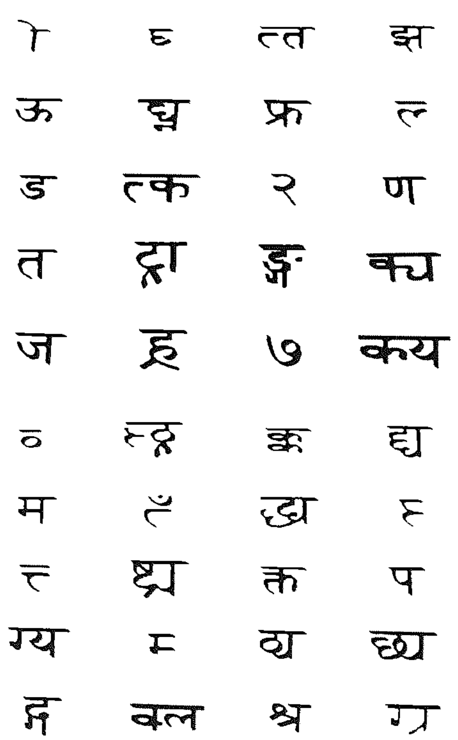
27	PR	3.2	5.8	8.1	10.8	0.7	5.7
28	PRI	-0.5	0.0	-0.8	-0.3	-0.4	0.1
29	RB	3.2	-0.7	8.1	6.8	2.9	2.1
30	RFM	1.5	-0.7	1.3	1.1	-0.1	0.7
31	RK	-1.1	0.4	-0.7	-0.5	-0.3	-1.3
32	RKI	0.7	0.8	-0.1	0.2	-0.6	3.0
33	RL	-0.5	3.5	2.2	3.0	-0.3	4.1
34	RP	0.3	-0.3	-1.1	-0.2	0.0	1.6
35	RW	1.5	0.8	0.6	-0.1	1.6	3.0
36	SA	-1.2	2.4	-1.2	-0.7	0.7	3.9
37	SI	0.2	0.4	1.3	1.6	0.6	3.4
38	SK	-0.7	0.0	0.8	0.0	-1.3	-0.1
39	SM	-0.9	-0.3	-0.8	-0.3	0.0	2.1
40	ST	-0.5	-1.5	4.1	4.6	-0.6	-0.2
41	TL	0.3	0.4	1.9	0.9	-0.1	1.4
42	VS	-1.0	-0.7	3.0	1.5	-0.6	1.9
43	VT	-1.6	1.2	0.4	0.2	-1.6	-1.7
44	YO	-1.1	0.4	2.6	4.3	-0.6	1.4
	Mean	**0.0**	**0.5**	**1.6**	**1.7**	**-0.1**	**1.4**
	SD	**1.4**	**1.6**	**3.0**	**3.0**	**1.3**	**1.9**

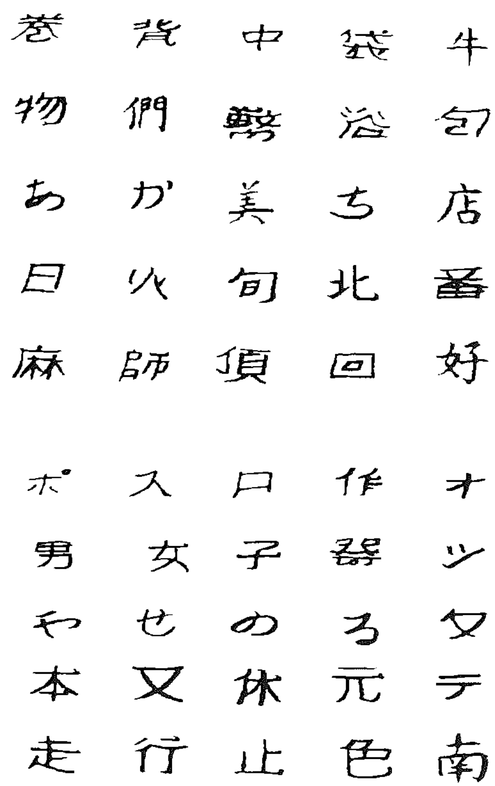
APPENDIX 25. Individual z-scores (from the control children's mean) of the 44 dyslexic adults on the nonword serial recall task.

N	name	Nonword serial recall
1	AQ	1.2
2	AUD	1.7
3	BH	-1.3
4	CE	-0.4
5	CH	0.9
6	CMD	-0.4
7	DS	1.7
8	GB	2.1
9	HI	1.6
10	HR	1.4
11	IM	-1.3
12	JC	0.5
13	KO	0.1
14	LF	-0.5
15	LL	1.1
16	LM	0.6
17	MAN	-0.9
18	MAR	-0.3
19	MB	0.0
20	MD	0.8
21	MP	0.7
22	NAH	-1.4
23	NEI	-0.6
24	NH	3.1
25	NL	0.1
26	NR	-1.3

27	PR	3.7
28	PRI	-0.5
29	RB	2.5
30	RFM	-0.1
31	RK	-1.3
32	RKI	0.5
33	RL	2.8
34	RP	1.3
35	RW	-1.6
36	SA	2.0
37	SI	0.7
38	SK	-0.6
39	SM	0.3
40	ST	0.6
41	TL	0.6
42	VS	-0.5
43	VT	0.4
44	YO	0.7
	Mean	**0.4**
	SD	**1.3**

APPENDIX 26. Hindi and Japanese characters.





APPENDIX 27. Identity and order conditions of the same-different array matching tasks of consonants and symbols.

CONSONANTS IDENTITY			CONSONANTS ORDER		
tnlrhcpd	tnlrhcpd	S	dflvcpsj	dflvcpsj	S
dnlrhbkw	dnlrhbkw	S	pvcjlsdf	pvcjlsdf	S
wjfsghnp	wjfsghnp	S	vcdplfjs	vcdplfjs	S
npqdfwch	npqdfwch	S	clvfpdsj	clvfpdsj	S
npxzjbct	npxzjbct	S	fdcjvslp	fdcjvslp	S
bchjsglr	bchjsglr	S	vdsflpcj	vdsflpcj	S
dfsglrnp	dfsglrnp	S	jdvclspf	jdvclspf	S
bksgzxvn	cjsgzxvn	D	cdjvfpsl	dcjvfpsl	D
hkrdsgzq	hcpdsgzq	D	fvjcldsp	fjvcldsp	D
sgrqdtph	sgzcdtph	D	pdfslvjc	pdsflvjc	D
tkvntghj	tkvfsghj	D	lpvdjsfc	lpvjdsfc	D
bhdlgqkv	bhdlrtkv	D	fcljsdpv	fcljdspv	D
hdqnpkxm	hdqnpwfm	D	vfpcsdlj	vfpcsldj	D
dfsglrtq	dfsglrnp	D	ddsflpcj	vdsflpjc	D

SYMBOLS IDENTITY

SYMBOLS ORDER

–·~!@£¦$	–·~!@£¦$	S	!%\<#@*&	!%\<#@*&
·–£¦$%<¥	·–£¦$%<¥	S	@\!#%*<&	@\!#%*<&
%~*–·<Ã#	%~*–·<Ã#	S	%#!*<\@&	%#!*<\@&
´¹¢@£–!%	´¹¢@£–!%	S	\<@&#!*%	\<@&#!*%
~!@£¦$%<	~!@£¦$%<	S	#&\!<@%*	#&\!<@%*
Æ%~°!¢@¥	Æ%~°!¢@¥	S	<*\!#&%@	<*\!#&%@
<¦$(°¥*#	<¦$(°¥*#	S	&#\!*%<@	&#\!*%<@
~*¦$ÆÃ#´	!<¦$ÆÃ#´	D	!%\<#@*£	%!\<#@*£
¦£*°´¹¢@	¦$(°´¹¢@	D	&<%*#\@!	&%<*#\@!
*#<%@(°´	*#~!@(°´	D	<!#%&@*	<!%#&@*
<Ã#~*´(°	<Ã#£¥´(°	D	&@\!<#%*	&@\<!#%*
~%@($¢*#	~%@(°¥*#	D	\<@&#!*%	\<@&!#*%
–·<¦$~£Æ	–·<¦$(ÃÆ	D	<&!*@\#%	<&!*@#\%
¥(°*#¢´£	¥(°*#¢@·	D	<\@&#!*%	<\@&#!%*

APPENDIX 28. Individual z-scores (from the control mean) of the smaller group of dyslexics on the orthographic tasks of spelling and reading.

N	name	Spelling		Reading Speed		Reading Accuracy		Reading Comprehension	Text Reading	
		words	nonwords	words	nonwords	words	nonwords	words	Speed	Accuracy
1	AQ	6.2	0.7	2.3	1.7	0.1	3.6	2.3	0.9	0.6
2	AUD	5.8	0.1	0.6	7.1	0.4	8.5	3.6	0.9	4.6
3	BH	6.5	2	2.5	8.4	3.1	8.5	0.4	1.6	7.4
4	DS	4.5	1.4	2.8	0.3	5.4	4.1	-0.2	-0.7	1.0
5	IM	4.3	1.4	3.1	6.2	6.3	6.3	1.1	1.5	6.2
6	JC	3.2	-1.8	1.7	0.8	4	4.9	0.4	0.4	0.6
7	KO	5.7	1.4	4.4	8.4	3.3	9.4	0.4	-0.1	0.6
8	LM	2.2	2	-0.5	1.7	-0.2	4.9	1.1	-1.2	1.8
9	MAN	0.2	2	-1.2	2.6	-1.3	8.1	2.3	-0.2	2.2
10	MAR	2.1	3.3	-0.1	2.6	-0.6	1.8	-0.2	0.2	-1.0
11	MB	1.4	2	-0.2	3.5	1.1	3.2	-1.4	-0.1	0.6
12	MD	4.1	5.9	1.4	0.3	1.5	7.2	1.7	0.3	3.0
13	NAH	0.8	-1.2	5.8	-1	4.9	4.9	1.1	-0.3	-0.6
14	NR	2.9	0.1	0.5	1.7	-0.1	0.9	-0.8	0.5	0.6
15	RFM	8.5	0.1	2.7	3.5	2.6	5.4	-0.8	-0.1	1.4
16	RK	1.7	2	-0.4	3	-0.8	0.5	-0.2	-0.5	3.0
17	RP	5.3	0.7	-1	3.9	-0.2	7.6	-1.4	-0.2	-0.2
18	SA	1.5	5.2	-1.3	5.7	-1.4	13.4	2.9	1.2	1.8
19	SI	5.3	2	2.7	5.3	3.5	12.1	-0.2	1.7	6.2
20	SK	2.8	1.4	2	0.3	0.2	3.6	0.4	-0.5	1.8
21	SM	2.3	0.7	-0.6	3.9	-0.5	9	1.1	0.2	5.8
22	ST	3.3	-1.2	7	2.1	9.8	3.2	-0.2	2.1	4.2
23	TL	5.4	2	3.6	3.5	2	7.2	2.9	0.4	6.6
24	VS	2	0.1	5.2	2.1	3.4	8.5	1.1	0.9	2.2
25	YO	1.6	2	4.7	2.1	9.3	7.2	1.7	1.6	3.8
	Mean	**3.6**	**1.4**	**1.9**	**3.2**	**2.2**	**6.2**	**0.8**	**0.4**	**2.5**
	SD	**2.1**	**1.7**	**2.3**	**2.5**	**3.1**	**3.2**	**1.4**	**0.9**	**2.4**

APPENDIX 29. Individual z-scores (from the control mean) of the smaller group of dyslexics on the sublexical phonology tasks.

N	name	Digit span	Nonword Serial Recall	Word Serial Recall	Phoneme Counting	Spoonerisms
1	AQ	-3.2	2.7	1.7	2.5	3.2
2	AUD	-4.2	3.3	2.3	-0.2	4.4
3	BH	-1.3	-0.6	0.7	0.3	10.5
4	DS	-3.5	3.3	2.7	4.5	2.9
5	IM	1.5	-0.6	-1.8	0.0	0.0
6	JC	-2.8	1.7	1.1	-0.5	7.9
7	KO	-2.3	1.2	1.1	2.2	9.3
8	LM	-2.2	1.9	1.2	2.7	4.9
9	MAN	-2.2	-0.1	0.7	0.5	-0.3
10	MAR	-1.7	0.7	0.1	-0.2	0.9
11	MB	0.0	1.1	0.1	2.7	1.7
12	MD	-1.0	2.1	1.3	3.2	5.5
13	NAH	0.8	-0.7	0.0	0.3	1.7
14	NR	-1.8	-0.6	-0.6	2.2	-0.6
15	RFM	-1.7	1.0	0.7	0.3	11.4
16	RK	-0.7	-0.6	0.3	-0.5	-0.6
17	RP	-2.3	2.8	1.6	0.3	-0.6
18	SA	-4.0	3.7	3.3	5.5	3.8
19	SI	-3.3	2.0	-1.0	1.5	2.0
20	SK	0.7	0.3	0.5	-0.2	2.6
21	SM	-2.0	1.5	1.6	-0.2	4.9
22	ST	-1.7	1.9	0.3	0.3	4.4
23	TL	-1.8	1.9	1.9	1.2	2.6
24	VS	-2.3	0.5	0.4	0.0	0.0
25	YO	-1.7	2.0	-0.1	5.5	4.7
	Mean	**-1.8**	**1.3**	**0.8**	**1.3**	**3.6**
	SD	**1.4**	**1.3**	**1.1**	**1.8**	**3.4**

APPENDIX 30. Individual z-scores (from the control mean) of the large group of dyslexics on the visuospatial learning and recognition tasks.

			D&P			
N	**name**	**WMS-R Visual Memory**	**Learning immediate**	**Learning delayed**	**Recognition**	**H&J Recognition**
1	AQ	-0.2	-0.5	-0.5	1.3	0.8
2	AUD	-2.5	-0.5	-0.5	0.6	-0.4
3	BH	-1.1	-0.5	-0.5	1.7	0.2
4	CE	-0.4	--	--	--	-0.4
5	CH	--	-0.5	-0.5	1.0	0.0
6	CMD	-0.5	-0.5	1.4	0.6	1.4
7	DS	0.2	-0.5	-0.5	4.2	-0.5
8	GB	-1.1	-0.5	0.5	-0.5	0.5
9	HI	-1.1	--	--	--	-0.8
10	HR	0.5	-0.5	-0.5	-0.5	-0.3
11	IM	0.4	-0.5	-0.5	0.6	-1.2
12	JC	0.0	-0.5	-0.5	0.3	-0.1
13	KO	0.5	-0.5	-0.5	-0.5	-0.5
14	LF	-0.9	-0.5	3.4	-0.8	-0.4
15	LL	0.2	-0.5	1.4	-1.2	0.6
16	LM	0.2	-0.5	-0.5	-0.5	0.5
17	MAN	-1.5	-0.5	-0.5	-1.2	0.1
18	MAR	0.4	-0.5	-0.5	0.3	1.6
19	MB	-0.7	-0.5	-0.5	1.3	0.6
20	MD	-0.5	1.5	-0.5	0.6	0.7
21	MP	-1.6	-0.1	-0.5	-0.5	-0.2
22	NAH	0.2	--	-0.5	--	-1.7
23	NEI	-0.4	0.7	--	-1.5	0.1
24	NH	-1.5	-0.5	1.4	-1.2	0.3
25	NL	-2.0	-0.5	-0.5	1.3	0.1
26	NR	1.5	-0.5	1.4	2.4	0.6

27	PR	0.0	--	--	--	-1.3
28	PRI	-0.2	-0.5	-0.5	0.6	0.6
29	RB	-1.5	1.1	1.4	-1.2	1.6
30	RFM	0.5	-0.5	-0.5	1.3	0.2
31	RK	0.2	-0.5	-0.5	-0.1	-0.5
32	RKI		0.7	-0.5	0.3	-0.4
33	RL	-0.2	-0.1	-0.5	-0.5	1.4
34	RP	-1.3	-0.5	1.4	1.0	0.9
35	RW	-1.6	-0.5	-0.5	1.0	1.5
36	SA	-1.5	3.5	1.4	2.8	0.5
37	SI	0.9	-0.5	-0.5	-1.5	-0.7
38	SK	-1.1	-0.5	-0.5	-0.1	-0.4
39	SM	0.9	-0.5	-0.5	1.3	0.2
40	ST	0.5	-0.5	-0.5	-1.5	-2.1
41	TL	-1.3	-0.5	-0.5	2.4	0.7
42	VS	0.9	--	--	--	-1.3
43	VT	-0.5	-0.5	-0.5	1.3	-0.4
44	YO	-0.7	-0.5	-0.5	0.3	-0.2
	Mean	**-0.4**	**-0.2**	**-0.1**	**0.4**	**0.0**
	SD	**0.9**	**0.8**	**1.0**	**1.3**	**0.9**

APPENDIX 31. Individual z-scores (from the control mean) of the <u>smaller</u> group of dyslexics on the visuospatial learning and recognition tasks.

N	name	WMS-R Visual Memory	D&P Visual Learning immediate	D&P Visual Learning delayed	D&P Visual Recognition	H&J Recognition
1	AQ	-2.4	-0.4	-0.5	0.8	1.3
2	AUD	-1.7	-0.4	-0.5	0.2	-0.2
3	BH	-0.2	-0.4	-0.5	1.2	0.6
4	DS	-1.8	-0.4	-0.5	3.5	-0.3
5	IM	-1.7	-0.4	-0.5	0.2	-1.1
6	JC	-0.3	-0.4	-0.5	-0.2	0.2
7	KO	0.4	-0.4	-0.5	-0.8	-0.3
8	LM	-0.4	-0.4	-0.5	-0.8	0.9
9	MAN	-0.2	-0.4	-0.5	-1.5	0.4
10	MAR	1.1	-0.4	-0.5	-0.2	2.3
11	MB	-1.1	-0.4	-0.5	0.8	1.0
12	MD	-1.3	2.6	-0.5	0.2	1.1
13	NAH	-1.0	--	--	--	-1.7
14	NR	0.0	-0.4	2.2	1.8	1.1
15	RFM	-2.1	-0.4	-0.5	0.8	0.5
16	RK	0.0	-0.4	-0.5	-0.5	-0.3
17	RP	-1.0	-0.4	2.2	0.5	1.4
18	SA	-2.1	5.5	2.2	2.2	0.9
19	SI	-1.1	-0.4	-0.5	-1.8	-0.6
20	SK	-0.5	-0.4	-0.5	-0.5	-0.2
21	SM	-2.5	-0.4	-0.5	0.8	0.6
22	ST	-1.7	-0.4	-0.5	-1.8	-2.3
23	TL	-1.4	-0.4	-0.5	1.8	1.2
24	VS	0.3	--	--	--	-1.3
25	YO	0.3	-0.4	-0.5	-0.2	0.0
	Mean	**-0.9**	**0.0**	**-0.1**	**0.3**	**0.2**
	SD	**1.0**	**1.4**	**0.9**	**1.3**	**1.1**

APPENDIX 32. Individual z-scores (from the control mean) of the large group of dyslexics on the sorting and recognition condition of the Hindi and Japanese tasks.

		H&J SORTING						H&J RECOGNITION					
		Simultaneous			Sequential			from Simultaneous			from Sequential		
N	name	Hindi	Japanese	Total	Hindi	Japanese	Total	Hindi	Japanese	Total	Hindi	Japanese	Total
1	AQ	2.6	-0.3	1.0	2.1	2.2	2.3	0.2	0.8	0.5	0.5	1.4	1.1
2	AUD	1.1	0.4	0.8	0.6	0.8	0.8	-0.8	-0.1	-0.4	-0.3	-0.2	-0.3
3	BH	1.1	0.5	0.9	0.5	0.8	0.7	0.3	0.6	0.5	-0.2	-0.1	-0.1
4	CE	-1.0	-0.3	-0.7	1.2	2.2	1.9	0.5	-0.7	-0.1	-0.2	-0.8	-0.6
5	CH	-1.0	0.2	-0.3	-0.2	0.6	0.2	-0.2	-0.2	-0.2	0.8	-0.2	0.3
6	CMD	-1.0	1.0	0.3	1.2	0.9	1.1	1.2	1.2	1.3	1.8	0.8	1.4
7	DS	-0.8	-0.6	-0.8	0.3	0.2	0.2	-0.3	0.3	0.0	-0.5	-1.3	-1.1
8	GB	0.3	0.8	0.7	2.4	1.1	1.9	0.5	-0.5	0.0	1.5	0.4	1.0
9	HI	0.3	0.6	0.6	2.2	0.3	1.3	-0.5	-1.5	-1.1	0.0	-0.6	-0.4
10	HR	-2.1	0.1	-0.9	0.3	0.0	0.1	-1.7	-0.7	-1.3	0.2	1.0	0.7
11	IM	-0.2	-0.2	-0.2	1.2	-0.8	0.1	-0.3	-1.8	-1.2	-0.6	-1.3	-1.1
12	JC	0.9	0.8	1.0	0.3	1.4	1.0	0.6	-0.2	0.2	0.0	-0.5	-0.3
13	KO	-0.2	0.6	0.4	0.6	-0.3	0.1	-0.6	-0.9	-0.9	0.2	-0.2	-0.1
14	LF	0.9	-0.4	0.1	1.0	2.0	1.7	-0.3	-0.2	-0.3	0.0	-0.8	-0.5
15	LL	0.7	0.6	0.8	0.3	1.4	1.0	0.6	0.6	0.7	0.6	0.2	0.4
16	LM	0.9	0.5	0.8	2.8	1.4	2.2	0.8	-0.9	-0.1	2.1	-0.1	1.0
17	MAN	0.3	0.1	0.2	-0.6	0.6	0.1	0.0	0.5	0.3	0.2	-0.4	-0.1
18	MAR	0.9	-0.4	0.1	1.7	2.8	2.5	0.6	1.6	1.2	0.8	2.3	1.8
19	MB	-0.4	-0.6	-0.6	-0.1	-0.8	-0.5	0.9	-1.1	-0.1	0.2	1.9	1.3
20	MD	0.3	0.5	0.5	1.3	2.2	2.0	0.2	0.8	0.5	0.3	1.0	0.8
21	MP	0.3	1.6	1.3	0.8	2.6	2.0	-0.2	-0.7	-0.4	0.6	-0.4	0.1
22	NAH	-1.4	-1.2	-1.5	-0.6	-0.5	-0.6	-1.7	-1.5	-1.7	-0.5	-2.0	-1.5
23	NEI	1.7	-0.3	0.6	1.5	1.5	1.7	0.5	-0.7	-0.1	1.1	-0.4	0.4
24	NH	1.3	1.0	1.4	3.7	1.8	3.0	2.0	-1.2	0.4	0.8	-0.2	0.3
25	NL	0.0	0.1	0.1	1.2	1.4	1.4	0.3	-0.5	-0.1	0.8	-0.2	0.3
26	NR	-0.2	1.2	0.8	1.5	1.5	1.7	0.9	0.1	0.5	-0.3	1.4	0.7

27	PR	1.5	-0.2	0.6	1.0	2.2	1.8	-0.8	-1.4	-1.2	-1.1	-1.3	-1.4
28	PRI	-1.9	0.0	-0.9	0.1	-0.8	-0.4	0.2	0.9	0.6	0.2	0.8	0.6
29	RB	0.9	0.4	0.7	2.6	2.5	2.8	1.4	0.9	1.2	1.8	1.5	1.8
30	RFM	3.2	0.0	1.4	1.3	-0.3	0.5	0.5	-0.1	0.2	0.8	-0.5	0.1
31	RK	-1.9	-1.6	-2.0	0.6	-0.5	0.1	-0.9	-0.9	-1.0	0.2	0.0	0.1
32	RKI	0.9	1.7	1.6	0.5	1.1	0.9	-0.8	0.1	-0.4	0.3	-1.0	-0.5
33	RL	1.5	1.0	1.4	1.3	1.2	1.4	0.5	1.8	1.2	1.0	1.5	1.4
34	RP	0.7	0.5	0.7	1.3	1.8	1.8	1.9	0.8	1.4	1.0	-0.4	0.3
35	RW	0.3	-0.2	0.0	0.1	0.6	0.4	0.9	1.3	1.2	1.0	1.8	1.6
36	SA	0.9	0.4	0.7	1.9	0.9	1.5	0.8	0.1	0.4	0.6	0.2	0.4
37	SI	-1.7	-0.8	-1.4	-0.8	-1.4	-1.2	-0.5	-1.1	-0.9	-0.5	-0.5	-0.6
38	SK	-1.4	0.5	-0.3	0.8	1.5	1.3	-0.8	-0.5	-0.7	-0.5	0.2	-0.1
39	SM	0.7	0.2	0.5	-0.4	-0.6	-0.6	0.8	0.3	0.6	-0.3	-0.1	-0.2
40	ST	-0.2	-0.8	-0.7	-0.6	-1.1	-0.9	-0.9	-3.2	-2.3	-0.6	-2.4	-1.8
41	TL	0.3	-0.2	0.0	0.3	0.2	0.2	0.9	0.1	0.5	1.5	0.2	0.9
42	VS	-0.2	0.5	0.3	-0.2	0.0	-0.1	-0.6	-1.7	-1.3	-1.6	-0.8	-1.3
43	VT	0.3	0.5	0.5	1.3	0.9	1.2	-0.2	-0.7	-0.4	-1.1	0.4	-0.3
44	YO	-0.2	0.5	0.3	-0.4	0.2	-0.1	-0.5	-0.2	-0.4	-0.2	0.0	-0.1
	Mean	**0.2**	**0.2**	**0.2**	**0.9**	**0.8**	**0.9**	**0.1**	**-0.2**	**-0.1**	**0.3**	**0.0**	**0.1**
	SD	**1.1**	**0.7**	**0.8**	**1.0**	**1.1**	**1.0**	**0.8**	**1.0**	**0.9**	**0.8**	**1.0**	**0.9**

APPENDIX 33. Individual z-scores (from the control mean) of the smaller group of dyslexics on the sorting and recognition condition of the Hindi and Japanese tasks.

		H&J SORTING						H&J RECOGNITION					
		Simultaneous			Sequential			from Simultaneous			from Sequential		
N	name	Hindi	Japanese	Total	Hindi	Japanese	Total	Hindi	Japanese	Total	Hindi	Japanese	Total
1	AQ	3.1	0.0	1.3	4.0	2.8	3.9	0.3	1.4	0.9	0.8	1.9	1.7
2	AUD	1.5	0.7	1.1	1.6	1.2	1.6	-0.7	0.3	-0.2	-0.3	0.1	-0.1
3	BH	1.5	0.8	1.2	1.3	1.2	1.5	0.4	1.2	0.9	-0.1	0.2	0.1
4	CE	-0.7	-0.3	-0.5	1.0	0.5	0.8	-0.2	0.9	0.3	-0.5	-1.1	-1.0
5	CH	0.0	0.1	0.1	2.5	-0.5	0.7	-0.2	-1.7	-1.1	-0.7	-1.1	-1.2
6	CMD	1.2	1.1	1.3	1.0	1.9	1.9	0.7	0.2	0.5	0.2	-0.2	-0.1
7	DS	0.0	0.9	0.7	1.6	0.0	0.7	-0.5	-0.7	-0.7	0.4	0.1	0.2
8	GB	1.2	0.8	1.1	5.2	1.9	3.8	0.9	-0.7	0.2	3.0	0.2	1.6
9	HI	0.5	0.4	0.5	-0.5	1.0	0.6	0.1	1.0	0.6	0.4	-0.1	0.1
10	HR	1.2	-0.2	0.4	3.4	3.5	4.2	0.7	2.4	1.7	1.2	2.9	2.7
11	IM	-0.2	-0.3	-0.3	0.4	-0.5	-0.2	1.1	-0.9	0.2	0.4	2.4	1.9
12	JC	0.5	0.8	0.8	2.8	2.8	3.4	0.3	1.4	0.9	0.6	1.4	1.3
13	KO	-1.4	-1.0	-1.3	-0.5	-0.2	-0.4	-1.7	-1.4	-1.7	-0.5	-1.9	-1.6
14	LF	0	1.5	1.1	3.1	2.1	3.0	1.1	0.5	0.9	-0.3	1.9	1.2
15	LL	3.8	0.2	1.8	2.8	0.0	1.2	0.6	0.3	0.5	1.2	-0.2	0.4
16	LM	-1.8	-1.4	-1.9	1.6	-0.2	0.6	-0.9	-0.7	-0.9	0.4	0.4	0.4
17	MAN	1.0	0.8	1.0	2.8	2.4	3.1	2.0	1.4	1.9	1.4	-0.1	0.7
18	MAR	1.2	0.7	1.0	3.7	1.4	2.7	0.9	0.5	0.8	1.0	0.5	0.9
19	MB	-1.6	-0.6	-1.1	-0.8	-1.2	-1.3	-0.4	-0.9	-0.7	-0.5	-0.2	-0.4
20	MD	-1.4	0.8	0	1.9	2.1	2.4	-0.7	-0.2	-0.5	-0.5	0.5	0.1
21	MP	1.0	0.5	0.8	-0.2	-0.4	-0.4	0.9	0.9	1.0	-0.3	0.2	0.0
22	NAH	0.0	-0.6	-0.4	-0.5	-0.9	-0.9	-0.9	-3.4	-2.3	-0.7	-2.3	-2.0
23	NEI	0.5	0.1	0.3	1.0	0.5	0.8	1.1	0.5	0.9	2.1	0.5	1.4
24	NH	0.0	0.8	0.6	0.1	0.3	0.3	-0.5	-1.6	-1.1	-2.0	-0.5	-1.4
25	NL	0.0	0.8	0.6	-0.2	0.5	0.3	-0.4	0.2	-0.1	-0.1	0.4	0.2
	Mean	**0.5**	**0.3**	**0.4**	**1.6**	**0.9**	**1.4**	**0.2**	**0**	**0.1**	**0.3**	**0.2**	**0.3**
	SD	**1.3**	**0.7**	**0.9**	**1.6**	**1.3**	**1.6**	**0.8**	**1.3**	**1**	**1**	**1.2**	**1.2**

APPENDIX 34. Individual z-scores (from the control mean) of the 25 dyslexics on the identity and order conditions of the same-different array matching tasks.

		CONSONANTS				SYMBOLS			
		Identity		Order		Identity		Order	
N.	**name**	**RT**	**Errors**	**RT**	**Errors**	**RT**	**Errors**	**RT**	**Errors**
1	AQ	0.4	0.2	-0.5	3.2	-0.3	0.1	-1.3	4.6
2	AUD	1.7	0.5	0.5	1.1	0.2	0.9	-0.4	2.8
3	BH	1.6	-0.4	0.2	-0.1	0.2	0.1	0.7	-0.3
4	DS	2.2	3.8	4.8	4.4	-0.5	0.1	-1.2	2.2
5	IM	0.0	4.5	-0.7	3.0	-0.4	1.5	-0.4	4.0
6	JC	4.4	1.1	1.2	1.7	2.1	0.5	3.6	0.9
7	KO	0.2	-1.0	-1.3	3.6	-0.6	0.9	-1.4	1.3
8	LM	-0.8	2.3	-0.4	3.0	0.2	2.5	3.4	2.8
9	MAN	1.3	0.8	-0.3	-0.8	-0.1	-0.5	0.1	-1.3
10	MAR	-1.0	-1.0	-0.2	2.6	0.2	1.5	-0.5	2.6
11	MB	-1.3	4.2	-0.4	0.7	0.1	-0.5	-0.2	0.5
12	MD	4.1	1.1	2.0	-0.1	0.2	-0.3	-0.1	2.2
13	NAH	1.5	2.6	-0.3	2.8	-0.4	1.5	-0.3	2.2
14	NR	2.3	-0.4	1.6	0.7	1.1	-0.7	1.0	-0.3
15	RFM	4.1	-0.4	0.0	1.5	-0.8	1.5	-1.0	3.0
16	RK	0.9	-1.0	-0.1	-1.2	-0.3	-0.1	-0.8	-0.1
17	RP	5.2	1.1	1.6	0.1	1.1	-0.3	1.0	-0.9
18	SA	0.4	-0.4	0.1	0.1	-1.0	1.1	0.5	1.3
19	SI	1.1	1.1	0.2	0.3	0.2	-0.3	-0.1	0.9
20	SK	-0.2	0.8	-0.2	0.7	-1.0	-0.1	-0.3	-0.5
21	SM	1.0	0.2	-0.1	0.9	-0.4	1.9	-1.0	-0.1
22	ST	0.9	0.8	0.1	0.7	0.3	-0.7	-0.2	1.8
23	TL	1.5	2.0	1.6	2.1	-0.6	2.1	0.6	2.8
24	VS	1.9	0.5	0.6	-0.1	0.5	-0.5	0.9	-0.5
25	YO	0.1	0.5	-0.8	-0.6	-0.8	-0.5	-0.7	-0.9
	Mean	**1.3**	**1.0**	**0.4**	**1.2**	**0.0**	**0.5**	**0.1**	**1.2**
	SD	**1.7**	**1.5**	**1.2**	**1.5**	**0.7**	**1.0**	**1.2**	**1.6**

APPENDIX 35. Individual z-scores (from the control mean) of the 25 dyslexics on the identity and order conditions of the 'same' and 'different' trials of the array matching tasks.

		CONSONANTS								SYMBOLS							
		Identity				Order				Identity				Order			
		Same		Different		Same		Different		Same		Different		Same		Different	
N	name	RT	Errors	RT	Errors	RT	Errors	RT	Errors	RT	Errors	RT	Errors	RT	Errors	RT	Errors
1	AQ	-0.2	-0.8	1.4	0.8	-0.9	-0.7	0.6	3.6	-0.6	-0.7	0.0	0.4	-1.8	-0.6	0.2	5.6
2	AUD	1.3	0.4	1.9	0.4	0.3	0.2	0.8	1.1	0.1	-0.1	0.3	1.2	-0.5	1.2	-0.5	3.0
3	BH	1.4	-0.2	1.7	-0.4	0.2	0.2	0.3	-0.2	0.2	-0.7	0.2	0.4	0.9	-0.6	0.3	0.0
4	CE	1.1	-0.2	3.9	5.2	3.6	-0.7	5.2	4.9	-0.7	-0.7	-0.2	0.4	-1.3	1.2	-1.1	2.3
5	CH	-0.3	1.0	0.5	5.2	-0.8	2.0	-0.4	2.7	-0.6	0.6	-0.1	1.7	-0.9	0.3	0.2	4.7
6	CMD	3.2	-0.8	5.6	2.0	0.7	-0.7	1.7	2.0	1.7	-0.7	2.4	0.9	3.3	1.2	3.6	0.9
7	DS	-0.3	-0.2	1.1	3.2	-1.5	0.2	-0.5	3.8	-0.8	0.6	-0.3	0.9	-1.7	-0.6	-0.9	1.9
8	GB	-0.7	0.4	-0.9	0.8	-0.5	4.7	-0.4	2.0	-0.1	-0.1	0.6	3.2	2.4	1.2	4.5	3.0
9	HI	1.5	-0.8	0.9	-0.8	-0.1	-0.7	-0.6	-0.6	-0.2	-0.7	0.0	-0.4	0.2	-0.6	0.0	-1.2
10	HR	-1.1	0.4	-0.7	5.2	-0.3	0.2	-0.2	2.7	-0.2	-0.7	0.8	2.2	-0.7	1.2	-0.3	2.8
11	IM	-1.0	-0.8	-1.7	2.0	-0.5	0.2	-0.2	0.7	0.4	-0.7	-0.3	-0.4	-0.2	1.2	-0.2	0.5
12	JC	3.6	-0.8	4.2	-0.8	1.4	-0.7	2.6	0.0	0.2	-0.1	0.2	-0.4	-0.3	1.2	0.1	2.3
13	KO	0.8	-0.2	2.6	3.6	-0.4	-0.7	-0.5	3.1	-0.8	-0.7	0.1	2.2	-0.8	-0.6	0.4	2.8
14	LF	2.0	-0.2	2.5	0.0	1.0	0.2	2.2	0.7	1.1	-0.1	1.2	-0.9	0.7	-0.6	1.3	0.0
15	LL	2.8	-0.8	5.7	0.0	-0.2	-0.7	0.3	1.8	-0.9	0.6	-0.6	1.7	-1.3	0.3	-0.5	3.5
16	LM	0.9	0.4	0.9	-0.8	-0.1	-0.7	0.0	-1.1	-0.3	-0.1	-0.2	-0.1	-0.8	0.3	-0.7	0.0
17	MAN	3.9	-0.2	6.6	1.6	1.1	-0.7	2.3	0.2	1.3	-0.7	0.6	-0.1	1.0	-0.6	0.9	-0.7
18	MAR	0.1	-0.8	0.9	0.0	-0.2	1.1	0.7	-0.2	-1.0	-0.7	-1.0	1.7	0.0	-0.6	1.1	1.9
19	MB	1.0	2.8	1.3	-0.4	0.2	2.9	0.3	-0.4	-0.6	-0.1	-0.2	2.4	-0.1	1.2	-0.1	0.9
20	MD	-0.2	1.0	-0.2	0.4	-0.4	-0.7	0.3	0.9	0.3	-0.1	0.0	-0.4	-0.4	-0.6	-0.2	-0.2
21	MP	1.0	-0.8	0.7	0.8	0.0	0.2	-0.2	0.9	-1.1	-0.7	-0.9	0.2	-1.1	0.3	-0.8	0.0
22	NAH	0.8	-0.2	0.7	1.2	0.0	-0.7	0.2	0.9	0.5	-0.1	0.1	-0.9	-0.6	0.3	0.2	2.1
23	NEI	1.0	-0.2	2.0	2.8	1.3	1.1	1.7	2.0	-0.8	-0.7	-0.6	2.9	0.4	1.2	0.6	3.0
24	NH	1.7	0.4	1.9	0.4	0.6	-0.7	0.4	0.0	0.9	-0.1	0.1	-0.6	0.9	1.2	0.8	0.9
25	NL	0.1	1.0	0.0	0.0	-0.5	-0.7	-1.1	-0.4	-0.7	-0.1	-1.0	-0.6	-0.7	1.2	-0.6	-1.2
	Mean	**1.0**	**0.0**	**1.7**	**1.3**	**0.2**	**0.1**	**0.6**	**1.2**	**-0.1**	**-0.3**	**0.0**	**0.7**	**-0.1**	**0.3**	**0.3**	**1.6**
	SD	**1.4**	**0.8**	**2.1**	**1.9**	1.0	**1.4**	**1.4**	**1.6**	**0.8**	**0.4**	**0.7**	**1.2**	**1.2**	**0.8**	**1.3**	**1.8**

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