# Predictors of Exception Word and Nonword Reading in Dyslexic Children: The Severity Hypothesis

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Abstract

The classification of dyslexic children into discrete subtypes yields a poor description of the dyslexic population at large. **M**ultiple regression methods were used to examine continuous variation in component reading subskills (nonword and exception word reading) and their underlying cognitive skills within a group of 59 9-15 year-old dyslexic children. Two measures of phonological skills contributed unique variance to nonword reading: phonological processing and verbal short-term memory skills. In contrast, the only unique predictor of exception word reading was reading experience. The results are discussed within a connectionist framework that views the decoding deficit in dyslexia as stemming from poorly specified phonological representations. The extent of the nonword reading deficit is determined by the severity of the underlying phonological impairment. In contrast, exception word reading is influenced more by print exposure.

# Predictors of Nonword Reading in Dyslexic Children.

The strong developmental association between phonological skills and learning to read (Fowler, 1991; Goswami & Bryant, 1990; Share, 1995) provides a back-drop to the theory that the proximal cause of developmental dyslexia is a phonological processing deficit (Brady & Shankweiler, 1991; Morton & Frith, 1995; Snowling, 2000; Stanovich & Siegel, 1994). Within this view, literacy development is affected in dyslexic children who come to the task of reading with poorly specified phonological representations (Elbro, Borstrom & Petersen, 1998; Hulme & Snowling, 1992).

However, cases of children with dyslexia **who** do not have a phonological processing impairment(Castles & Coltheart, 1996; Goulandris & Snowling, 1991; Hanley, Hastie & Kay, 1992) pose a problem for the phonological deficit hypothesis. In contrast to dyslexic children with poor nonword reading (phonological dyslexia; Campbell & Butterworth, 1985; Hulme & Snowling, 1992; Temple & Marshall, 1983), developmental surface dyslexic children place extensive reliance on phonological strategies for reading and spelling (Coltheart, Masterson, Byng, Prior & Riddoch, 1983).

Individual differences in dyslexia have been conceptualised using dual-route (Castles & Coltheart, 1993) and connectionist (Seidenberg & McClelland, 1989) models of reading. According to the dual-route model, reading can be accomplished either by a direct reading system involving mappings between printed words and their meanings, or by a phonological system incorporating grapheme-phoneme correspondences. The direct route is used for reading exception words and familiar regular words, whereas nonwords have to be read using the phonological reading system. In contrast, within connectionist models, exception word and nonword reading is accomplished using a single mechanism operating over distributed representations of orthographic and phonological units. Such models gradually abstract the statistical relationships between orthographic inputs and phonological outputs, allowing novel words to be read through generalisation of this knowledge (Seidenberg & McClelland, 1989). Generalisation within connectionist models depends upon the structure of orthographic and phonological representations (Plaut, McClelland, Seidenberg & Patterson, 1996).

The case-study approach for investigating individual differences in dyslexic children's reading behaviour cannot consider the prevalence of these subtypes within the wider population of developmental dyslexic children. Castles and Coltheart (1993) used the dual-route framework to develop a method for classifying a large sample of dyslexic children into subtypes of phonological and surface dyslexia. They attempted to classify 53 dyslexic children by comparing performance on tests of exception word and nonword reading. Initial analyses used a regression procedure to determine the proportion of their dyslexic sample for whom a single component reading skill (either nonword or exception word reading) was outside the normal range. Eight (15%) children from their sample could be classified as having a specific deficit in nonword reading (phonological dyslexia) and 10 (20%) as having a specific deficit in exception word reading (surface dyslexia). Thus, a large proportion of individuals could not be classified using this method, since they were outside the normal range on both types of reading tasks.

Therefore, Castles and Coltheart employed a less conservative method than the original, by classifying individuals into subtypes (using the same regression method)if they showed greater discrepancies for their age in their ability to read one set of items (words or nonwords) relative to the other. Using this criterion, they were able to classify 55% of their sample as showing a phonological dyslexic profile, and 30% as showing surface dyslexia[1].

A limitation of Castles and Coltheart's regression procedure was that it made reference to a normative sample of children of the same age, who were much better readers than the dyslexic children in the study (Snowling, Bryant & Hulme, 1996). Using a similar approach but with a more conservative reading-age matched design, Manis, Seidenberg, Doi, McBride-

Chang and Peterson (1996) identified relatively few children who demonstrated dissociations between nonword and exception word reading once reading age was taken into account; specifically, 24% of their sample could be classified as showing a phonological dyslexic profile and only 2% were classified as showing surface dyslexia. Similarly, when Stanovich, Siegel and Gottardo (1997) used a reading-age matched design to identify subtypes using the same regression method, only 17 phonological dyslexic children (25%) and 1 (1.5%) child with surface dyslexia subtype could be classified from the 68 children in their sample. Thus, in contrast to Castles and Coltheart (1993), the results from both these studies indicated a much lower incidence of developmental phonological dyslexia and very few children with the profile of developmental surface dyslexia.

Aside from the issue of how best to classify dyslexic children, it is important to understand the variation in cognitive skills that underlies the individual differences observed in their reading abilities (Snowling, 1987). Manis et al.,(1996) and Stanovich et al.,(1997) compared the cognitive skills of the subgroups that they were able to classify in their samples (in relation to normal readers of the same age) as either phonological or surface dyslexic children. Children showing a phonological dyslexic profile had poorer phoneme awareness than reading-age matched normal readers, while those with a surface dyslexic profile were indistinguishable from the younger controls, even on tasks measuring orthographic skill.

Rather than look for discrete patterns of impairments in reading and reading-related cognitive skills, an alternative way of conceptualising these individual differences is in terms of continuous variation among the cognitive skills that underpin reading (Castles, Datta, Gayan & Olson, 1999; Olson, Kliegel, Davidson & Foltz, 1985; Snowling, Goulandris & Defty, 1997). An assumption of the dual route model is that component reading skills can be selectively impaired. However, such models do not simulate learning (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) and are therefore silent as to how deficits in reading-related cognitive skills that differ in severity affect reading performance.

Within the connectionist framework, both the nature of underlying representations and the efficiency of learning resources can lead to differential impairments of exception word and nonword reading (Seidenberg & McClelland, 1989; Harm & Seidenberg, 1999). Although subsequent models were able to achieve more accurate levels of nonword reading in their simulations by using improved phonological representations, the SM 89 model inadvertently demonstrated that impairments in the representations of phonological knowledge disproportionately affect nonword reading more than exception word reading. Seidenberg and McClelland (1989) also discussed the results of a simulation in which they reduced the number of hidden units, which resulted in both poor nonword and exception word reading.

When considering different profiles of reading impairment, Manis et al, (1996) proposed that a basic resource limitation could cause a pattern of surface or delay dyslexia by slowing mastery of all print-pronunciation associations (cf. Windfuhr & Snowling, in press). Furthermore, this limitation may be moderated by other factors such as amount of exposure to text or emphasis on phonics instruction in the curriculum. As an alternative, Stanovich et al.,(1997) proposed that the delayed reading profile observed among surface dyslexics might be due to mildly depressed phonological skill combined with exceptionally inadequate reading experiences.

Taking these observations together with the findings of Manis et al. (1996) as a starting point, Harm & Seidenberg (1999) simulated "sub-types" of dyslexia in a connectionist model of reading. In this model, a phonological network was pre-trained to allow it to encode information about the phonotactic constraints of English. Phonological knowledge was represented in an attractor network, a structure that was implemented to complete, clean up or repair incomplete or noisy phonological patterns using knowledge of the phonological structure that is represented by the weights. To simulate phonological dyslexia the network's capacity to represent phonological information was reduced in two ways, the least disruptive being to impose a degree of weight decay within the phonological network. In addition to imposing weight decay, the second, more severe impairment of phonological representation was created by removing a set of phonological clean-up units, continuing to impose a degree of weight decay and severing connections within the phonological layer. Finally, the third, most severe impairment involved making the computations in the phonological attractor more noisy[2].

Harm and Seidenberg's simulations showed that the more severe the impairment to the phonological network, the greater the nonword reading deficit. Moreover, with more severe phonological deficits, the network had to draw more upon general processing resources. Only in the case of the most severe impairments was exception word reading also affected. In contrast, altering the learning parameter to a non-optimal level affected the model's capacity to read exception words, with a lesser effect on nonword reading.

Thus, within a connectionist framework, children with more severe phonological processing deficits might be expected to show more significant nonword reading impairments. The corollary of this is that children with surface dyslexic profiles have less severe phonological impairments (in line with the findings of Manis et al.,1996 and Stanovich et al.1997). Since these children's reading behaviour is similar to that of younger reading-age matched controls, a possible explanation for their difficulties is that they lack sufficient reading experience to ensure familiarity with the range of exception words typically known by a child of their age (Stanovich et al. 1997). Indeed a number of studies have reported empirical evidence in support of an association between reading experience (indexed by measures of print exposure) and reading accuracy (Cunningham and Stanovich, 1991; McBride-Chang, Manis, Seidenberg, Custodio & Doi, 1993; c.f., Barker, Torgeson & Wagner, 1992).

The aim in this study was to investigate individual differences in dyslexic children's reading by assessing the concurrent predictors of exception word and nonword reading accuracy. Rather than attempting to classify the dyslexic children into discrete sub-types, we chose to use a regression approach to examine which reading-related cognitive skills most strongly account for the continuous variation in dyslexic children's reading behaviour. In line with connectionist formulations, we predicted that individual differences in phonological processing skill would account for variation in both exception word and nonword reading. However, since the generalisation in connectionist models needed for nonword reading depends upon having segmentally structured phonological representations (Brown, 1997), we predicted that phonological skills would be stronger predictors of nonword than exception word reading. In contrast, we predicted that variation in exception word reading would be more closely associated with overall levels of reading ability (Metsala et al., 1998) and print exposure (Barker, Torgeson & Wagner, 1992; Cunningham & Stanovich, 1991; McBride-Chang et al, 1993; Stanovich & West, 1989).

The rationale for the choice of tasks followed from the well-accepted view that phonological deficits are at the core of dyslexia (Stanovich & Siegel, 1994). Two sets of phonological tasks were included in the assessment battery. Following Gombert (1992), tasks tapping metalinguistic awareness of the phonological structure of speech, namely, phoneme deletion and rhyme production, and those tapping implicit phonological processes, namely nonword repetition, verbal short-term memory and speech rate, were included. In addition, to assess the influence of reading experience on individual differences in reading skill, the dyslexic children completed tests of title and author recognition as measures of print exposure.

## Method

### Participants

Dyslexic readers The dyslexic children who took part in the study were recruited from schools, education authorities and dyslexia centres in the North of England. Colleagues in these various centres were asked to suggest volunteers for the research who were of at least average IQ (WISC-III IQ of at least 85) and reading at least two years behind their chronological age. Initial contacts were followed up with a letter outlining the aims and methods of the study. Sixty two dyslexic children agreed to participate and all fulfilled the following selection criteria: either a standard score for reading achievement of less than 85 or, in the case of any referred child with a documented reading problem, a standard score below 90 with a standard score for spelling below 85. This procedure resulted in the exclusion of 3 children; two obtained reading scores that were too high (standard scores of 90 and 94) and one child's reading age was much higher than that of the rest of the group.

The dyslexic sample comprised 59 children aged between 9 years and 15 years 6 months, with a mean age of 12 years 2 months (SD =18 months). To confirm that the sample was of average intelligence, they were administered two subtests from the Wechsler Intelligence Scale for Children (III-UK) (Wechsler, 1992). Their mean Vocabulary sub-test score was 9.86 (SD = 3.04) and the mean Block Design score was 10.31 (SD = 2.76). All dyslexic children were reading below the 20th centile for their age (range = 0.5 - 19); mean percentile = 7.2, SD = 5.3). Their reading ages, as measured by the

Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993) Basic Reading Scale ranged from 6 years 3 months to 9 years 9 months, with a mean reading age of 8 years 2 months (SD = 11 months). Standard scores on this test ranged from 59 to 87 with a mean of 75.8 (SD = 7.22). On the WORD Spelling test scores ranged from 6 years 3 months to 9 years 9 months, with a mean spelling-age of 7 years 10 months (SD = 10 months). Standard scores ranged from 58 - 94, with a mean of 73.2 (SD = 8.07).

Control sample Each dyslexic child was matched individually with a younger normal reader whose reading age was within 4 months of the dyslexic child's reading age on the WORD test. The normal readers all attended state primary schools in the City of York. The control sample comprised 59 children aged between 6 years 6 months and 9 years 10 months, with a mean age of 8 years 2 months (SD = 10 months). Their reading ages (WORD) ranged from 6 years 3 months to 9 years 9 months, with a mean reading age of 8 years 2 months (SD = 10 months). Standard scores ranged from 90 to 109, with a mean of 100 (SD = 4.77) and percentile scores were between 25 and 73 (mean = 49, SD = 12.3). All control children had reading ages within 6 months of their chronological age.

Tests and Materials[3]

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The test battery was divided into two parts. First, a series of tests were administered to all children in order to determine their relative proficiency in reading exception words and nonwords. Second, a series of tasks tapping reading-related language and cognitive skills were administered to investigate the concurrent predictors of component reading skills. Owing to constraints on the amount of time children could be released from class, a reduced set of these tests was given to controls.

Component Reading Skills

Both groups of children were administered tests of component reading skills.

Nonword reading 1. Each child read 32 nonwords, printed on individual cards in lower case letters (Geneva font, 24-point). Twenty four monosyllabic nonwords taken from the set used by Manis et al., (1996) and 8 two-syllable nonwords, e.g., polmex, torlep from Castles and Coltheart (1993). The 24 one-syllable nonwords varied in the frequency of their orthographic rime unit; 8 items contained high frequency rimes (e.g., lum, veed) 8 items contained low frequency rimes (e.g., choub, vep) and 8 nonwords had no close orthographic neighbours (e.g., phuve, glaje) (after Treiman, Goswami & Bruck, 1990~~; see Appendix 1~~). Coefficient alpha was computed to be 0.87 (Cronbach, 1951).

Nonword reading 2 . The Graded Nonword Reading Test (GNWRT; Snowling, Stothard & McLean, 1996) was used as an additional measure of nonword decoding skill. This standardised test contains 20 nonwords , 10 monosyllabic (e.g., sted, gromp) and 10 two-syllable nonwords (e.g., hinshink, stansert), varying in phonological complexity. Alpha was 0.96 (Cronbach, 1951).

Exception word reading. Children read 44 exception words used in the Manis et al., (1996) study (after Adams & Huggins, 1985). These items consisted of exception words graded in their word frequency, including high- (e.g., island, busy) and low-frequency (e.g., colonel, sovereign) items. Due to time constraints, it was necessary to discontinue this task after 10 consecutive errors but pilot testing showed this gave a reasonably accurate measure of exception word reading skill. Alpha was 0.89(Cronbach, 1951).

Phonological awareness

Rhyme fluency. In this task, children had to provide as many words orally to rhyme with a target item, as they could in 60 seconds (cf. Muter et al., 1998). The task comprised 6 items (day, plate, fright, chair, mitten, feather) and a score was obtained by adding together the totals across all items. Nonword responses were counted as correct. Alpha was 0.91 (Cronbach, 1951).

Phoneme deletion (after McDougall, Hulme, Ellis & Monk, 1994). In this task, children were required to 'take-away' a phoneme from a set of 24 nonwords, and to say what would be left. The items included 3 subsets of 8 nonwords which varied in difficulty according to whether the phoneme to be removed was in an initial (e.g., "bice" without the /b/ would be "ice"), medial (e.g., "hift" without the /f/ would be "hit") or final position (e.g., "teap" without the /p/ would be "tea"). The critical phoneme had to be deleted from a cluster in 16/24 cases. One repetition of the item was allowed for each item. Cronbach alpha was 0.83 (Cronbach, 1951).

Phonological Processing

Nonword Repetition (dyslexic children only). The Children's Nonword Repetition Test (CNRep; Gathercole, Willis, Baddeley, & Emslie, 1994) was administered to assess the child's ability to repeat unfamiliar nonwords. The test comprises 40 nonwords, 10 two, three, four and five syllables items (e.g., ballop, blonterstaping). The split-half reliability was reported as 0.66 for children with a mean age of 4 years 9 months.

Verbal memory span (after McDougall, Hulme, Ellis & Monk, 1994) (dyslexic children only). Children were asked for immediate serial recall of items from sets containing 8 one, two and three syllable nouns, to determine memory span. Children listened to strings of words spoken aloud by the experimenter, and tried to repeat them back in the correct order. Two trials were given at each list length, starting with a list of two for each set of words. Testing was discontinued for each set once errors were made on both trials at a particular length. Memory span was calculated as the longest list length on which the child was completely correct plus an additional score of 0.5 for list lengths on which only one trial was correct. Memory span was calculated by averaging scores across the three word lengths. Cronbach alpha was 0.77 (Cronbach, 1951).

Speech Rate (dyslexic children only). This task required children to articulate 10 pairs of 1, 2, and 3 syllable words taken from the memory span task, as quickly as possible (McDougall, Hulme, Ellis & Monk, 1994). Two trials were completed at each length, using different pairs of words. Speech rate (i.e., the number of words articulated per second) was calculated at each length and a final raw score was obtained by averaging across the 3 lengths. Cronbach alpha was 0.86 (Cronbach, 1951).

Print Exposure

Print exposure has been shown to be a strong predictor of reading skill in normal populations, even when phonological awareness is controlled (Cunningham & Stanovich, 1991). Two measures of print exposure were administered to the dyslexic group, a Title Recognition Test (TRT; adapted from Cunningham & Stanovich, 1990) and an Author Recognition Test (ART; adapted from Stanovich & West, 1989). Both measures require participants to simply scan the list and check those names known to be authors on the ART and check titles known to be names of books.

Author Recognition The version used in the present study consisted of a total of 40 items ~~(see Appendix 2 for full item list)~~: 25 actual target items (real authors) embedded among 15 foils (names that were not authors). Cronbach alpha was computed to be .75.

Title Recognition The version used in the present study consisted of a total of 40 items: 25 actual children's book titles and 15 foils for book names ~~(see Appendix 2 for full item list)~~. Cronbach alpha was computed to be .49.

Procedure

The dyslexic children were tested individually in one two hour session that included breaks as required. Children came into the laboratory or were tested either at home or school in a quiet room. The control children were tested on a shorter battery lasting about one hour, in two sessions within the same week. Testing took place in a quiet room at school.

Both the TRT and the ART were mailed to all of the dyslexic participants. The return rate was 40 out of the 59 individuals in the dyslexic sample (68%). Hence, a separate set of analyses is reported with the Print Exposure variables as predictors of reading.

## Results and Discussion

Reader-group differences

The performance of the dyslexic readers and the RA-controls on the core assessment battery is shown in Table 1. Scrutiny of the data describing the performance of the dyslexic children on the tests of reading and reading-related measures suggested that all variables, with the exception of rhyme production, were reasonably normally distributed. Rhyme production showed a significant skew with the majority of participants gaining low scores. These data were therefore transformed logarithmically for use in subsequent analyses; all other data were analysed using raw scores.

Univariate analyses indicated significant group differences on the nonword reading test 1 (Manis et al., 1996) requiring reading of nonwords containing vowel digraphs. Group differences on the nonword reading test 2 (Snowling et al., 1996) were in the same direction - the dyslexics read 54% of these items correctly compared to 61% in the control group, but the differences were not significant. The dyslexic group also performed significantly less well on the phoneme deletion task. The groups did not differ in exception word reading or in rhyme production.

Taken together, these findings confirm that the present sample of dyslexic readers is representative of others studied in the literature (Bruck, 1990; Rack, Snowling & Olson, 1992; Swan & Goswami, 1997). By contrast, the exception word reading skills of this group of dyslexics were at the level expected for their reading age (Metsala et al., 1998).

Concurrent predictors of reading skills among dyslexic and normal readers

As an initial step in investigating the concurrent predictors of nonword and exception word reading, a correlational analysis was conducted on measures of age, reading skills and phonological awareness, separately for dyslexics and RA-controls (Table 2). Strong correlations between the two nonword reading tests ($r$=.75, $p$<.001) justified the use of a composite variable in this analysis. The nonword reading composite was derived by taking the sum of the standardised nonword reading scores.

As expected, for reading-age controls, there were strong correlations of age with nonword reading (r =.61), exception word reading (r =.78) and phoneme deletion (r =.53). For the dyslexic readers, whose reading is out of line with development, none of these correlations were significant (r =.08, .24 and -.09 respectively). Rhyme fluency correlated with phoneme deletion in dyslexics but not with any of the other measures for either group.

Consistent with the above findings, reading age was strongly correlated with both nonword reading and exception word reading for dyslexic readers and both reading sub-skills were correlated with phoneme deletion. In contrast, the correlations between phonemic awareness and reading were only moderate in dyslexic children and the inter-correlation of nonword and exception word reading, though significant, was relatively low (r = .29).

These findings highlight the fact that the development of orthographic knowledge in dyslexic readers must proceed to an extent independently of the normal foundation in phonological skills (cf.Olson et al, 1985; Snowling, 1980). This might be because word identification can benefit from additional sources of activation, semantic representations being a likely candidate, whereas nonword reading cannot (Frith & Snowling, 1983; Nation & Snowling, 1998; Stanovich, 1980). Among nondyslexic readers, the relatively stronger relationship between phonemic skills and nonword reading (r =.71) than between phonemic skills and exception word reading ($r$ =.41) is consistent with this view.

To assess this possibility, we ~~went on to carry out~~conducted hierarchical regressions assessing the contribution of phonological skills to exception word and nonword reading. Because we were interested in the extent to which phonological skills were uniquely associated with the ability to read different types of word, it was important to control first for overall reading level because this measure can be considered to tap a range of different reading-related processes, including print exposure. We did this by entering age and reading level (WORD raw score) on the first two steps (Table 3). For normal readers, age and reading age accounted for 67% of the variance in exception word reading. After these variables were controlled, phonological skills accounted for no further variance in the model. For dyslexics, age and reading age accounted for a similarly high 52% of the variance, the majority being attributable to reading age. Once again, phonological skills accounted for no further variance. Taken together, these results suggest that phonological awareness contributes to exception word reading through shared variance with reading skills. It is probable that reading age picks up variance due to print exposure which accounts for its greater power in predicting exception word reading. In contrast, phonological awareness accounted for additional variance in the prediction of nonword reading for both groups, even when its contribution to reading age was controlled.

Predictors of individual differences in dyslexic reading.

The data available from the dyslexic readers was more extensive than for the controls. Further exploration of the predictors of reading skills was therefore possible for this group. A correlational analysis, controlling for chronological age (Table 4), produced moderate correlations between the nonword reading composite, phoneme deletion ($r$ =.49, $p$<.001), speech rate ($r$ =.34, $p$<.01) and nonword repetition ($r$ =.40, $p$<.01) and relatively low but significant correlations between nonword and exception word reading ($r$ =.28, $p$<.05). Exception word reading correlated with phoneme deletion ($r$ =.35, $p$<.01) but not with any other phonological variable, though the correlation with vocabulary was marginal ($r$ =.24, $p$<.07).

To reduce the data set before exploring the concurrent predictors of reading skills among dyslexic children, a principal component analysis with varimax rotation was conducted on the data from the five phonological variables (see Table 5). This analysis revealed a two-factor solution. The first factor (phonological skill) accounted for 43.1% of the variance (Eigen value = 2.15) and received high loadings from nonword repetition, phoneme deletion and rhyme fluency. The second factor (verbal short-term memory; STM) accounted for 21% of the variance (Eigen value = 1.05) and received high loadings from word span and speech rate. Contrary to

Gombert's hypothesis, tests of implicit and explicit phonological processing loaded together on the first factor, with tasks considered to tap short-term memory processes (Hulme et al. 1984) forming a separate factor.

Factor scores were derived on the basis of the principal components analysis and used to explore the concurrent predictors of reading sub-skills once variations in age, overall level of reading and IQ were taken into account. The results of these analyses are shown in Table 6. Age and IQ accounted for a significant 13% of the variance in the prediction of exception word but only 5% of the variance in nonword reading skill which was not significant. After age and IQ were controlled, a substantial amount of variance in both exception word and nonword reading skill was accounted for by reading level (for exception word reading 40% and for nonword reading 16%). Neither phonological variable accounted for unique variance in exception word reading after these other factors. However, both were significant predictors of nonword reading, together accounting for a total of 18% of the variance.

To assess the relative strength of phonological skills and verbal STM as predictors of nonword reading, the order of entry of these variables was manipulated in a further set of regression equations. Both were significant independent predictors of nonword reading, phonological skill accounting for 7.6% and verbal STM for 9.7% of variance when entered at the final step.

Print Exposure as a concurrent predictor of reading

A further set of analyses was conducted to investigate the role of print exposure as a concurrent predictor of nonword and exception word reading. These analyses were conducted separately since data was available for only 40 dyslexic children.

Print exposure was calculated by subtracting the proportion of distracters identified from the proportion of correct titles or authors recognised and then forming a composite measure using the summed z scores for each variable. Print exposure correlated strongly with age ($r$=.33, $p$ <0.05) and also with both reading age ($r$=.45, $p$<0.01) and exception word reading ($r$=.42, $p$<0.01), but not with nonword reading ($r$=0.07). Two simultaneous regressions were conducted to examine the relative strength of print exposure as compared to phonological skill as a concurrent predictor of exception word reading (Table 7).

Consistent with the previous analyses, when WORD reading age was entered into the model, it was the only predictor of exception word reading ($\beta$= .614, p<0.001). However, when reading age was omitted, the measure of print exposure accounted for significant unique variance in exception word reading ($\beta$= .396, p<0.05). Neither phonological awareness nor phonological processing contributed significant variance to exception word reading when print exposure was controlled. These results are in line with a number of other studies that have also reported measures of print exposure as significant predictors of accuracy in single word reading after controlling for the effects of age, IQ and phonological skill (Cunningham & Stanovich, 1991; McBride-Chang et al., 1993).

## General Discussion

Although there have been a number of attempts to classify dyslexic children according to the patterns of reading impairment they show, (e.g., Castles et al., 1999; Seymour, 1986), the classification of dyslexic children into sub-types yields a poor description of the dyslexic population at large. Accordingly, in this study a correlational design was used to investigate how individual differences in reading skill among dyslexic and normal readers were related to variations in their phonological skills and reading experience.

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As a group, the dyslexic readers in the present study were no worse at exception word reading than RA-controls (Metsala et al., 1998); ~~and~~ once reading age and IQ were taken into account, the only unique predictor of exception word reading was reading experience as indexed by reading age or print exposure. In contrast, the dyslexic readers were impaired in nonword reading and the nonword reading deficit was associated with the severity of the phonological impairment.

The present analyses revealed two sorts of evidence for the association between nonword reading and phonological skills. In both normal reader and dyslexic samples, phonemic awareness accounted for independent variance in nonword reading after age and reading skill were taken into account. In further analyses focusing on the dyslexic readers only, phonological processing ability and verbal STM both accounted for independent variance in nonword reading.

Although these results might be taken to imply that phonological skills are important for nonword but not exception word reading, the moderate correlations between phoneme awareness and exception word reading suggest that even the ability to read words which do not conform to regular grapheme-phoneme correspondences, depends on having access to segmental phonological representations. The relatively smaller contribution of phoneme awareness to exception word reading among the nondyslexic readers suggests that phonemic skills are necessary but not sufficient to read exception words.

Another factor that contributes to the acquisition of exception word reading, over and above having a foundation of print-to-sound-mappings in place, is individual variation in semantic skills (Nation & Snowling, 1998a; Plaut et al., 1996). Indeed, semantic activation is particularly important to avoid regularising English exception words. In addition, exception word reading depends upon experience reading irregular forms, consistent with our finding that print exposure was a concurrent predictor of exception word but not nonword reading.

The interpretation offered here is in line with both connectionist (Plaut, McClelland, Seidenberg & Patterson, 1996) and developmental models of reading (Ehri, 19970). Unlike dual-route formulations, these models propose a single mechanism for the processing of regular and exception words. Within Seidenberg and McClelland's (1989) model and subsequent generations of it, a system of mappings between orthographic inputs and phonological outputs computes pronunciations not only for regular and exception words on which the model has been trained, but also for novel letter strings.  Similarly within Ehri's framework, the orthographic system of the fluent reader is built on a foundation of mappings between print and phonology (see also Seymour, 1994).

The results reported here are also compatible with Share's self-teaching hypothesis (Jorm & Share, 1983; Share, 1995) according to which 'phonological recoding (print-to-sound translation) performs a self-teaching function enabling the learner to acquire the detailed orthographic representations necessary for fast, efficient visual word recognition' (p. 96, Share, 1999). In a recent series of experiments, Share (1999) was able to demonstrate empirically that the observed rapid rates of orthographic word learning in young children could be attributed primarily to phonological recoding and not simply to the experience of seeing a word repeatedly in print (i.e. mere visual exposure). Nonetheless, Share (1999) acknowledged the secondary role of individual differences in word-specific learning skill (Barret al, 1992;

Cunningham & Stanovich, 1990; 1993; Olson, Datta, Gayan, &De Fries, 1999; Olson, Frosberg, Wise & Rack, 1994;).

Although the group reading deficit in dyslexia has been characterised as a nonword reading deficit (van Izjendoorn & Bus, 1994; Rack, Snowling & Olson, 1992), the present results highlight individual differences between dyslexic children in their ability to decode nonwords as well as in their exception word reading skill. Importantly, while the dyslexic children's exception word reading ability was closely tied to their reading experience, their nonword reading was related to two measures of phonological skill, namely phonological processing and verbal short-term memory (STM). The independent contribution of phonological processing and verbal STM to this model suggests that the two measures are tapping different resources (cf. McDougall et al. 1994).

We speculate that the phonological processing measure assesses the nature and integrity of underlying phonological representations by assessing performance on tasks that require access to these representations. The verbal STM measure comprised memory span and speech rate for the same set of words and therefore tapped lexical knowledge as well as phonological processing (Hulme et al., 1991). It follows that it may be a measure of more general verbal resources than the factor score representing phonological processing.

Analogous with the idea that the nature of phonological representations, as well as more general verbal resources, predict nonword reading, Harm and Seidenberg (1999) showed that reducing the network's capacity to represent phonological information in different ways affected nonword reading to differing extents. Mild to moderate degrees of phonological impairment created by imposing a level of weight decay within the phonological network primarily affected nonword reading. When more severe impairments were simulated by also severing connections within the phonological network, the network had to draw more heavily upon general processing resources. Within this view, differences in general processing capacity can moderate the extent to which poor phonology disrupts the ability to read nonwords. It is possible that children with better memory span for words in the face of phonological difficulties are those who can draw more easily upon such general resources. These same children might be expected to show relatively better nonword reading.

One of the attractions of connectionist models of reading is that they can explain how patterns of reading impairment, which at the behavioural level seem discontinuous, may represent continuities in performance at a more fundamental cognitive level (e.g. Castles et al., 1999; Morton & Frith, 1995). The hypothesis forwarded in the present paper is that the pattern of reading impairment observed in individual cases of dyslexia depends upon the *severity* of a child's phonological processing deficit, more general processing resources, and also upon their reading experience. Indeed, Castles et al (1999) recent study examining discrete subtypes of dyslexia, reported results consistent with the severity hypothesis. Although they reported different etiologies for the phonological and surface dyslexic patterns, supporting a view of partial independence of phonological and orthographic skill, the surface dyslexics were also impaired to a degree on measures of phonological processing.

It is likely that there are also other sources of individual variation, notably a child's semantic abilities (Nation and Snowling, 1998b; Plaut, 1997). The limited variation in semantic skills among children defined as dyslexic according to a discrepancy between IQ and reading attainment precluded investigation of the role of semantic factors in reading impairment in the present study.

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## Appendix 1

*Materials Used in the Nonword Reading Test 1*

| 1 syllable | | | 2 syllables |
|---|---|---|---|
| HF | LF | NCWN | |
| fip | vep | sprenk | tashet |
| chob | leck | phuve | polmex |
| vag | chud | wreeb | gurdet |
| lum | yol | gheab | tadlen |
| cheed | loash | smaip | dethix |
| yoal | soag | glouze | latsar |
| veed | foop | glaje | torlep |
| chail | choub | stieb | lishon |

# Appendix 2

*Materials Used in the Title Recognition Test*

| Target book titles | Distracter book titles |
| --- | --- |
| B.F.G | Space Brownies |
| Animal Farm | Without Wishes |
| Pride and Prejudice | Squashed Bananas |
| 1984 | The Phantom Fool |
| Superfudge | The Adventures of Mary Higgins |
| The Adventures of Tom Sawyer | Trading Vanities |
| IT | Feverish |
| Goodnight Mister Tom | Try, Try, Try Again |
| Jane Eyre | Reasons for Trying |
| Bury Me Deep | Dreams of New York |
| The Teacher | Irrelevant Fantasies |
| Treasure Island | Arthur and Orangutan |
| Forever | Voyage to the Underworld |
| Great Expectations | Green Treason |
| Lord of the Rings | Dawn Days |
| Macbeth | |
| The Babysitters Club | |
| Mort | |
| Flowers in the Attic | |
| The Pigman's Legacy | |
| To Kill a Mocking Bird | |
| Blitzcat | |

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The Accident

The Chronicles of Narnia

Life, the Universe and Everything

*Materials Used in the Author Recognition Test*

| Target authors | Distracter authors |
| --- | --- |
| Dean Koontz | A.C.Leach |
| Dick King-Smith | Paul Dobson |
| Betsy Byars | Anthony Lynch |
| Judy Blume | Martin Downing |
| Danielle Steel | Richard Westfield |
| Virginia Andrews | Jennifer Platt |
| Jackie Collins | John O'Sullivan |
| James Herbert | Tommy McCabe |
| Robert Westall | Michael Hartshone |
| Sue Townsend | Carolyn Young |
| William Shakespeare | Rosie Gunning |
| Victoria Tonner | John Ainsley |
| Stephen King | L.J. Storey |
| John Steinbeck | Judith Pearson |
| Enid Blyton | Joanna Austin |
| Charles Dickens | |
| Terry Pratchet | |
| J.R.R Tolkein | |
| Agatha Christie | |
| George Orwell | |
| Jane Austen | |

~~H.G. Wells~~

~~Catherine Cookson~~

~~Barry Hines~~

~~C.S. Lewis~~

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Footnote

[1] These patterns were later described as 'soft' subtypes by Stanovich, Siegel and Gottardo, 1997).

[2] Harm and Seidenberg described a number of ways in which the surface dyslexia or 'reading delay' profile of reading behaviour could arise in their model, including reduced training of the model (i.e., reduced reading experience), a non-optimal learning rate, and a reduction in the capacity of the model to encode information regarding mappings from orthography to phonology (Seidenberg & McClelland, 1989).

[3] The full item lists for unpublished tests can be obtained from the first author.

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Table 1
Performance of dyslexic readers and RA- controls on reading and phonological awareness tasks

| | | Dyslexics | RA-Control | F(1,116) | MSe | *p* |
|---|---|---|---|---|---|---|
| Nonword reading 1[1] | *M* | 41 | 51 | 7.80 | 0.038 | 0.01 |
| | SD | 17 | 22 | | | |
| Nonword reading 2[1] | *M* | 54 | 61 | 2.73 | 0.052 | 0.10 |
| | *SD* | 20 | 25 | | | |
| Exception word reading[1] | *M* | 25 | 26 | 0.16 | 0.023 | >0.1 |
| | *SD* | 15 | 15 | | | |
| Phoneme deletion[1] | *M* | 50 | 58 | 4.16 | 0.039 | 0.05 |
| | SD | 20 | 19 | | | |
| Rhyme production[2] | *M* | 1.43 | 1.46 | 1.06 | 0.031 | >0.1 |
| | *SD* | 0.19 | 0.16 | | | |

Notes

1 % correct

2 Number of rhymes produced (log)

Table 2

Correlations among reading and phonological awareness skills for dyslexics and reading-age controls

| | | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| 1. | Age | | | | | | |
| 2. | Reading | Dyslexic | .20 | | | | |
| | | Control | .88[c] | | | | |
| 3. | Nonword composite | Dyslexic | .08 | .44[c] | | | |
| | | Control | .61[c] | .70[c] | | | |
| 4. | Exception words | Dyslexic | .24 | .71[c] | .29[a] | | |
| | | Control | .78[c] | .80[c] | .55[c] | | |
| 5. | Phoneme deletion | Dyslexic | -.09 | .37[b] | .48[c] | .32[b] | |
| | | Control | .53[c] | .64[c] | .71[c] | .41[b] | |
| 6. | Rhyme | Dyslexic | -.06 | .15 | .20 | .08 | .37[b] |
| | | Control | .01 | .07 | .04 | .03 | .03 |

Notes

[a] $p<0.05$

[b] $p<0.01$

[c] $p<0.001$

Table 3

Hierarchical Regressions predicting nonword and exception word reading for the dyslexic and reading-age control groups

| | Exception words | | Nonwords | |
|---|---|---|---|---|
| | $R^2$ change | *p* | $R^2$ change | *p* |
| Dyslexic | | | | |
| 1. Age | .05 | *ns* | .00 | *ns* |
| 2. Reading Age | .47 | .001 | .19 | .001 |
| 3. Rhyme | .00 | *ns* | .02 | *ns* |
| 4. Phoneme Deletion | .01 | *ns* | .10 | .01 |
| | | | | |
| 2. Reading Age | .47 | .001 | .19 | .001 |
| 3. Phoneme Del. | .01 | *ns* | .12 | .01 |
| 4. Rhyme | .00 | *ns* | .00 | *ns* |
| Control | | | | |
| 1. Age | .61 | .001 | .37 | .001 |
| 2. Reading Age | .06 | .01 | .12 | .001 |
| 3. Rhyme | .00 | *ns* | .00 | *ns* |
| 4. Phoneme Deletion | .01 | *ns* | .12 | .001 |
| | | | | |
| 2. Reading Age | .06 | .01 | .12 | .001 |
| 3. Phoneme Deletion | .01 | *ns* | .12 | .001 |
| 4. Rhyme | .00 | *ns* | .00 | *ns* |

Table 4

Partial correlations (controlling for age) among cognitive abilities and reading skills for dyslexics

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Reading (Word; raw score) | | | | | | | | | | |
| 2. Nonword composite | .44 | | | | | | | | | |
| 3. Except | 70[c] | .28[a] | | | | | | | | |
| 4. Phoneme deletion | .39[b] | .49[c] | .35[b] | | | | | | | |
| 5. Rhyme | .16 | .20 | .09 | .37[b] | | | | | | |
| 6. Speech rate | -.07 | .34[b] | -.07 | .24 | .18 | | | | | |
| 7. CNRep | .23 | .40[b] | .10 | .49[c] | .44[c] | .30[a] | | | | |
| 8. Word Span | -.14 | .13 | -.07 | .15 | .08 | .28[a] | .32[a] | | | |
| 9. Vocabulary | .32b | .20 | .24 | .40b | .27a | .22 | .31a | .15 | | |
| 10. Block Design | .17 | -.00 | .21 | .25 | .08 | -.07 | .012 | .029 | .27a | |

Note [a] *p*<0.05 [b] *p*<0.01 [c] *p*<0.001

Table 5

Principal component analysis showing factor loadings describing the performance of the dyslexic readers on the 5 phonological tasks.

| | Factor 1<br>Phonological Skill | Factor 2<br>Verbal STM |
|---|---|---|
| Nonword Repetition | .71 | .42 |
| Word Span | .03 | .84 |
| Speech Rate | .18 | .73 |
| Phoneme Deletion | .78 | .12 |
| Rhyme Fluency | .81 | -.03 |

Table 6

Results of hierarchical regressions predicting nonword and exception word reading skills among dyslexic readers

| | Nonwords | | Exception words | |
|---|---|---|---|---|
| | $R^2$change | p | $R^2$change | p |
| 1. Age | | | | |
| Block Design | | | | |
| Vocabulary | .049 | ns | .130 | .05 |
| 2. Reading Age | .159 | .01 | .396 | .001 |
| 3. Phon Skill | | | | |
| Verbal STM | .176 | .01 | .000 | ns |
| 3. Verbal STM | .099 | .01 | | |
| 4. Phon Skill | .076 | .01 | | |
| 3. Phon Skill | .078 | .05 | | |
| 4. Verbal STM | .097 | .01 | | |

Table 7

Contribution of Print Exposure to variance in exception word reading in the dyslexic group (n=40)

| | Exception word reading | |
|---|---|---|
| | B | p |
| *Model 1* | | |
| Reading age | .614 | $p<0.001$ |
| Phonological awareness | .016 | NS |
| Phonological processing | -.006 | NS |
| Print exposure | .153 | NS |
| *Model 2* | | |
| Phonological awareness | -.114 | NS |
| Phonological processing | -.077 | NS |
| Print exposure | .396 | $p<0.05$ |