INDIVIDUAL DIFFERENCES IN DYSLEXIA

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ABSTRACT

With the phonological deficit hypothesis of dyslexia as a back-drop, this review discusses the issue of how indivdual differences in its behavioural manifestation should be conceptualised. It begins by reviewing ways of classifying children with dyslexia from a clinical perspective and proceeds to describe the cognitive neuropsychological approach to classification that has focused on the reading and spelling profiles of such children. It argues that children's reading difficulties should be couched within the framework of typical reading development and that sub-typing systems that have not acknowledged developmental data have limitations. An interactive model of learning to read is used to propose that individual differences in dyslexia depend upon the severity of the phonological processing difficulties experienced by an individual child, the proficiency of other cognitive skills and the environment in which they learn.

Key words

Dyslexia *subtypes* *individual differences* *phonological skills*

phonological dyslexia *surface dyslexia*

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Introduction

Although the first case of unexpected reading difficulty in childhood was described over a century ago (Morgan, 1896), the definition of dyslexia continues to be debated (Lyon, 1995; Stanovich, 1994; Tonnessen, 1997). Dyslexia is commonly defined as a specific difficulty in learning to read, despite normal IQ and adequate educational opportunity. It is a disorder of development that primarily affects the acquisition of literacy and the most widely accepted view is that it lies on the continuum of language disorder. Thus, dyslexia is characterised by verbal processing deficits (Vellutino, 1979) and a specific theory that will be considered here views impairments in phonological processing to be at its core (Brady & Shankweiler, 1991; Morton & Frith, 1995; Snowling, 1995; Stanovich & Siegel, 1994; see Brady, 1997, for a review).

The phonological deficit theory of dyslexia is compelling. First, it is well grounded in theory. The strong developmental association between phonological skills and learning to read forms a back-drop to much dyslexia research (Goswami & Bryant, 1990; Share, 1995). The theory also makes sense of the different manifestations of dyslexia across the age-span from pre-school (Scarborough, 1990) to adulthood (Pennington, van Orden, Smith, Green & Haith, 1990; Paulesu, Snowling, Gallagher, Morton, Frackowiak, & Frith 1996). Second, phonological sensitivity shares heritable variance with reading skills (Olson, Wise, Conners, Rack & Fulker, 1989) and importantly, there is substantial evidence that interventions that enhance phonological skills facilitate reading development in dyslexia (Snowling, 1996).

The traditional view concerning the mechanisms that account for the relationship between phonology and learning to read is that children who do well on tests of phonological awareness are quick to understand how phonemes and graphemes relate in the orthography, and to use this knowledge of letter-to-sound rules as a self-teaching device (Share, 1995). Hence, successful reading depends upon learning explicitly how to assign sounds to letters sequentially, and to blend them to synthesise a pronunciation. However, an alternative view (Ehri, 1992; Rack et al, 1992; Laing & Hulme, 1999) argues instead for a direct mapping mechanism according to which children at the very earliest stages of learning to read are able to set up direct mappings between orthography and phonology. According to this view, children learn to read by directly mapping sequences of letters to their pronunciations and not by relying on decoding rules (Marsh. Friedman, Welch & Desberg, 1981).

From the cognitive perspective, the phonological deficit theory proposes that delayed phonological development in dyslexia affects the development of phonological representations that are the foundation for orthographic development (Snowling & Hulme, 1994; Metsala, 1997). In turn, awareness of the phonological components of spoken words is not available at a time when this is critical for the acquisition of reading and spelling skills (Elbro, Borstrom & Petersen, 1998; Fowler, 1991). Typical consequences are a slow rate of literacy development, poor generalisation of word reading skills to nonword reading and poor spelling development (Snowling, 2000 for a review).

A significant problem for the phonological deficit hypothesis, however, is the existence of cases of developmental dyslexia that do not appear to have phonological processing impairments. This chapter will consider the extent to which a unitary theory of dyslexia can explain the variation seen among dyslexic children. We begin by examining the different ways in which dyslexic children have been classified into sub-types, and then go on to describe an alternative approach that investigates how cognitive skills can explain the variety of reading behaviours seen in dyslexia (Griffiths & Snowling, 2002). We argue that the existence of children with quite different reading profiles is consistent with a view that there is continuous variation in underlying cognitive and linguistic skills in dyslexia, in interaction with reading experience. We end by proposing a version of the phonological deficit theory that can account for individual differences in children's reading difficulties.

THE CLASSIFICATION OF DYSLEXIC CHILDREN

The attempt to classify dyslexic children into different sub-types has a long tradition. Influenced by the medical model, some of the earliest forms of classification grouped dyslexic children according to their neuropsychological symptoms. Kinsbourne and Warrington (1963) used patterns of sub-scores on the Wechsler Intelligence Scales as a means of classification. Children with a Performance IQ at least 20 points lower than their Verbal IQ scores who had associated problems with finger differentiation and right-left orientation were described as having developmental Gerstmann syndrome. Children with the opposite pattern, higher Performance than Verbal IQ, were described as having language-retardation. However, as Kinsbourne & Warrington (1963) noted, these categories fail to account for many poor readers.

Mattis, French and Rapin (1975) also used a neuropsychological approach to classify a group of dyslexic children with 90% success. The largest subgroup, 48% of the sample, had problems with speech articulation, graphemic motor skills and poor sound blending and were described as having 'articulatory and graphomotor dysco-ordination' difficulties. Twenty-eight percent who had difficulties with naming and labelling were considered to have a 'language disorder' and the smallest subgroup (14%) had 'visuo-spatial difficulties', predominantly problems with visual discrimination, and visual memory. Using similar methodology, Denckla (1977) identified five sub-groups of dyslexia, the majority having some form of language deficit. One subgroup had globally poor language abilities, another poor articulation and grapho-motor skills and a third with an 'anomic' repetition 'disorder' encompassing deficits in naming (with a tendency to make semantic errors), poor digit span and sentence repetition. There was also a subgroup with verbal learning and memory deficits and one described as having a 'dysphonemic sequencing disorder', with deficits in digit span, sentence repetition, and naming (all characterised by phonemic substitutions or reversals), with additional syntactic difficulties.

An alternative and more objective approach to the classification of children with dyslexia involves the use of multivariate techniques to examine statistical relationships among different neuropsychological deficits (Fletcher, Morris, Lyon, Stuebing, Shaywitz, Shankweiler, Katz and Shaywitz, 1997). In one such study, Doehring and Hoshko (1977) used factor analysis to delineate three subgroups of dyslexia on the basis of reading-related skills. The first group had severe oral reading difficulties but performed well on visual and auditory matching tasks. A second group demonstrated slow auditory-visual letter association skills and a third group with slow auditory- visual association of words and syllables had difficulties with phonic analysis, blending and sequencing. However, like the clinical approaches, this technique does not always reveal distinct and homogenous subtypes. Petrauskas and Rourke (1979) reported that between 20-50% of children in their sample could not be readily sub-typed using factor analytic techniques and Naidoo (1972) used cluster analyses to discern four subgroups of dyslexic readers, but found considerable overlap between the groups. A further problem is that clusters can reflect random departures from normality and may be spurious (Satz & Morris 1981).

Thus, early attempts to delineate subtypes of dyslexia had numerous limitations. Indeed it is worth noting that the sub-types that emerged were inevitably a function of the tasks used to test the dyslexic readers. These, in turn, reflected the disciplinary background or clinical experience of the researcher. Moreover, the factorial structure revealed was not always easy to characterise. From a theoretical perspective, a particular shortcoming was the failure to specify the nature of the reading disorder that the children manifested.

Hence, it was never clear whether the deficits associated with particular sub-types were a necessary or sufficient explanation for the late emergence of reading in individual cases (Marshall 1984).

READING AND SPELLING PROFILES IN DYSLEXIA

The importance of differentiating dyslexic children according to the kinds of problems they have with reading and writing has long been recognised by those concerned with remediation (Mykelbust and Johnson 1962; Johnson and Mykelbust 1967). An influential approach to sub-typing that started from the reading and spelling errors made by dyslexic children was that of Boder (1971,1973). Boder’s technique was simple. She began by presenting children with words to read aloud and noted those that were read automatically. She assumed that these words were already part of the child’s sight vocabulary. When a word was not read immediately, she allowed 15 seconds for the child to attempt to decode it using phonic skills. She then gave a spelling test comprising words they had read correctly (known words) and words they had been unable to decode (unknown words).

Over sixty percent of the sample was described as <u>dysphonetic dyslexics</u>. They had a limited sight vocabulary and showed difficulties with word attack skills including phonic analysis and synthesis. They were said to spell 'by eye' alone and were unable to spell words unless they were in their sight vocabulary. A second, smaller group (10%) of the children had difficulties in building up a sight vocabulary. This <u>dyseidetic</u> group read laboriously 'by ear', being unable to memorise the visual shapes of words so to read them as a whole, and all of their misspellings were phonetic. Boder also identified a third group comprising 22% of her sample that showed errors typical of both the dysphonetic and dyseidetic groups. These children were the most severely handicapped since they could not draw upon either visual or phonic skills.

Boder's approach was well motivated and offered clinicians the opportunity to devise remedial programmes to suit the individual needs of dyslexic children, although it was not rigorous methodologically. A more formal approach to the classification of dyslexic children in terms of their reading and, to a lesser extent spelling performance, took its lead from the discipline of cognitive neuropsychology (Shallice, 1988) to become a dominant approach in the UK and Europe during the 1980s. It is to this approach that we now turn.

Analogies between acquired and developmental reading disorders.

Cognitive neuropsychologists who study the reading skills of neurological patients have described a variety of ways in which the adult reading system can fractionate following brain damage (see Ellis, 1994 for a review). Two contrasting patterns of breakdown involve the selective impairment of either the phonological pathway that is specialised for the reading of novel words, or the lexical or semantic pathway (Coltheart, 1978; Plaut, McClelland, Seidenberg & Patterson, 1996) that is involved in the reading of exception words. Patients with phonological dyslexia have impairments of the phonological reading system. They typically show poor reading of nonwords in the context of good reading of familiar words, and they make predominantly dysphonetic spelling errors (Patterson, Marshall & Coltheart, 1985). Patients with surface dyslexia can no longer recognise many words that were once familiar by sight. However, they retain the ability to sound out words to a degree, using the alphabetic properties of English. As a consequence of this strategy, they are prone to make regularization errors on irregular words in English, such as yacht, or colonel, by treating them as one would a nonword. They also tend to spell phonetically.

The first case of phonological dyslexia in childhood was described by Temple and Marshall (1983). The case study was about a 17 year old girl, HM, who was reading around the 10 year level. HM produced all the characteristic symptoms of an acquired phonological dyslexic; she had difficulties reading novel words as well as long regular words and her reading errors included visual paralexias, e.g. press read as "pass" and derivational errors, e.g. imagine read as "image". Despite her decoding difficulties, HM was reported to read exception words well. In fact, she did not make many regularization errors and did not show the usual advantage of regular over irregular words. When she mis-read words, her attempts tended to include components of other words, suggesting she was trying to use visual analogies.

Within the same framework, Coltheart, Masterson, Byng, Prior, & Riddoch (1983) described the case of CD, a 15 year-old dyslexic, with a reading-age of around 11 years. CD showed the pattern of deficit characteristic of acquired surface dyslexia. Consistent with this description, she read regular words better than irregular words, many of her reading errors were regularizations, e.g. quay – >[kwEI] ; come --> [k´Um]. However, in one respect CD was not typical of surface dyslexia; although she was observed to read phonologically, her 'sub-lexical' reading skills were not proficient and her reading of nonwords was not as good as might be expected. More intact nonword reading has been reported in cases of developmental surface dyslexia reported subsequently, both in children (MI; Castles & Coltheart, 1996) and in adults (JAS; Goulandris & Snowling, 1991; Allan; Hanley, Hastie & Kay, 1992).

Thus, the cognitive neuropsychology offered a principled approach to the classification of dyslexia, by reference to a model of reading development. However, it was not without its critics (Snowling, 1983; Wilding, 1989). An important issue, as with all single case research, was the representativeness of the cases that were described. Seymour (1986), following a case-series of such children, concluded that the dyslexic population is heterogeneous but without distinct sub-types. Furthermore, as Bryant and Impey (1986) showed, there is also variation in the reading skills of normal readers. This normal variation clearly needs to be taken account of before concluding that a particular set of reading behaviours is the hallmark of a specific sub-type of dyslexia.

More generally, a problem for the cognitive-neuropsychological approach was that it was not couched in developmental terms. As Frith (1985) pointed out, it is possible to conceptualise dyslexia in its classic form as a failure to proceed to the alphabetic phase of development, when children first begin to use phonological skills for reading. The profile of phonological dyslexia exemplifies this phase of development well (Seymour & Elder, 1986). However following developmental arrest at this stage, literacy acquisition can often proceed, so that the profile of surface dyslexia might emerge as a consequence of reading delay with failure to progress further. What is important then is to try to explain the reading behaviour of dyslexic children in terms of their underlying cognitive skills and to highlight in particular, deficiencies in the processes considered to be pre-requisites for satisfactory literacy acquisition.

A DEVELOPMENTAL PERSPECTIVE ON DYSLEXIA

Snowling, Stackhouse and Rack (1986) used Frith's (1985) model of literacy acquisition as a framework for examining the association between the cognitive deficits of seven dyslexic readers and the patterns of reading difficulty observed. By dividing the cases according to reading level, they also made a preliminary assessment of how reading experience might be related to changes in reading and spelling profile – in some cases as a response to teaching.

The study involved three dyslexic children reading at the 7-year-level and four older dyslexics who had attained a reading age of at least 10 years; all had poor nonword reading skills and were classified as showing developmental phonological dyslexia. The study also included two groups of normally developing readers, reading at the 7- and the 10- year levels for the purpose of developmental comparison.

Consistent with Frith's hypothesis, the dyslexic children, particularly those of low reading age appeared to be arrested in the logographic phase of development. Thus, their reading was inherently inaccurate with a preponderance of visual errors and there was a notable absence of the regularization errors seen frequently among controls. In all cases but one, nonword reading skills were impaired relative to reading-age matched controls; the exception was a boy who had received extensive tutoring and a second boy had difficulties with two- but not one-syllable nonwords. In similar vein, the spelling skills of the dyslexics were poorer overall than the controls and they showed a marked tendency to make dysphonetic spelling errors, e.g., FISH as fine, BUMP as bunt, GEOGRAPHY as gorphy.

Whilst there was some variation between cases, all displayed the phonological deficits that have been shown to characterise dyslexia, including problems of phonological awareness, verbal memory and nonword repetition. It seemed reasonable to conclude that deficiencies in the phonological processes that are required for successful literacy development had caused a difficulty in acquiring alphabetic skills (cf. Campbell & Butterworth, 1985). However, in some cases, progress to the alphabetic phase had been possible, especially where the child had benefited from remediation.

One of the children studied by Snowling et al. (1986), JM, was followed longitudinally to assess the effects his phonological difficulties would have on learning to read in the long term. When first seen, JM was 8 years old and, although a boy of superior intelligence, he had only just begun to read and spell. At this stage in his development, he was what could be described as a 'logographic' reader - he could read words but not new or unfamiliar words and his spelling was dysphonetic e.g. he spelled CAP as gad, POLISH as bols and REFRESHMENT as refent. JM made roughly half the average rate of progress in his literacy development over the next four years, and his reading profile did not change (Snowling and Hulme, 1989); he still had significant difficulty in nonword reading and his spelling remained dysphonetic.

JM was next tested when he was 13 years old (Hulme & Snowling, 1992). One of the main aims of this study was to pinpoint the locus of his phonological processing deficit by administering tests that placed differential emphasis on phonological input and phonological output processing. A test of complex nonword discrimination revealed that JM's auditory processing of speech input was intact. He also had no difficulty discriminating words from confusable nonwords when compared with RA-controls in a lexical decision task. In contrast, JM had great difficulty when required to repeat the complex nonwords he had discriminated – in fact, his performance fell outside of the range of normal controls when asked to repeat the stimuli. Taken together, these data provided powerful evidence for a differential deficit in JM affecting output phonology.

The finding of selective deficits at the level of output phonology in JM suggested that output phonological representations play an important role in learning to read. Hence, Hulme and Snowling (1992) proposed that children use output phonology when mapping the letters in printed words onto the sound structure of spoken words. The development of such mappings is critical to progress through the alphabetic phase of development. JM lacked stable output representations and it seemed therefore that the development of his sight vocabulary had been delayed. Furthermore, he had been unable to abstract and use letter-sound rules to facilitate his reading because of his output difficulties.

The conclusion that JM's orthographic development was constrained by his phonological difficulties seems, on the face of it, clear-cut. To place his reading difficulties in context, it is interesting to note that Vellutino and Scanlon (1991) reported a retrospective analysis of several hundred impaired readers showing that as many as 83% were deficient in mapping alphabetic symbols to sound. So, the theory that phonological deficits affect transition to the alphabetic phase of literacy development has considerable currency. It is plausible that a proportion of those who gain alphabetic skill do so in response to remediation. But, are there additional or different deficits associated with developmental surface dyslexia that impede progress?

One of the first hypotheses to be forwarded about the cause of the surface dyslexic profile in childhood was that a perceptual deficit affected the acquisition of visual word forms, at least in a minority of cases of 'dyseidetic' dyslexia (Boder, 1973). More recently, Goulandris and Snowling (1991) reported the case of JAS, a dyslexic undergraduate who resembled a surface dyslexic in her performance. JAS performed competently on phonological tasks but her visual memory for both letters and for abstract shapes was severely impaired. Thus, it was plausible that her poor visual memory had compromised the development of orthographic skills perhaps, by limiting her ability to remember the graphemic sequences that represent the varying spelling patterns of English (see Romani, Ward and Olson (1999) for a modification of this view)

However, the finding that surface dyslexia is associated with visual memory deficits has not been replicated consistently (Castles & Coltheart, 1996; Hanley et al., 1992; Seymour & Evans, 1993). As we have seen, this might be because, in some cases the profile of surface dyslexia comes about as the consequence of remediated phonological problems, while other times it reflects a more specific cognitive deficit implicating visual processing.

The regression approach to sub-typing.

A different approach to the classification of children into sub-types in relation to patterns of reading performance in the normal population was described by Castles and Coltheart (1993) who studied a sample of 53 dyslexic children. Fundamental to this approach is the use of regression to identify dyslexic children whose reading of either nonwords or exception words falls outside of the expected range for their age. Castles and Coltheart initially focused on individuals for whom a single 'component' reading skill was outside the normal range. On this criterion, 8 (15%) of their sample could be classified as having a specific deficit in nonword reading (phonological dyslexia) and 10

(19%) as having a specific deficit in exception word reading (surface dyslexia). Using a less stringent method, Castles and Coltheart went on to identify the proportion of individuals who were outside the normal range for both component skills, but more so for one than the other. Using this criterion, they were able to classify 55% of their sample as phonological, and 30% as surface developmental dyslexics.

The method chosen by Castles and Coltheart to identify sub-types of dyslexia made reference to a normative sample of children of the same age as the children with dyslexia. These children, by definition, read at a higher level than the dyslexics. If relative efficiency of different reading strategies is bound to the overall level that the reader has attained, then extrapolation from the reading patterns of children at one level to another is an inappropriate way of defining abnormal patterns of reading (Snowling, Bryant & Hulme, 1996; Stanovich, Siegel & Gottardo, 1997).

Following Castles and Coltheart's (1993) procedure, but using a more rigorous 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, they classified 12/51 phonological and 1/51 surface dyslexics in this way. The remaining 75% of the sample showed a normal (though delayed) pattern of reading performance. A similarly low incidence of sub-types was also reported by Stanovich et al, (1997) with 74% of children showing component reading skills within the normal range.

An important feature of the Manis et al., (1996) and Stanovich et al., (1997) studies is that these investigators went on to compare the children conforming to the description of phonological dyslexia with those considered to show the surface profile on tests of phonological and orthographic processing skill. The phonological task used by Manis et al (1996) required the child to listen to a nonword and say what came immediately before or after a target phoneme, e.g., which sound comes before the [t] sound in /skwupt/? The orthographic choice task required the child to decide which of two visually presented letter strings was a correctly spelled word, e.g., streat/street. Stanovich et al (1997) used the Rosner auditory analysis test (Rosner & Simon, 1971) as their phonological measure; this task required the child to delete either a syllable or phoneme from a spoken word and say what is left. Their orthographic measure was a 'word-likeness choice' task which required the child to decide which nonword letter string was more 'word-like' than the other, e.g., filf-filk. In both studies, when compared with younger reading age-matched controls, children identified as showing a phonological dyslexic profile showed poor phonological awareness skills. In contrast, the performance of children with a surface dyslexic profile was indistinguishable from that of normal reading-age controls, even on tasks measuring orthographic skill.

The most straightforward interpretation of these results is that surface dyslexia is characterised by a delayed pattern of reading development, whilst developmental phonological dyslexia represents a developmental reading disorder. A similar conclusion was reached by Snowling, Goulandris and Defty

(1996) who carried out a detailed case study of two children conforming to each profile. It is important to note, however, that this conclusion does not address the important question of what accounts for by far the largest majority of dyslexic children: those who cannot be classified into a distinct sub-type. A comprehensive theory of dyslexia must account not only for the cognitive deficits that underlie the disorder but also for variation in its behavioural manifestations (Morton & Frith, 1995).

Predictors of nonword and exception word reading skill among dyslexic readers.

In a recent study of our own involving a sample of 58 dyslexic readers, we took a slightly different approach to the investigation of individual differences (Griffiths 1999). Our starting point was the knowledge that phonological awareness is an excellent predictor of individual differences in normal reading development, and that dyslexic children showing different reading profiles have been found to differ in phonological skills. In addition, we noted that it is not unusual in development for children to compensate for basic deficits by drawing on compensatory resources; in dyslexia, children differ not only in the severity of their phonological deficit but also in the proficiency of skills, such as visual memory or semantic processing (Snowling, Goulandris & Stackhouse, 1994).

From previous studies, we expected that it would be possible to identify relatively few sub-types using the regression methodology. We therefore decided to use a multivariate approach to determine the concurrent predictors of individual differences in component reading skills among dyslexic children. We assessed each child's ability to read nonwords and exception words before proceeding to investigate their performance on tests of phonological awareness (phoneme deletion and rhyme production), phonological processing (nonword repetition, verbal short-term memory and speech rate), visual memory for abstract shapes and vocabulary knowledge. In addition, we included two tests tapping speed of information processing, in line with current ideas that some dyslexic children suffer a double deficit affecting phonological awareness and processing rate (Bowers & Wolf, 1993).

There were substantial correlations between measures of phoneme awareness and both nonword reading and exception word reading among our dyslexics and their younger reading-age matched controls. As a group, however, the dyslexic readers were no worse at exception word reading than the controls, and regression analyses did not identify predictors of exception word reading once overall reading attainment (or exposure to print) was taken into account. In contrast, there were several important predictors of nonword reading. 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. More importantly, further analyses focusing on the dyslexic readers alone, revealed three predictors of the ability to read novel words. First, as predicted, phonological processing was a strong predictor of nonword reading, accounting for 8 % of unique variance in this skill. Second, both visual memory and speed of processing accounted for independent variance in nonword reading. Interestingly, the contribution of phonological awareness was not significant when variations in phonological processing had been controlled.

The results of this study are broadly in line with the conclusions of Manis, Stanovich and their colleagues (op cit). In our study, we were able to classify 16 (27%) children as having a phonological dyslexic profile and only one (2%) as surface dyslexic. However, to the extent that such children can be considered extremes on a distribution of nonword reading skill, individual differences on this continuum were predicted by phonological processing skills; in general terms, children with more of a surface dyslexic-like profile have relatively good phonological ability while those with a phonological dyslexic profile have more severe phonological deficits (Griffiths & Snowling 2002). There are additional predictors too. The ability to remember sequences of visual items is associated with better nonword reading skills. In addition, speed of processing influences reading profile in that children with a slow speed of processing tend to be better non-word readers. Furthermore, we found that the tendency to regularize exception words among dyslexics was associated with good nonword reading.

It is perhaps important to stress that the kind of analysis outlined here is quite compatible with the fact that, clinically, quite marked differences in reading profile can be observed. Indeed, as we show below, it is possible to select from most samples of dyslexic children, a number who show rather clear-cut patterns of deficit. NW and CHD were two such children whom we first assessed when they were 10 years 8 months old (Griffiths, 1999). Both were well behind in their reading development (each had a reading age of 8 years 9 months) and their spelling was more impaired. The performance of these children on tests of nonword and exception word reading and on related processing tasks is summarised in Table 1.

Insert Table 1 about here

NW shows many of the features of surface dyslexia. His nonword reading was relatively good, considering his overall level of reading ability, while his exception word reading was more impaired. Indeed 67% of his reading errors were regularizations, e.g., he read SWORD as [swç:d], and NINTH as [nInT] and his spelling errors were primarily phonetic, e.g, he spelled INSTRUMENT -> 'instroment', QUALITY -> 'qualety', DESCRIBE -> 'discribe'. By contrast, CHD showed many of the features of phonological dyslexia. Although his exception word reading was at the same level as that of NW, he could read only 31% of the nonword set given to both boys. He made relatively fewer regularization errors (50%) and a higher proportion of lexicalisations and nonword substitutions indicating a failure to apply phonological strategies, e.g., he read WOUNDED as [wUnd], and REACT as [ri:tS], ACHE [QntS] and AISLE as [Ilz]. CHD's spelling was characterized by a large proportion of dysphonetic spelling errors, e.g, he spelled DESCRIBE -> discrap, QUALITY -> quaty, ELECTRIC -> eletric, PARAGRAPH -> powergrapth, and ELEPHANT -> elephat. Although he was able to reconstruct the number of syllables in the word, he would often reduce consonant clusters to single letters, and errors on single phonemes would often be substitutions for phonemes which may only differ by a single phonetic feature (e.g. substituting a [b] for a [p] sound).

The pattern of reading profile demonstrated by NW and CHD was, in each case, associated with a distinctive pattern of behaviour on the other cognitive tasks they were given. NW's phonological awareness skills were quite good for his level of reading ability. On a test of phoneme deletion which required NW to take-away a specified sound from a spoken nonword, and say what remained, (e.g. [baI:s] without the [b] would give [aI:s], he managed to get 63% correct, whereas CHD scored only 46%. Likewise, NW's phonological processing skills, as measured by nonword repetition, verbal memory and speech rate were better than those of CHD.

One of CHD's strengths was his speed of information processing, as assessed by the coding and symbol search sub-tests from the WISC III, and his visual memory span for a set of abstract shapes was average for his age. On these tasks, NW displayed weaknesses. It is perhaps also worth noting that CHD scored higher on a test of print exposure than NW.

The cases of NW and CHD illustrate how two dyslexic readers, of similar age and overall ability, and reading at the same level may show markedly different profiles. However, the balance of their strengths and weaknesses is such that their behaviour is predictable in a principled way from a model of reading behaviour in which individual differences in reading strategy are the consequence of developmental interactions between phonological processing skills, visual and speed of processing resources

Taken together, the findings of our study are consistent with a modified version of the phonological deficit hypothesis. Dyslexic children do have phonological deficits. However, unsurprisingly, the severity of their phonological impairment is variable. Some dyslexic children show phonological impairments when compared with younger reading-age matched controls, others only in relation to age-matched peers. Nonetheless, it is reasonable to suppose that the phonological deficit is implicated in reading failure in both cases. Furthermore, the impact of the deficit can be moderated by other cognitive skills. We have argued elsewhere that some dyslexic children rely heavily on sentence context to get around their problems at the level of word decoding (Nation & Snowling, 1998). We suggest here that a child's visual memory capacity can also afford a compensatory resource for learning (cf. Hulme & Snowling, 1992). Our results also imply that a child with slow speed of processing has better chance of developing phonological reading strategies than one with fast processing speed, although this does not guarantee they will be able to learn to read the exception words of English (cf. Bowers, 1995).

TOWARDS AN UNDERSTANDING OF INDIVIDUAL DIFFERENCES IN READING DISABILITY

The hypothesis that we have forwarded concerning the role of cognitive skills in the development of dyslexic children's nonword reading skills takes for-granted that reading development is an interactive process. It seems to us that the conclusion that poor phonological skills are at the basis of reading impairment in dyslexia is inescapable (Stanovich & Siegel, 1994). However two independent factors, visual memory and speed of processing represent secondary 'risk' or 'protective' factors when identified in association with a phonological deficit (Vellutino, Scanlon, & Tanzman 1991). How can the interaction of these factors be conceptualised in relation to what is known about the process of learning to read?

For a theoretical explanation of phonological and surface dyslexia, Manis et al. (1996) turned to the connectionist model of reading of Seidenberg and McClelland (1989). In this model, reading was conceptualised as the transfer of patterns of activation between sets of orthographic input and phonological output units, via a set of hidden units. The network was gradually trained to learn the associations between orthographic and phonological strings by a process of feedback using a learning algorithm known as back propagation. The associations were coded by means of weights on the connections that change as a function of learning. An important feature of this model and others like it is that, as the model learns, the knowledge that it embodies generalises (Van Orden, Pennington & Stone, 1990). Thus, such models read words that they have not been trained on with reasonable success, and show higher performance on regular words with consistent spelling-sound mappings than on inconsistent or exception words. Connectionist models, such as this, provide a useful framework for the analysis of developmental disorders because these can be traced to limitations either in the representations involved in the learning process or to the processing resources available.

From the perspective of Seidenberg and McClelland's (1989) model, Manis et al. (1996) proposed that phonological dyslexia could arise as a consequence of deficits at the level of phonological representations (Brown, 1997; Fowler, 1991; Snowling & Hulme, 1994; Swan & Goswami, 1997). In contrast, surface dyslexia might be due to a computational resource limitation causing slowness in learning. Alternatively, it could arise in the same way as phonological dyslexia, but where the child had received extensive training in phonics. They left open the possibility that a visual deficit, affecting orthographic representations, could bring about this profile.

The data from our recent study can be similarly interpreted within the connectionist framework. To do this we must first describe a recent modification of the Seidenberg and McClelland (1989) model implemented by Harm and Seidenberg (1998). In this model the phonological network was pre-trained before learning trials began, in an analogous way to that in which a child's phonological development proceeds prior to the start of learning to read. Within this model, Harm and Seidenberg simulated acquired phonological dyslexia by reducing the network's capacity to represent phonological information. One way of doing this involved imposing a degree of weight decay within the phonological network. Speculatively, we suggest that our measure of phonological processing can be conceived of as an index of weight decay; dyslexic children with poorer phonological processing skills suffer greater weight decay. A more severe impairment of phonological representation was created by also severing connections within the phonological layer. In an analogous manner, the dyslexic children in our study with poorer phonological awareness, who by default also had poorer phonological processing, had more severe impairments of nonword reading.

In the study we have just described, a second constraint on the operation of the phonological pathway was signalled by poor visual memory. Harm and Seidenberg 's simulations show that the more severe the phonological deficit, the more the network has to draw upon general processing resources. Visual memory might be thought of here as part of a more general processing resource. Within this view, differences in general processing capacity can moderate the extent to which poor phonology disrupts the ability to read nonwords.

Current connectionist models are silent as to the role of speed of processing in the determination of patterns of reading behaviour. Our suggestion is that children who demonstrate slow speed of processing have difficulty setting up connections between orthography and phonology because activations across orthographic and phonological units are mis-timed. Similar proposals linking slow speed of processing with difficulties in establishing memory representations for printed words have been made recently by Wimmer, Mayringer and Landerl (1998) on the basis of findings from German speaking dyslexic children who do not show deficits in phonological awareness, and Bowers and Wolf (1993). In short, a mis-timing of sources of activation may have its principle effect on the acquisition of orthographic knowledge, leaving slow and laborious decoding possible.

The phonological representations view articulated here has close similarities with the 'phonological core-variable difference model' of Stanovich and his colleagues (Stanovich & Siegel, 1994). According to Stanovich and Siegel (1994), poor phonology is related to poor reading performance, irrespective of IQ; poor readers differ from normal readers in skills close to the phonological core of the deficit (e.g. phonological awareness), and discrepancy-defined poor readers differ from generally poor readers in skills further from the core (e.g., listening comprehension and working memory). The phonological-core variable deficit model is silent about individual differences in dyslexia. By contrast, the phonological representations hypothesis implies that phonological deficits can interact with underlying cognitive strengths and weaknesses to determine individual differences in reading behaviour. In our view, a child's reading deficit is predicted by the 'severity' of their phonological deficit in interaction with their profile of strengths and weaknesses.

CONCLUSIONS

In this chapter we have reviewed a range of different approaches to the classification of children with dyslexia. There have been a number of recurring themes. Despite their appeal to the clinician who sees a wide range of different phenomena in the behavioural symptoms of dyslexia, none of the approaches have been successful in assigning all dyslexic children to a sub-type. In every taxonomy to date, a significant number of children have been left unclassified and the theoretically motivated distinction between developmental phonological and developmental surface dyslexia also fail to capture the range of variation observed.

A second theme is that the largest sub-type of dyslexia is associated with language processing impairments. Arguably, the theme is replicated in the larger numbers of children showing phonological than surface dyslexia. A recent sub-typing study using cluster analysis, reported by Fletcher et al (1997), came to similar conclusions. Nine sub-types of reading disability were identified following the assessment of 232 children of mixed abilities on a large battery of cognitive measures. Five of these sub-types were described as 'specific', predominantly consisting of dyslexic children. Four of these five specific subtypes included children displaying impairments on a phonological awareness measure, with variations in accompanying impairments in rapid automatised naming and verbal short-term memory. The fifth specific subtype included children who were not impaired in phonological awareness but on measures which involved rapid and/or sequential processing (the 'rate deficit' group). The other clusters comprised the normal ability children, a global language impaired subgroup, and the majority of the below average ability subgroups

It might be argued that the attempt to relate differences in literacy profile with associated cognitive skills is essentially correlational and therefore not without its shortcomings. However, as Bishop (1998) has pointed out, since dissociations in development are rare, developmental associations are important because they can highlight the dependence of changes in one cognitive system on the acquisition of skills in related domains. With respect to dyslexia, it seems likely that the failure to learn to read (and spell) along normal lines is a direct consequence of phonological deficits. However, in determining individual differences in reading skill, these differences interact with other factors, such as the semantic and visual skills that children bring to bear by way of compensation, and the ways in which they are taught (Vellutino et al., 1991).

An important methodological consideration often neglected by researchers exploring the nature of individual differences in developmental dyslexia is the problem of external validation of variation in dyslexia. Stanovich et al. (1997) explored the stability and reliability of the phonological and surface dyslexic subtypes identified in their sample using a CA- matched group of normal readers. Additional measures of nonword and word reading included in the battery allowed the authors to examine what proportion of dyslexic children could be classified as either phonological or surface dyslexia when a CA-match design was employed but using alternative measures for classification of the sample. One reanalysis employed nonword reading as the measure of sublexical skills and word reading as the measure of lexical reading skills, and the other used spelling performance as the indicator of lexical skills. No child who fulfilled the criteria for surface dyslexia using the original method of classification was also reliably classified across both these additional methods. In contrast, six children originally classified as phonological dyslexics were consistently classified when these alternative measures were employed. Hence, the phonological subtype would appear to be a more reliable and distinct subtype than the surface dyslexic profile.

A recent behaviour genetic analysis of the heritability of word recognition skills in twins selected from the extremes of a distribution representing relative strength in phonological and orthographic processing is consistent with this view (Castles, Datta, Gayan & Olson, 1999. In this study, the contribution of environmental variance to the word recognition skills of children with a "surface-dyslexic" profile was greater than to those with a "phonological dyslexic" profile, and they also had poorer scores on a test of print exposure. In contrast, almost two thirds of the variance in word recognition scores for the phonological-dyslexic subgroup was due to genetic factors pointing to a possibly inherited deficit in spoken language skills.

In a related study, Olson, Datta, Gayan and DeFries (1999), investigated the heritability of word recognition in children who varied in speed of processing. The slowest third of the group who were significantly poorer on orthographic tasks, showed a relatively low heritability for word recognition deficits, but a high shared-environment influence. The opposite pattern was seen for the high speed group. These findings complement the results we have reported which suggest speed of information processing speed may be an important cognitive skill which may 'modify' the effects of variations in a phonological deficit on an individual's behavioural profile of reading development. However, studies of the heritability of different forms of dyslexia are at a relatively early stage though Grigorenko et al. (1997) have reported evidence consistent with the idea that different genetic substrates underlying different 'types' of dyslexia. Further empirical research is required before a full understanding is possible of how the problems of different dyslexic children can be traced to the neurobiological substrate.

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Table 1. Performance of two dyslexic children, NW and CHD, on tests of reading and reading-related skills.

	NW	CHD
Word reading (WORD)	34(raw score)	34 (raw score)
Nonword reading	63%	31%
Exception word reading	36%	36%
Regularization errors	67%	50%
Phoneme deletion	63%	46%
Nonword repetition	82%	63%
Verbal Memory span	3.5	3.3
Speech rate	2.6 words/sec	1.8 words/sec
Visual Memory span	2.5	3.5
Speed of Processing	4th (percentile)	66th (percentile)