COGNITIVE IMPAIRMENTS IN DEVELOPMENTAL DYSLEXIA

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DECLARATION

I, Lynne Gosman Duncan, hereby certify that this thesis has been composed by myself, that it is a record of my own work, and that it has not been accepted in partial or complete fulfilment of any other degree or professional qualification.

Signed: Date: 30th September, 1991

I was admitted to the Faculty of Science of the University of St.Andrews under Ordinance General No. 12 on 1st October 1987, and as a candidate for the degree of Ph.D. on 1st October 1988.

Signed: Date: 30th September, 1991

I hereby certify that the candidate has fulfilled the conditions of the Resolution and Regulations appropriate to the Degree of Ph.D.

Signature of Supervisor: Date: 30th September 1991

Signed: Date: 30th September, 1991

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ABSTRACT

The nature of cognitive impairments in developmental dyslexia was investigated in two studies. The issue of heterogeneity was addressed and an attempt was made to identify cognitive processes which might feature in a dimensional model of reading ability.

The first study examined the hypothesis that developmental dyslexics are delayed in their general perceptual development. Phonological, visual and tactile segmentation skills were assessed together with nonword naming ability. As a group, the dyslexics were only impaired for reading age at phoneme deletion and nonword naming. However, individual variation was present within the dyslexic group. Individuals exhibiting severe impairments were identified in tests of rhyme judgement, auditory organisation and visual segmentation. The perceptual delay hypothesis received only limited confirmation. The dyslexic group was impaired at the most analytical level of phonological segmentation, but not at more holistic levels. Visual and phonological segmentation skills showed some association, but were dissociated from performance in the tactile modality.

The second study further explored these findings using a new sample. This dyslexic group also suffered nonword naming impairments for reading age. However, like their reading age controls, they showed a processing advantage for onset and rime units in a phonological deletion task but not in an orthographic lexical decision task. The efficacy of long-term memory representations was assessed. Individuals within the dyslexic group displayed a very deviant performance in a repetition memory task, and the group as a whole was impaired at recognising words to which they had been repeatedly exposed.

It was concluded that the difficulties experienced by individual dyslexic children were varied, and that less frequent problems were likely to be overlooked by assessing impairment in developmental dyslexia in terms of group performance.

Further investigation of how visual and memory processes relate to reading development would be a worthwhile addition to the extensive work linking phonological processing with reading achievement.

CHAPTER 1

APPROACHES TO MODELLING SKILLED WORD RECOGNITION

1.1 HISTORICAL BACKGROUND

Reading disorders have proved to be rich sources of data for those studying the normal reading process. Descriptions of developmental and acquired dyslexia show subtle aspects of performance that yield fascinating glimpses into the possible mechanisms of reading. By comparison, when normal readers are observed, these mechanisms remain relatively impenetrable.

> In any well made machine one is ignorant of the working of most of the parts - the better they work the less we are conscious of them ..... it is only a fault which draws our attention to the existence of a mechanism at all.
>
> Kenneth Craik (1943)

Early reports of acquired and developmental dyslexia, such as those by Hinshelwood (1895) and Morgan (1896), were primarily documentations of the behaviour observed in these subjects, rather than experimental manipulations. The authors were struck by the contrast between two features of their subjects' performance, namely, their preserved numerical ability in the face of obvious reading difficulties. Both authors diagnosed "Word-Blindness", perceiving the reading process as the preservation and storage of the visual impressions produced by words, and they made speculative attempts to localise this specific aspect of visual memory in the proximity of the left occipital lobe.

By 1925, descriptions of reading disorders had become more incisive, and correspondingly more detailed theories were being constructed. In this year, Orton expounded a theory of reading which was based on his examination of developmental dyslexics. His theory sought to explain the presence of certain salient errors which had attracted his attention in the error corpus. He had noticed that developmental dyslexics confused reversible letters like *b* and *d* and identified these errors as a feature of the syndrome. Orton's theory also concerned visual memory. He suggested that reading acquisition involves learning to ignore the mirror images of letters and words stored in the nondominant hemisphere. He proposed that his subjects were suffering from a developmental delay in establishing normal hemispheric dominance for written language. The resulting misperceptions were responsible for the deficiencies in the subjects' recall of letters and words.

Franz (1930), likewise, endeavoured to relate the types of errors that he observed to processes underlying reading. His observations were of an acquired dyslexic who, intriguingly, produced long sequences of semantic errors of the type *hen* -> 'egg', when asked to read certain words. Franz thought that the normal association between a written word and its spoken response had broken down, causing too many potential responses to become available. Franz accepted the likelihood that brain damage underlay the symptoms he had observed but was careful to point out that it would be necessary to specify the processes involved in normal and impaired performance before any relation to brain structures could be inferred.

Recently, a more structured approach to neuropsychology has emerged with just such a goal. Neuropsychology has drawn upon an area of experimental psychology known as cognitive psychology to form *cognitive neuropsychology*. Within this framework the vast sources of neurological data have been utilised to produce rigourous and testable models of word recognition. The significance of this advance for the study of both normal and impaired reading merits a more detailed description of the principles underlying this approach.

The theoretical tenets derive from cognitive psychology, whose founders, true to tradition in psychology, conceptualised the operation of the brain in terms of the state-of-the art technology of the day, which at that time was the digital computer. The brain was seen as being engaged in symbol manipulation involving a series of processing stages. These stages were represented as boxes in diagrams modelling psychological processes, similar to the flowchart descriptions of computer programs.

One of the most fundamental assumptions, and one particularly relevant to neuropsychology, is the principle of modularity. Marr (1976) described this principle as follows:

> Any large computation should be split up and implemented as a collection of small subparts that are as nearly independent of one another as the overall task allows.

Marr had formed this hypothesis as a result of his experience of programming complex tasks. On the basis of his knowledge of vision he thought that it could be extrapolated to describe cerebral processes. Shallice (1984) comments on the relevance of such an assumption to neuropsychology:

> a lesion might well damage any particular subsystem selectively. A dissociation would occur between performance of any task that makes heavy use of the subsystem which would be impaired and the performance of other tasks which could be normal.

The comparison of case studies demonstrating "pure" neurological deficits and the componential analysis of tasks, made it possible to identify double dissociations between patterns of performance. Two distinct subtypes of patients would be described who were both impaired in their performance of a task but whose impairments were of a qualitatively different nature. In one group a particular cognitive process A was shown to be impaired while cognitive process B was preserved. In the other group the opposite pattern would hold. Assuming subtractivity, it could be inferred that these processes form independent modules necessary for normal performance of the task and have been selectively damaged in these groups of patients. This was held to signify independent processes. This procedure has been used to construct theoretical models which could be tested using neurological or experimental data.

The models of skilled reading which have issued from cognitive neuropsychology during the past two decades have dominated recent conceptualisations of reading and reading disorders and deserve evaluation.

1.2 DUAL ROUTE MODELS

An investigation of acquired dyslexia by Marshall & Newcombe, which appeared in 1973, was to have an enormous impact on the nature of subsequent research. Marshall & Newcombe made a psycholinguistic analysis of the reading errors made by their patients.[1] Two main dyslexic syndromes were proposed:

Deep Dyslexia

(a) Paralexic errors
- i. semantic e.g. *speak* -> 'talk'
- ii. visual e.g. *bad* -> 'bed'
- iii. derivational e.g. *truth* -> 'true'

(b) Word class effects
(c) Function word substitutions e.g. *the* -> 'is'
(d) Inability to read nonwords e.g. *wux*

Surface Dyslexia

(a) Regular words (e.g.*hint*) read more accurately than irregular words (e.g. *pint*)
(b) Visual errors e.g. *spy* -> 'shy'
(c) Regularisation errors e.g. *grind*-> 'grinned'
(d) Neologisms produced e.g. *hiss* -> 'hish'
(e) Homophones problematic e.g. *some* -> = sum

Marshall & Newcombe claimed to have demonstrated a double dissociation, confirming existing speculation that there were two possible procedures for converting print into sound. Cognitive psychologists had observed that novel letter strings could be pronounced successfully despite having no representation in the reader's *lexicon* of known words. They had suggested that some mechanism for assembling pronunciations may exist. However, realising that the pronunciations of some words were unique (e.g. *pint*) and had to be learned, they surmised that there must also be a direct visual approach to reading. Marshall & Newcombe were able to provide neurological evidence in their study of two routes from print to sound.

[1] see Coltheart (1982) for a contemporary discussion of the significance of this approach.

They incorporated this evidence in a model of the normal reading process which formed the basis of what became known as the Dual Route Model of Reading:

> _Direct Visual Route_
>
> impaired in surface dyslexics since they read regular words more accurately than irregular words, but preserved in deep dyslexics as they showed no such regularity effect
>
> _Indirect Phonological Route_
>
> impaired in deep dyslexics since they had great difficulty in reading nonwords, but preserved in surface dyslexics as they were able to read nonwords

These differential impairments were judged by Marshall & Newcombe to signify "functionally separable" processes. The basis of this claim has been criticised by Marcel (1980), who drew attention to the corpus of errors that the surface dyslexics had made in response to regular words. Marcel maintained that in surface dyslexia damage to the direct visual route was invariably accompanied by damage to the indirect phonological route. Although the observation that these surface dyslexics were showing a mixed pattern of impairments did not falsify Marshall & Newcombe's theory, it became necessary to identify patients with purer deficits to substantiate their claim that either route can operate normally when the other is damaged. Such evidence was later provided in the contrast between an acquired phonological dyslexic, W.B. (Funnell, 1983), and an acquired surface dyslexic, M.P. (Bub, Cancelliere & Kertesz, 1985). W.B. showed virtually no lexical impairment, correctly naming 90% of real words despite being completely unable to name a single nonword, whereas M.P. had difficulty retrieving lexical phonology from print but showed normal naming of nonwords and regular words.

Marshall & Newcombe's formulation generated a phenomenal amount of research aimed at delineating the properties of the proposed routes to phonology. Numerous case studies appeared describing acquired dyslexics and attributing their various impairments to component structures or to their interconnections, in the Dual

Route Model. By 1988, Ellis & Young were able to divide acquired dyslexia into eight main syndromes.

Having traced the historical roots of the Dual Route Model, we will now examine empirical investigations of the normal reading process. Dual Route Theory could be said to have had consequences for every phase in the study of reading, from the theoretical interpretation of results right down to the choice of experimental stimuli. It is from this perspective that a key issue in the evolution of the Dual Route Model, namely the nature of the phonological route, will be reviewed.

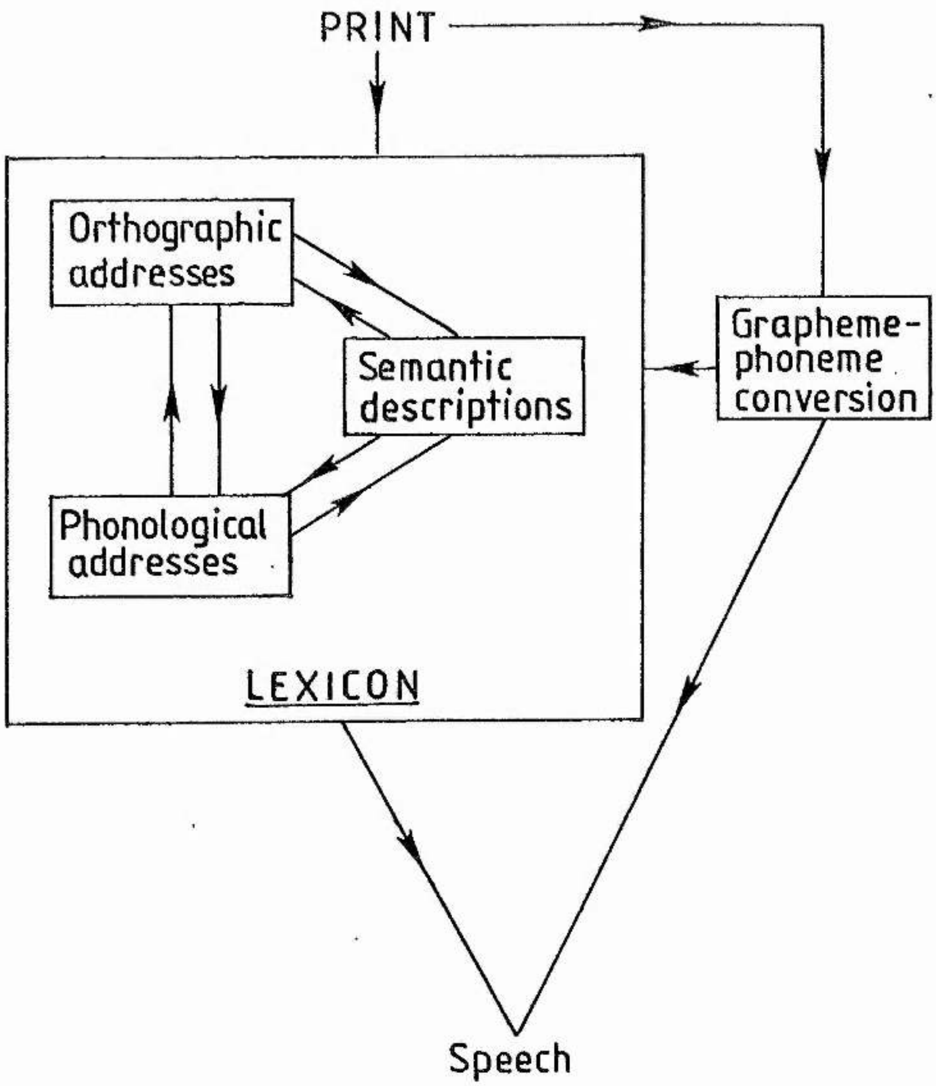
Coltheart (1978) was the first to tackle this issue in what Humphreys & Evett (1985) have labelled the "strong version" of Dual Route Theory (see Figure 1). Coltheart argued that an internal system of grapheme-phoneme correspondences (*GPC's*) were used to translate print into sound in the phonological route. He proposed that two stages were involved in this nonlexical procedure:

> First the letter string is parsed into those letters or letter groups which correspond to phonemes. Then the system of GPC's is used to assign a phoneme to each of the units produced by parsing.

How an operational system of GPC's might be derived is harder to deduce. English is not a transparent orthography since the spellings of many words reflect their meaning or derivation rather than their pronunciation (Henderson, 1982). There are considerable practical difficulties in implementing a procedure to translate spelling into sound in such an orthography. Coltheart's solution was to contend that a set of rules devised by the linguists Wijk (1966) and Venezky (1970), had "psychological reality". The Wijk-Venezky procedures gave correct phonological representations for a large class of *regular* words by assigning the most common grapheme-phoneme correspondence given the orthographic context. Consequently, these procedures would yield incorrect pronunciations of a smaller class of *exceptions*. Coltheart cited Baron & Strawson's (1976) finding that exception words were read more slowly than regular words as experimental support for his distinction between these classes of words. Coltheart concluded that when the phonological route is in operation, the

FIGURE 1

THE DUAL ROUTE MODEL OF WORD RECOGNITION
(From Humphreys & Evett, 1985)



phonology of a letter string is assembled solely by the application of GPC's. Furthermore, he was unequivocal on the independence of this phonological route from the influence of its lexical alternative, the visual route.

Henderson (1982) and Kay (1985) have highlighted some methodological inadequacies in the Baron & Strawson study and in other studies of this type. However, both conclude that there is empirical evidence that skilled adult readers find exception words harder to read than regular words, despite a marked variability in the size of reported effects. Seidenberg, Waters, Barnes & Tanenhaus (1984) accounted for some of this variation by demonstrating that in naming tasks, this "exception effect" was reduced by controlling for orthographically irregular spelling patterns in words like *yacht*, and absent when high frequency stimuli were used. However, it has become clear that some of the residual variation in the size of the exception effect arose because of the bluntness of Coltheart's notion of regularity. Experimental subjects have been shown to be sensitive to far finer distinctions. Patterson & Morton (1985) listed nine types of words whose pronunciations may be affected not only by the regularity of their own pronunciations in terms of GPC rules, but also by the consensus of pronunciations across the set of monosyllabic words sharing a similar orthographic pattern.

It is not obvious how Coltheart's system of GPC rules could account for these distinctions; the significance of this issue, however, is trivialised by the implications of finding similar effects in nonword pronunciation. According to the strong version of Dual Route Theory, nonwords can only be read using the GPC's in the nonlexical route. It undoubtedly follows that the assembly of nonword phonology should not be influenced by factors which are identified with the lexical processing route (Humphreys & Evett, 1985). Nevertheless, in a seminal paper, Glushko (1979) presented evidence that nonwords are sometimes pronounced to rhyme with an irregular word that contains similar features. Thus, what he labelled "inconsistent" nonwords like *heaf* were not always assigned the pronunciation predicted by GPC theory i.e./**hi:f**/. Instead, their pronunciation followed that of an irregular word sharing the same vowel and terminal consonant sequence, said by Glushko to define their "orthographic neighbourhood". So, *heaf* would be pronounced to rhyme with *deaf*. Furthermore, subjects were found to take longer to pronounce these "inconsistent" nonwords than matched "consistent" nonwords like *hean*.

1.3 LEXICAL ANALOGY MODELS

Glushko produced a new theory to account for these results. Regular words, exception words and nonwords were all held to be pronounced using similar kinds of stored knowledge:

> In an activation framework, a word is not regular or exceptional only in terms of its own spelling-to-sound correspondence. Rather, a word is consistent or inconsistent with the orthographic and phonological structure it activates.

This stance is the basis of lexical analogy theories of reading.

Kay & Marcel (1981) employed a pronunciation biasing technique in order to test the predictive power of the opposing theories. According to Dual Route Theory, antecedent words could not affect the pronunciation of nonwords. However, lexical analogy theorists would predict that presentation of an irregularly pronounced word e.g. *head*, before a nonword containing the same inconsistent vowel-consonant segments e.g. *yead*, would bias the subject to produce an irregular pronunciation. This latter prediction was sustained by the experimental results since the above procedure was successful in invoking irregular pronunciations of nonwords in 39% of the responses. This was found to be a significant biasing effect when compared to control conditions in which the nonword was preceded by a regular word with the same orthography e.g. *bead*, or by an irregular word with a different orthography e.g. *hood*, where 4% and 13% of nonword pronunciations were irregular, respectively.

Henderson (1985) was wary of evidence based on priming studies for they may introduce special anticipatory strategies untypical of normal performance. However, Glushko (1979) was able to demonstrate that irregularities also occurred in unprimed nonword pronunciation.[2] Patterson & Morton (1985) report a study by Evett, Patterson & Morton (1985) which replicated Kay & Marcel's "*head, yead* -> /**jɛd**/" effect on 44% of their experimental trials. However, they also discovered a considerable bias effect (in the range of 20%) due to shared phonology i.e. *shed, yead* -> /**jɛd**/. Thus, Kay & Marcel may have overestimated the biasing effect of orthography. Nevertheless, the basic effect, even if somewhat reduced, awaited an explanation. Moreover, Rosson (1983) has claimed that the pronunciation of an ambiguous nonword can be biased by association, using a word which is semantically related to an irregular word sharing the same ending i.e. *feel*, *louch* -> /**lʌtʃ**/, via the pronunciation of *touch*, the semantic associate of *feel*.

1.4 PATTERSON & MORTON'S REVISED DUAL ROUTE MODEL

It was apparent that the assembly of phonology could no longer be regarded as solely the product of a fixed system of grapheme-phoneme correspondences. Did this mean that the Dual Route Theory should be abandoned in favour of a lexical analogy approach? Patterson & Morton (1985) argued to the contrary. While conceding that the Dual Route Theory was no longer viable in its original form, they contended that with modification, the theory was capable of accommodating such data.

Patterson & Morton relinquished the strong hypothesis of functional independence between the lexical and nonlexical processes, for in their view:

> a hypothesis of separable routines ... does not require that the routines operate with complete independence in the normal system

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[2] see also Kay (1982).

This is concordant with a later expansion on modularity by Marr (1982).

> The principle of modular design does not forbid weak interactions between different modules in a task but it does insist that the overall organization must, to a first approximation, be modular.

Patterson & Morton (1985) insist that maintaining the "separability" of the two processes is of consequence. They argue that it admits the possibility that one or other of the processes may be impaired or lost as a result of neurological damage. Thus, the link between the neurological and experimental data is maintained.[3] Patterson & Morton also point out that variables may act upon the processes independently and suggest that it would be difficult to disentangle such actions if the two processes were treated as one. Patterson & Coltheart (1987) were later to cite the robust latency advantage for words over nonwords as further support for keeping the translation mechanisms separate.

Basically, Patterson & Morton's modifications consisted of supplementing the original system of GPC's in the nonlexical routine with a set of correspondences which operated upon larger sized units. These additional units were called *bodies* and defined as the "vowel-plus-terminal-consonant" segments of monosyllables that remained when the initial consonants or consonant clusters were removed. This set of correspondences was said to consist of one-to-several mapping rules which operated in a probabilistic manner.

Patterson & Morton claimed that this single modification permitted Glushko's (1979) findings to be explained. They considered "ambiguous" bodies e.g. *eaf* -> /**i:f**/ or /εf/, to be the only segments which required the existence of more than one orthography-phonology mapping. The phonology of these bodies would have to be selected at random, slowing down the response. In their account of Kay & Marcel's (1981) results, Patterson & Morton suggested that the biasing word e.g.*head*, temporarily caused this normally impartial selection process to favour the irregular

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[3] Patterson (1981) and Seidenberg (1988), however, have expressed reservations concerning the implications of functional interaction for the explanatory value of neurological data.

alternative for any *ead* segment i.e. / ɛ**d**/. They listed three prerequisites which would need to be incorporated in the model for this to occur:

1. The stimulus word *head*, activates the orthographic body *ead*.
2. The phonological response /**h** ɛ **d**/, activates the phonological code /ɛ**d**/.
3. The nonlexical system operates in such a way that concurrent activation of the two end elements of a mapping temporarily increments the future likelihood of following the pathway between them.

In general, Patterson & Morton assumed that 70% of phonology was assembled using GPC's, and the remaining 30% was derived through the use of their "body" system. Furthermore, they insisted that there was no interaction between these two systems.

The explanation of Rosson's (1983) data has proved a more formidable task and one which Patterson & Morton did not undertake in any detail, hoping that certain methodological faults in the study would render it not replicable. However, Kay (1987) has reported a replication of this result and an explanation is now required.

Unfortunately for Patterson & Morton's (1985) theory, other results have emerged which were not predicted by their model. Kay (1987) has also demonstrated that initial *consonant(s) + vowel* segments sometimes influence nonword pronunciation. Another pertinent finding reported by Rosson (1985), indicated that the relative strength of the GPC's and body mappings associated with a particular letter string may interact in assembling its phonology. However, Kay & Bishop (1987) suggested that this effect may be limited, applying only to the stimuli with unique *cores*[4] which were used in this experiment.

Any putative Dual Route Theory must now explain these added influences upon the assembly of phonology. In turn, any proposals concerning the use of lexical analogies must allow these analogies to be applied at multiple levels of

[4] the spelling following the initial consonant(s) e.g. *force*

segmentation. In fairness, Marcel (1980), when constructing an early lexical analogy model, had recognised the need to account for such influences, in particular, the ability to pronounce nonwords like *kwib* that contained orthographic segments which did not occur in any English word (i.e. *kw*). He proposed that although representations were at the whole word level, they were segmentable into multiple sublexical units. However, his theory has been criticised by Patterson & Morton (1985), who view these representations as segmented rather than segmentable.

Many authors have noted that what were previously diametrically opposed theories are becoming harder to distinguish as concessions are made on both sides to account for the available data (e.g. Baron, 1985; Carr & Pollatsek, 1985; Henderson, 1985; Humphreys & Evett, 1985; Olson & Keenan, 1985; Patterson & Coltheart, 1987). In their recent review, Patterson & Coltheart (1987) contend that the two models are not, in fact, divided over the issue of separate lexical and nonlexical processes. They argue that lexical analogy models contain an implicit distinction between the two processes since only words actually appear in their own orthographic neighbourhoods.

Henderson (1985) suggested that part of the reason for this theoretical quagmire was that lexical analogy theorists had not undertaken to specify the procedures by which phonology was derived in their model. Carr & Pollatsek (1985) agreed with this assessment. They also pointed out that it was not obvious how models which store only whole word representations could explain neurological damage that selectively destroyed the use of subword units in assembling phonology but preserved the use of whole word phonology. However, they added that it was possible to imagine *post hoc* additions to the theories which could account for such damage. One wonders if Patterson & Coltheart's (1987) hypothetical neurological dissociation between the accurate reading of nonwords and regular words, and the impaired (i.e. regularised) reading of exception words, would actually succeed in distinguishing the latest versions of the two models as it once might have done. Indeed, Norris & Brown (1985) concluded that it was difficult to envision any absolute empirical test which would be capable of differentiating the two theories.

1.5 CONNECTIONIST MODELS

Seidenberg has been prolific in expressing his conviction that the time has come to adopt a fresh approach to modelling word recognition (e.g. Seidenberg et al, 1984; Seidenberg, 1985a; Seidenberg, 1985b; Seidenberg, 1988). In 1985, a target article appeared in *The Behavioural and Brain Sciences* by Humphreys & Evett which argued for an analogy-type approach to word recognition on the basis that the available data contradicted Dual Route Theory. In his response to this article, Seidenberg expressed the following view:

> they (H&E) haven't established a principled reason why a revised dual route model couldn't handle these phenomenon. ... However, this follows for wholly negative characteristics of these models, namely the arbitrariness of the basic information-processing vocabulary in which they are stated, and the lack of constraints on the introduction of new theoretical entities. Although particular versions of the dual route model might be inconsistent with particular data, they can always be elaborated in ad hoc ways.

In echoing the criticism of underspecification given above, he maintained that this had become a feature of the cognitive neuropsychological approach, embodied in its central assumption that inferences can be made as to the "functional architecture" of a processing system without knowledge of the processes involved. In another article (Seidenberg, 1985b), he pursued this critique of the approach:

> It leads to a kind of theorizing in which facts about word recognition are explained on the basis (of) processing mechanisms stipulated in order to account for them. Norris & Brown (1985) are correct in observing that there are several different ways to deal with empirical phenomena within models of this type; I take that to be the strongest indictment of the approach.

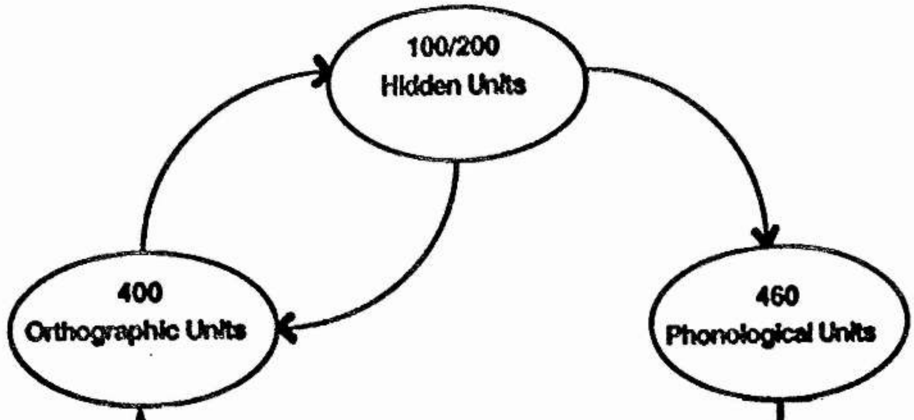
Seidenberg believes that the solution to the current impasse lies in a "connectionist" approach to modelling word recognition. This computational approach is now being used to model many aspects of human perception, learning and cognition (see McClelland & Rumelhart, 1986). McClelland, Rumelhart & Hinton (1986) pointed to the "neural inspiration" of the connectionist models which simulate the "parallel" nature of the brain as one explanation of their growing popularity. While molecular and cellular characteristics are not incorporated in any detail, the models contain neuron-like processing units which send excitatory and inhibitory signals to other units through a system of synapse-like weights.

The word recognition model implemented by Seidenberg & McClelland (1989a) differs from dual route accounts in that it contains neither spelling-sound correspondence rules nor a phonological lexicon of word pronunciations. Instead, all pronounceable letter strings are read using the knowledge encoded by a single set of connections. The model also contrasts with lexical analogy theories as there are no lexical nodes representing individual words and no feedback from orthographic neighbours. Rather, pronunciations are computed on a single, forward spread of activation through the network.

The structure of the implemented model can be seen in Figure 2. Initially, the letter string is converted into a pattern of activation across the orthographic units which allows activations of the hidden units to be computed according to the strengths of the individual connections between these levels. The hidden units then feed forwards to compute activations for the phonological units and backwards to compute new activations for the orthographic units (this latter step allows patterns produced by external input to the orthographic level to be sustained, reinforced and cleaned up). Seidenberg & McClelland (1989a) realised the importance of the context in which a letter or a phoneme occurred when specifying a letter string's orthographic or phonological content. In an attempt to accomplish this they chose to

FIGURE 2

STRUCTURE OF THE CONNECTIONIST MODEL OF WORD RECOGNITION IMPLEMENTED BY SEIDENBERG & McCLELLAND
(Adapted From Seidenberg & McClelland, 1989a)



adopt a variant of Wickelgren's (1969) "triples" scheme which encoded each triple as a distributed pattern of activation over a set of units, each of which is involved in the representation of many triples.

Seidenberg & McClelland (1989a,b) reported the findings of simulation studies run using the model described above to investigate some of the issues in human experimental psychology. The latency and accuracy of naming responses were simulated using the "phonological error score" calculated from the activation of the phonological units after each trial. The success of the model in producing phonological activations appropriate to the words in its vocabulary was assessed first and it was found that the model was very accurate, producing an error rate of only 2.7%. They then decided to simulate Glushko's (1979) study which found longer naming latencies for regular inconsistent words than for regular words. This finding has not proved particularly robust and is subject to certain qualifications. Seidenberg et al (1984) reported that the effect seemed to be confined to low frequency words whereas Taraban & McClelland (1987) failed to replicate the result at all. Seidenberg & McClelland described a simulation which approximated the Taraban & McClelland result using the same stimuli. This simulation allowed them to suggest that the variable results might have arisen because the effect as well as being restricted to lower frequency words may not be substantial enough to be identified in naming experiments.

In another simulation, this time using stimuli similar to the exception, strange and regular words employed in an experiment by Waters & Seidenberg (1985), Seidenberg & McClelland replicated the earlier finding that with low frequency stimuli, strange words produced the greatest number of errors, followed by exception and then regular words. Furthermore, as in the experimental study, they found no such effect with high frequency stimuli.

So far the model has produced a reasonable approximation to human performance. However, in simulations of nonword naming performance it hits a stumbling block. Although, the model has proved able to generalise its knowledge of word pronunciation to novel stimuli, producing largely plausible output, Besner, Twilley, McCann & Seergobin (1990) have demonstrated that in a simulation of a naming experiment by McCann & Besner (1987), the model was about 500% less accurate than normal subjects. Seidenberg & McClelland (1990) have been able to isolate certain minor shortcomings in their model which might account for this discrepancy. They began by directing attention to the fact that whereas the vocabulary of the average adult is in the order of 50,000 words, the implementation, so far, has been restricted to a very limited vocabulary of monosyllabic words similar to that of a young child. In addition, Seidenberg & McClelland conceded that the use of "Wickelphones" to encode context may have produced the large number of single feature errors reported by Besner et al (1990) and proposed that an encoding scheme which increased the differentiation of similar Wickelphones may improve the model's performance on nonwords.

Careful evaluation of encoding systems was also indicated among Pinker & Prince's (1988) criticisms of connectionist models. They submitted that the method of encoding information across the input and output layers may be more influential in determining the outcome than the architecture of the network itself. Although this criticism is less true of the more complex connectionist models, of which the Seidenberg & McClelland (1989a) model is an example, Bechtel & Abrahamsen (1991) emphasised that principled reasons for using a particular encoding scheme will need to exist. The use of schemes like Wickelphones, which were based on the "triples" developed by Wickelgren (1969), means that connectionist models have not yet succeeded in escaping the influence of linguistic rule systems. As always, the psychological reality of these schemes will need to be proved. From the evidence in the study by Besner et al (1990), it would appear that the Wickelphone scheme may not survive such examination.

An attempt has also been made to simulate the patterns of performance in acquired dyslexia using connectionist models. In 1989, Patterson, Seidenberg & McClelland gave a preliminary account of surface dyslexia by lesioning the

Seidenberg & McClelland (1989a) model. They discovered that damaging the hidden units produced a significant number of tests on which the model favoured the regularised pronunciation of an exception word to the correct pronunciation. Although such errors are a defining feature of surface dyslexia, there remain quantitative disparities between the simulations and the neurological findings. In particular, Patterson et al expected to simulate the performance of Type I surface dyslexics, since in common with the implemented model, they are believed to lack access to a semantic system. However, while these patients show *normal* reading of regular words and nonwords in conjunction with their poor performance on exception words, the model's performance on regular words and nonwords was outwith the normal range.

The emergence of connectionist models of reading is of particular interest to developmentalists investigating normal or impaired reading acquisition, the latter being the focus of the present study. Unusually for models of skilled reading, connectionist models contain an inbuilt portrayal of how this skill develops, and this feature was a fundamental part of the model implemented by Seidenberg & McClelland (1989a). In order to run the simulations described previously, the model had to approximate the normal adult's knowledge of English orthography and its correspondence to phonology. This knowledge had to be encoded in the weights on connections between processing units and to a large extent determined the model's ability to simulate the experimental data. Seidenberg & McClelland achieved this by preceding each simulation with a training regime during which the model could 'learn' the requisite knowledge. At the very start of this procedure only the basic architecture of the model was in place. The model was essentially a *tabula rasa*, with connection strengths in the network assigned random initial values between $\pm$ 0.5.

A training corpus of 2,897 words was chosen to provide a reasonable approximation to the set of *monosyllables* in the vocabulary of an average American reader. The training regime was divided into a series of 250 epochs, each containing

600 trials. The probability of a word being presented in any epoch was monotonically related to its estimated frequency according to adult norms. The use of this logarithmic transformation was not only motivated by practical constraints on the length of the training regime. It was also felt that compression of the frequency range would bring it more into line with the range experienced by a child and would counteract restrictions on the training set which particularly affected lower frequency words.

The process by which the model 'learned' to generate an appropriate phonological code is known as "back-propagation" (Rumelhart, Hinton & Williams, 1986). For each training word that was presented, the final patterns of activation that the model produced across the orthographic and phonological units were compared with their target patterns, the orthographic input pattern and the correct phonological code for this pattern, respectively. The discrepancy between actual and target patterns of activation was calculated for each unit and the model refined by adjusting the strengths of all the connections in the network in proportion to their contributions to the current inaccuracy of the model. It is interesting to note that Seidenberg & McClelland (1989a) suggested that the target phonological code involved in this procedure could in reality be:

> supplied as explicit external teaching input - as in the case in which the child sees a letter string and hears a teacher or another person say its correct pronunciation - or self-generated on the basis of the child's prior knowledge of the pronunciations of words and the contexts in which they occur.

By assaying the model's performance at various points during the training regime using Taraban & McClelland's (1987) set of stimuli, Seidenberg & McClelland were able to determine whether their model exhibited qualitatively similar characteristics to developing readers as it advanced towards its trained state. They concluded that the model captured many of the features described in Backman, Bruck, Hebert & Seidenberg's (1984) study of reading acquisition. For example, young readers in Grade 2 read exception, regular-inconsistent and ambiguous words less accurately than regular words. Early in training, the model also produces poorer output for exception words compared to regular-inconsistent words which in turn produced less accurate output than regular words. As children acquire reading skills, such differences between word classes gradually attenuate (in the case of low frequency words) or disappear (in the case of high frequency words). This was observed to happen in the model as well when a frequency by regularity interaction emerged during the latter stages of training.

Backman et al found that the reading of the normal readers in Grade 2 shared features with the reading of a group of poor readers from Grades 3 and 4. Seidenberg & McClelland (1989a) discovered that training their model with half the number of hidden units mimicked certain aspects of the poor readers' data. In particular, a general decrement in performance was produced, and despite doubling the number of training epochs, exception words produced poorer output than regular words for *both* high and low frequency stimuli. Seidenberg & McClelland concluded that although it was still possible for the model to make generalisations about spelling-sound correspondences with only 100 hidden units, the encoding of item-specific information concerning pronunciation had become more difficult.

While many details of the implementation will clearly need revision, the connectionist approach has proved potentially capable of accounting for some experimental, neurological and developmental findings despite having discarded many of the concepts traditionally held to be fundamental to the reading process. Of course, for the model to produce more realistic simulations, additional features need to be incorporated, notably the ability to handle multisyllabic stimuli (including stress assignment to syllables in pronunciation), the linking of the implemented system to semantic information (which will facilitate attempts to account for phonological and deep dyslexia e.g. Hinton & Shallice, 1989) and the inclusion of the effects of processing strategies. While it is tempting to become engrossed with the intricate modifications to the parameters of the model necessary to simulate quantitative results in the literature, Rosson (1985) warned of the "blinding effect" that this may have. She stressed the need to continue with research aimed at uncovering and clarifying the general principles involved in the reading process.

CHAPTER 2

APPROACHES TO MODELLING DEVELOPMENTAL DYSLEXIA

It is apparent from Chapter 1 that a theoretical crisis has descended upon the word recognition literature. While connectionist models contain much to portend a viable future, it is possibly too early to predict which, if any, of the current models will prevail. Therefore, heedful of Rosson's (1985) advice, the ensuing review will be of research with a primarily empirical motivation, namely, the characterisation of developmental reading disorders which bears directly upon the data to be presented in the later chapters. It is hoped that the foregoing outline of the models of skilled word recognition will prove helpful in appreciating the construction and interpretation of many of the experiments in this section. It should be borne in mind that it will be essential for any successful model of reading development, connectionist or otherwise, to accommodate the findings which will be presented.

2.1 EXCLUSIONARY CRITERIA: IDENTIFYING DEVELOPMENTAL DYSLEXICS FOR RESEARCH PURPOSES

First of all, a brief description of the criteria generally used to select the research population of developmental dyslexics is required. The consensus appears to have been to adopt the guidelines supplied by the World Federation of Neurology:

> [Dyslexia is] a disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence and sociocultural opportunity.
>
> Critchley (1975)

In 1979, Vellutino listed some additional conditions commonly used to exclude "secondary factors" in reading disability:

1. adequate peripheral visual and auditory acuity
2. absence of severe neurological or physical disability
3. absence of significant emotional or social problems

Excluding what are seen as extrinsic causes in this way greatly facilitates the identification of the target population of children who suffer from a very specific difficulty in acquiring literacy skills. Despite the widespread use of these criteria, the issue of whether this disorder can be shown to exist among children excluded by some of these conditions is still unresolved. However, both this question and the population to which it refers are outwith the scope of the present discussion.[1]

2.2 DEVELOPMENTAL DYSLEXIA AS A HOMOGENEOUS DISORDER

A strong tradition exists wherein developmental dyslexia is conceptualised as a unitary syndrome. Modern exemplars of this tradition can be traced back to the work of Orton, which was touched upon in Chapter 1. Vellutino (1979) reviewed some of the alternative single factor theories which have ensued. This included theories by Hermann (1959), who postulated a directional disturbance, Rabinovitch (1968), who proposed language and symbolic learning difficulties, and Bakker (1970), who argued that verbal sequential memory problems were solely responsible for developmental dyslexia.

When developmental dyslexia began to be related to the theories emanating from cognitive neuropsychology, it was not surprising that a unitary explanation was at first contemplated. Jorm (1979) claimed that developmental dyslexia had certain functional similarities to acquired deep dyslexia. He suggested that both syndromes were marked by deficient reading of nonwords and of low-imagery words, accompanied by a tendency to make visual errors. Jorm concluded that both difficulties involved a difficulty in reading via the phonological route. Ellis (1979) objected to this comparison on the grounds that while visual errors occur in virtually all of the acquired dyslexic syndromes, semantic errors were the defining feature of

[1] See Stanovich (1991) for a review of this issue in relation to intelligence, one of the most controversial exclusionary criteria.

deep dyslexia and these were apparently absent in developmental dyslexia. Jorm countered that the dyslexic child possesses some knowledge of grapheme -> phoneme rules which is sufficient to prevent them from reading, for example, *corn* as 'wheat'. However, the level of decoding skills in developmental dyslexia was a major factor in the rejection of Jorm's claims by Baddeley, Ellis, Miles & Lewis (1982). These authors studied a group of fifteen dyslexic boys who were approximately twelve years old. Baddeley et al demonstrated that even though the accuracy of these developmental dyslexics in reading nonwords was only 50%, they were less severely impaired than deep dyslexics whose nonword reading is typically virtually abolished. Baddeley et al also attributed the imageability effect that Jorm had reported, to a normal age-of-acquisition effect deriving from the tendency for abstract words to be learned later than imageable words.

Thus, the evidence seemed more supportive of a view put forward by Holmes in 1973, that the problems suffered by developmental dyslexics were similar to those of acquired surface dyslexics. Holmes reported that the "phonic" errors typical of surface dyslexia were also made by developmental dyslexics e.g. failure to apply the "e-rule", *wage* -> 'wag'; regularisation errors, *bristle* -> 'Bristol'. In addition, meaning was assigned on the basis of the response, not the target. However, Jorm (1979) argued that such errors which were held to be indicative of partial failure of grapheme -> phoneme rules, should not be interpreted as deriving from an impairment to the *visual* route. In fact, Jorm felt that many of these errors could be equally well described as visual errors e.g. *certain* -> 'carton'.

Snowling (1983) has also proposed that characterising developmental dyslexics as surface dyslexics may not be an accurate reflection of their problems. She was critical of the Baddeley et al (1982) study, suggesting that they were premature in playing down the phonological difficulties of the dyslexic children. Snowling cited a study by Firth (1972) and an earlier study of her own, Snowling (1981), as evidence in support of a substantial nonword naming difficulty in developmental dyslexia. In the 1981 study, Snowling also demonstrated that the ability of developmental dyslexics to read nonwords decreased dramatically as the phonological complexity of the stimuli increased. This indicated that one reason for the failure by Baddeley et al to discover a large nonword naming deficit might have been the simplicity of the monosyllabic stimuli that were used which together with phonics remediation may have masked fundamental difficulties.

2.3 DEVELOPMENTAL DYSLEXIA AS A HETEROGENEOUS DISORDER

(i) *Developmental Analogues of the Acquired Dyslexias*

In fact, it has transpired that the claims of Holmes (1973) and Jorm (1979) both contained an element of truth. Further attempts to apply the cognitive neuropsychological approach to the study of developmental dyslexia adopted the emphasis on single case studies as well as the psycholinguistic method. This step proved informative as what seemed to be developmental analogues of the acquired dyslexias began to be reported. While developmental dyslexics as a group may not have resembled any one of the acquired syndromes, this now appeared to be because the heterogeneity identified among acquired dyslexics also existed in the developmental disorder.

Johnston (1983) described the reading of an eighteen year old girl, C.R, and drew attention to the features she shared with deep dyslexics. In particular, C.R. was extremely bad at reading nonwords, scoring only 4% correct, and showed an imageability effect in word reading. Crucially, her reading also contained a few semantic errors e.g. *chair* -> 'table'; *down* -> 'up'; *seven* -> 'eight'. C.R. made one visual-then-semantic error as well, *sleep* -> 'lamb'. Unfortunately, it was difficult to draw any firm diagnostic conclusions from this case as the subject's I.Q. was below average and the possibility of detectable brain damage could not be ruled out since the subject reported receiving a blow to the head in early childhood.

Siegel (1985) reported four putative developmental deep dyslexics aged about eight years old with average I.Q's who also made some semantic errors e.g. *cat* -> 'kitten'. These children were unable to read nonwords and their responses were either lexicalisations or omissions. Siegel interpreted this as indicating a lack of phonological skills which she regarded as central to their production of semantic errors.

Temple & Marshall (1983) and Campbell & Butterworth (1985) have each reported cases of supposed developmental phonological dyslexia. These subjects demonstrated a dissociation between word and nonword reading similar to that found in acquired cases. In Temple & Marshall's case (a seventeen year old girl, H.M.) there were associated lexical difficulties but these were absent in Campbell & Butterworth's undergraduate subject, R.E.

Coltheart, Masterson, Byng, Prior & Riddoch (1983) identified a fifteen year old girl, C.D., who showed a similar pattern of reading to acquired surface dyslexics. She read regular words better than irregular words, tending to make regularisation errors e.g. *break* -> 'breek'. Moreover, she exhibited the classic feature of surface dyslexia, phonologically mediated comprehension, e.g. *bear* -> 'a drink ... beer'. However, C.D. was also impaired at reading nonwords, scoring only 31% correct, which was inconsistent with a purely lexical impairment.

Superficially, it appeared that the methods of cognitive psychology had adapted well to the study of developmental dyslexia since they had shown that the syndrome was heterogeneous in nature. This led Marshall (1984) to suggest that it may be possible to demonstrate a one-to-one mapping between the taxonomies of the acquired and developmental dyslexias. Marshall proposed that such isomorphism could extend to the interpretation of pathology:

> The syndromes of developmental dyslexia will accordingly be interpreted as consequent upon the selective failure of a particular adult component (or components) to develop appropriately, with relatively intact, normal (adult) functioning of the adult components.

Apart from the fact that the dual route model was taken to be the functional architecture of this adult system (the status of this model having already been discussed), what assumptions does Marshall's stance entail?

Marshall himself noted that "this is to adopt a highly modular, "preformist" approach to the development of the reading system". In this, Marshall seemed to be embracing Fodor's (1983) proposal that cognitive modules are necessarily innate. To the extent that reference is being made to modules that might derive from more "basic" attributes evolved for speech perception or visual pattern recognition, it is possible to countenance this nativist view. In fact, preliminary studies of the genetics of developmental dyslexia (e.g. Olson, Wise, Conners & Rack, 1989), have led Pennington (1990) to conclude that the accepted heritability component in the disorder may derive from genetic influences upon the development of spoken language skills. However, as reading is a culturally transmitted skill, the acquisition of which has only recently become widespread in Western countries, few psychologists are willing to entertain the notion that modules specialising in the conversion of print to sound have yet become part of our biological heritage (Ellis & Young, 1988).

The account of the process of reading acquisition favoured by Marshall (1984) was that "the modules underlying reading come into play at different points in time but in the same form that they take in the adult system". It is unclear just how far Marshall is prepared to take this account. The conclusion to this paper suggested some element of the devil's advocate in his stance, nevertheless, he has subsequently reiterated his support for an innate reading system (Marshall, 1987, 1989).

(ii) *Developmental Arrest*

Frith (1985) has been a convincing proponent of a more epigenetic view, arguing that constitutional and environmental factors all influence the acquisition of literacy. According to this view, the patterns of impaired and preserved skills in developmental and acquired dyslexia would not necessarily coincide. Snowling (1983) had earlier questioned the comparison of these disorders on similar grounds. She pointed out that the developmental level of the child, the extent of remedial training and even the choice of stimuli (as was seen in the discussion of connectionist models), could all alter the nature of the developmental dyslexic's performance. Frith (1985) advocated locating the causes of developmental dyslexia within the developmental process, which would create the following contrast between childhood and adult reading disorders:

> a developmental reading disorder is ... arrest at a particular phase in the developmental sequence. With an acquired disorder, a loss of a strategy may occur regardless of the order of acquisition. The patient may still retain a strategy that previously had been built up on the one he or she lost. A developmental disorder rules out such a case.

Frith went on to provide a model of the normal course of reading acquisition against which the performance of developmental dyslexics could be assessed. She considered a stage model to be the most appropriate framework since it would accommodate features of reading acquisition such as the gradual increases, plateaux, sudden improvements and drops in performance observed by Downing & Leong (1982). Frith chose to adapt an existing stage model devised by Marsh, Friedman, Welch & Desberg (1981) which was well supported by a body of empirical work. She captured the essence of this model in three stages, which were chosen so that they would link in with models of skilled reading. The strategies associated with these stages were described in the following way:

1.	*LOGOGRAPHIC STAGE*	instant recognition of familiar words using salient graphic features
2.	*ALPHABETIC STAGE*	knowledge and use of individual phonemes, graphemes and their correspondences to decode words
3.	*ORTHOGRAPHIC STAGE*	instant analysis of words into orthographic units without phonological conversion

Frith thought that the skills formed in each of these stages might be the source of the effects indicating multiple levels of segmentation in adult reading which were being reported by authors such as Shallice & McCarthy (1985). Nevertheless, the latter two stages of Frith's model bore a strong resemblance to the pathways of the Dual Route Model, with the alphabetic stage corresponding to the indirect phonological route and the orthographic stage corresponding to the direct visual route.[2]

Frith was now able to predict the types of developmental reading disorder which would be expected to occur given this developmental sequence. Assuming the dependence of later strategies upon those preceding them, she proposed that developmental dyslexics could be arrested either before Stage 2 or before Stage 3 (the failure of any of the strategies to develop at all was equated by Frith with severe subnormality or severe brain damage). Arrest at the Logographic Stage would produce reading showing a strong advantage for words over nonwords, and imageability effects. On the other hand, arrest at the Alphabetic stage would produce word length and regularity effects characteristic of the use of alphabetic skills; however, complete dependence upon such skills would not be expected since logographic skills should still be available. Frith maintained that these disorders corresponded to two of the six possible types of acquired dyslexia which would result from the loss of one or more of the strategies. She suggested that arrest at the Logographic Stage conformed to a type of acquired deep dyslexia in which orthographic skills were impaired, whereas arrest at the Alphabetic Stage was a variant of acquired surface dyslexia. Interestingly, the developmental deep dyslexics reported by Johnston (1983) and Siegel (1985) had reading ages of about six, and the developmental surface dyslexic of Coltheart et al (1983) had a reading age of around ten, thus corresponding to the general developmental sequence in Frith's model.

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[2] It is pertinent to note that although Frith's model is couched in traditional information-processing or *symbolic* terms, stage-like transitions of this type are also possible in connectionist models of development. The feasibility of this was demonstrated in Rumelhart & McClelland's (1986) model of past tense acquisition and confirmed in a simulation by Plunkett & Marchman (1989) that eliminated features of the earlier model which had proved controversial.

However, it is less clear how Frith's model would account for the reading of Campbell & Butterworth's developmental phonological dyslexic, R.E., who exhibited normal word reading despite marked phonological difficulties. Frith might suggest that compensatory strategies involving visual memory were built upon logographic skills, in this case to support normal word reading, but would one really want to say that the use of visual memory is a strategy outwith the normal process of reading acquisition? As Frith herself emphasised, her model was a framework which was designed to promote experimental investigation of reading development, and many such details remain to be worked out.

(iii) *Normal and Pathological Influences on Reading Strategy*

A question posed by Johnston (1983) is particularly germane at this point. To what extent are the isolated "pure" cases of developmental dyslexia typical of the population of developmental dyslexics as a whole? Potentially, the case study approach is extremely susceptible to distortion, caused by the selection of atypical subjects (Seymour, 1986; Wilding, 1989). Therefore, it is reassuring that the notion of heterogeneity has been upheld by group studies in which reading errors have been analysed.

Boder (1973) identified two distinct reading patterns within a group of 107 teenage developmental dyslexics. She referred to these patterns as "dysphonetic" and "dyseidetic" dyslexia, in which the impairments described were broadly similar to those found in the developmental cases of deep and surface dyslexia described above. However, in Boder's group the majority of subjects suffered from a combination of these impairments. This classification was very similar to the conclusions from another study by Ingram, Mason & Blackburn (1970). Mitterer (1982) set out to investigate the prevalence of these strategies in a younger age group. He studied 27 developmental dyslexics who were about eight years old and judged that there were at least these two types of developmental disorder.

Baron (1979) also confirmed Boder's findings, but extended this work to include children who were progressing normally through the early stages of reading acquisition. Thus, Baron demonstrated that beginning readers relying upon spelling-to-sound rules, whom he labelled "Phoenician", could be contrasted with other beginning readers making use of whole-word associations, whom he labelled "Chinese". An immediate assumption is that this reflects the developmental differences between normal readers predicted by Frith's model. However, as Snowling (1987) pointed out, this cannot be the whole explanation since Baron & Strawson (1976) have shown similar individual differences among proficient adult readers. Furthermore, Bryant & Impey (1986) published telling data which demonstrated that the patterns of "impairment" shown by the developmental surface dyslexic, C.D., and the developmental phonological dyslexic, H.M., were also found when the same tests were administered to a class of normal ten year olds. Only the developmental dyslexics' nonword naming performance was outside the normal range.

The discovery of heterogeneity among normal readers has serious repercussions for researchers such as Marshall (1984), who claim that the cause of developmental dyslexia can be inferred directly from the pattern of reading errors made by dyslexic children. It now seemed that causal inferences must await not only comparison with reading age controls, as recommended by Bryant & Impey (1986), but also the clarification of nonpathological influences upon reading strategies.

One such influence that is becoming widely recognised is the method of reading instruction that a beginning reader receives. Barr (1974-75) reported that the teaching technique experienced by children in their first year of reading instruction affected the strategies that they adopted for reading. More recently, Seymour & Elder (1986) studied beginning readers who were being taught through a standard initial procedure known as "look-and-say". Instruction using this technique involves the presentation of whole words for instant recognition without mention of spelling-to-sound correspondences. This study enabled Seymour & Elder to do much to clarify the nature of the reading skills available to children in Frith's Logographic Stage. Nevertheless, they noted considerable individual differences and speculated that the Logographic Stage may not necessarily occur if initial exposure to reading instruction were to take a different form.

A study by Wimmer & Hummer (1989) gave some support to this suggestion. These authors followed seven year old Austrian schoolchildren during the initial stages of reading acquisition. These children were exposed to a transparent orthography using a slowly advancing "phonics" approach. There was evidence of widespread use of phonological strategies after only six months of reading instruction and the authors concluded that the Logographic Stage is of limited importance to these children. Therefore, Frith's model may not be an invariant formulation of the process of reading development.

Johnston & Thompson (1989) compared the "phonics" and "language experience"[3] methods of reading instruction. These methods were found to have qualitatively different impacts upon reading performance, and to influence experimental effects which were previously thought to have diagnostic significance. The authors compared two groups of children matched on reading ability - New Zealand children who had been exposed only to a "language experience" approach and Scottish children who had received tuition in "phonics" from their first year at school. The authors used a lexical decision task to test these groups of children. In this task the children had to discriminate between words and nonwords. The nonword stimuli contained pseudohomophones (i.e. nonwords which sounded like real words when read aloud), in order to assess whether phonological recoding was taking place. When using a visual approach to reading, pseudohomophones should be easily classifiable as nonwords; it is only when their phonology is accessed that these nonwords might be mistaken for real words. The authors found that only the Scottish children were caught out by the pseudohomophones. This pattern of

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3 This approach is similar to the "look-and-say" method and eschews teaching children letter-sound relationships.

performance had been held to be developmentally typical e.g. Johnston, Rugg & Scott (1988), and indicative of a stage in reading where it was normal to carry out phonological recoding. Although the New Zealand children were as able as the Scottish children to identify the pseudohomophones when explicitly asked to do so, they were less accurate than the Scottish children at pronouncing these items. The performance of the New Zealand children was indicative of a preference for using a visual strategy in reading-related tasks which appeared to have been induced by the method of reading instruction that they had received.

Snowling (1987) also acknowledged that educational experience was likely to have an effect on reading strategy. She went on to argue that individual preferences, perhaps motivated by processing efficiencies, constituted another factor which merited investigation. She suggested that good readers who adopted a "Chinese" strategy may have developed normally and entered the alphabetic phase only to find that they were far more efficient at using a visual approach. Therefore, they may have concentrated upon this visual approach with slightly detrimental results for their alphabetic proficiency. Nevertheless, their potential to use these alphabetic skills enables their progression to the orthographic phase. The converse scenario would hold for readers adopting a "Phoenician" strategy. Furthermore, Snowling proposed that when developmental dyslexics suffer a phonological disorder, their subsequent reading development could also be shaped by the integrity of other cognitive resources such as visual or semantic skills.

Johnston, Anderson & Duncan (1991) have presented empirical support for this view in a study of developmental dyslexics. It was found that amongst the dyslexic children whose phonological segmentation skills were impaired for their chronological age, a more visual approach to reading was adopted, *providing that* visual segmentation skills were intact. The performance of the subjects who did not have normal visual segmentation skills reflected attempts to use a phonological strategy in reading. The authors assumed that the extent to which alternative strategies are adopted will also be subject to the effects of remediation and motivational factors.

Funnell & Davison's (1989) subject, Louise, may reflect a combination of these influences. She had a history of intermittent hearing loss which probably made a visual approach to reading appear more reliable. Her early experience of phonological difficulties also seemed to have promoted a conspicuous aversion to using "phonics" strategies in reading (Davison, personal communication). Both of these factors may have contributed to what the authors term her "lexical capture" approach, despite the existence of phonological skills which enabled her to master the International Phonetic Alphabet.

Thus, development which is atypical according to Frith's model can be found in studies of both good and poor readers. The evidence also implies that caution is needed when making diagnostic inferences from patterns of reading performance since these may reflect methods of reading instruction, or remediation, and individual strategy preferences, rather than giving a clear picture of impaired and preserved processing skills.

(iv) *Dimensional Classification*

In view of the above discussion, what now seems the best approach to the study of developmental reading disorders? To start with, the most appropriate way of conceptualising the heterogeneity present in the disorder needs to be assessed. As described earlier, one method popular in both group and case studies has been to assign developmental dyslexics to subtypes on the basis of their pattern of reading impairments. Assuming for the moment that the existing techniques are adequate indicators of underlying difficulties, do homogeneous subtypes really give a veridical picture of the variation in the developmental dyslexic population?

The concept derives from the delineation of syndromes in cognitive neuropsychology, and much of the criticism raised against the approach in that field is also applicable here. In 1984, Coltheart wrote that the concept of syndromes in the study of acquired dyslexia would be a transitory stage. He predicted that since a modular model of reading, like the dual route model, could be selectively impaired in many different ways, this would lead to many unique syndromes being produced. Furthermore:

> We might also expect fractionation of syndromes that is, demonstrations of the same syndrome with different underlying causes. For example, a patient will exhibit phonological dyslexia if he has either a) an impairment of graphemic parsing[4], or b) an impairment of phoneme assignment, or c) an impairment of blending.

Coltheart believed that this would prove too cumbersome a way of thinking about acquired dyslexia and might fruitfully be abandoned in favour of the interpretation of each case with reference to a single model of reading.

With the benefit of hindsight, Ellis (1987) reiterated this view and suggested that it is largely irrelevant whether, or not, new patients fall into pre-existing syndromes. What is really of interest to psychologists are patterns of performance and the implications that these yield for models of word recognition.

To return to the developmental literature, Wilding (1989) has argued that the "exclusive categorisation" of developmental dyslexics has led to the misrepresentation of many subjects' difficulties. For example, he considered the practicalities of establishing criteria for category membership and drew attention to a claim made by Coltheart et al (1983) that depressed accuracy scores to irregular words were a necessary and sufficient condition for classifying a poor reader as a developmental surface dyslexic. Wilding pointed out that this claim was ridiculous when performance was 0% for irregular words and 1% for regular words, but how does one determine the appropriate placing of cut-offs? Wilding also noted that so far developmental dyslexics have never shown a complete dissociation of the critical error categories. He illustrated this point in an extensive reanalysis of Holmes' (1973) data, where he questioned whether these subjects were indeed reading solely, or even mainly, using a GPC strategy and suggested that a substantial number of the

[4] Ellis (1985) was amused to note that despite their categorisation as phonological dyslexics, patients in this subtype have a fundamentally visual problem!

errors may instead reflect faulty matching to a sight vocabulary. This analysis also revealed considerable individual differences, leading Wilding to conclude that:

> developmental dyslexics do not fall into clearly distinguishable categories determined by different specific processing deficits

A similar view was put forward by Ellis (1985), who favoured a dimensional model of the heterogeneity present in developmental dyslexia over the traditional categorical model. The dimensional model, as described by Morris & Satz (1984), "orders children along dimensional axes in a multidimensional space". Ellis chose two skills which had featured in much of the previous research on subtypes to illustrate this model, namely, whole-word identification and grapheme -> phoneme conversion.

> One would expect most readers to be good, bad or indifferent on both tasks, but on a categorical model one might find several discrete clusters separated from the mass. [e.g. Boder's dysphonetic or dyseidetic subtypes] ... What the dimensional model predicts, however, is that there will be a complete and unbroken gradation of intermediate dyslexics linking such extreme cases.

The lack of absolute classification criteria for the developmental subtypes, highlighted by Wilding (1989), would be consistent with such a proposal. Moreover, regarding the variation in reading skill in terms of continuous dimensions in this way is really just adopting the consensus view that most human abilities are normally distributed.

Seymour (1990) agreed that category models were inappropriate and illustrated this in a scatterplot showing the nonword and low frequency word naming performance of cases which he studied in 1986. It was evident that neither accuracy nor latency partitioned the cases neatly into dysphonetic and dyseidetic subtypes.

A dimensional model of the heterogeneity in developmental dyslexia, therefore, appears very plausible. What implications does this have for theories of reading development? Frith's (1985) stage model would seem to be too rigid a framework as it does not allow for individual differences in reading acquisition. Furthermore, this model is descriptive rather than explanatory in nature. To have any hope of understanding normal or impaired reading development, it will be necessary to clarify how the strategies described in Frith's model are formed.

It was suggested earlier that reading may initially depend upon pre-existing skills designed for other purposes such as speech perception or visual pattern recognition. Recent developmental models of reading have begun to incorporate such skills as putative dimensional determinants of reading progress.

Morton (1989) gave an account of the information processing systems behind Frith's sequence of stages. He proposed that logographic recognition units for words initially map directly onto picture semantics, a hypothetical system thought to mediate between the visual world of objects and action. This system is said to have an established link to verbal semantics, a system set up for speech recognition and production. Knowledge about letters is gradually built up and as children gain a better appreciation of the elements within phonological representations of words, grapheme -> phoneme mapping rules are created. Thus, reading is no longer mediated by pictorial semantics and logographic reading has been abandoned. Meaning is procured via feedback from a response buffer to the verbal semantic system. The development of orthographic reading is separate and signifies that input representations have been constructed which take account of both letter position and morphological structure and these map directly onto verbal semantics providing an alternative route to word recognition. This model gives an intriguing account of logographic reading and suggests that phonological awareness, in some form, stimulates alphabetic reading. Unfortunately, it does not give similar insight into the processes which might lead to orthographic reading. While Morton's model is appealing because it liaises very well with a model of skilled reading, namely the Dual Route Model, it also shares certain of the drawbacks associated with this model which were discussed earlier.

Stuart & Coltheart (1988) have rejected the supposition that in normal development all children pass through the same stages in the same order. This view has already been considered in relation to the consequences of differing methods of reading instruction. Stuart & Coltheart, however, focus on the contribution that a child's existing skills make to reading development. They outlined a theory in which phonological awareness was assigned a central role, not only in determining the course of reading acquisition, but also in setting up "a route for direct lexical access". A child's ability to translate from *sound to print* was held to be crucial. Stuart & Coltheart suggested that beginning readers with good phonological segmentation skills and good knowledge of letter sounds could start to form an orthographic lexicon. Initially this would contain partial recognition units for words in their spoken vocabulary which they had never seen written down. Gradually, as they were confronted by these words in print, they were able to modify these preconceptions to encompass the conventions of the orthography. However, the authors speculated that an interactive relationship between phonological and orthographic skills might be necessary to account for the emergence of graphemic parsing ability.

Seymour (1990) recently formulated an alternative theory which was similar to Stuart & Coltheart's (1988) model in that phonological processing was regarded as having a causal role in reading development. However, Seymour retained all three of Frith's stages, albeit in an altered sequence. Logographic skills were held to develop concurrently with phonological skills, and both were fundamental to the construction of a fully operational orthographic system. Consequently, he refers to this as the *Dual Foundation Model* of reading development.

The emergence of these models marked recognition of the fact that previous models lacked an explicit account of the factors which *guide* a child's progress through the stages observed in reading acquisition. The putative "dimensions" contained in the last two theories mark significant attempts to rectify this omission. However, the specification of abstract notions like "phonological" or "visual" processing will be essential for the approach to be viable, especially if it is to be used to elucidate the impairments in developmental dyslexia.

The last section of the review reports upon research relevant to identifying psychological processes whose status may shape the acquisition of literacy skills.

CHAPTER 3

ESTABLISHING THE DIMENSIONS OF READING ABILITY

3.1 EVIDENCE LINKING PHONOLOGICAL PROCESSING WITH NORMAL AND IMPAIRED READING DEVELOPMENT

(i) *Studies of Nonword Naming*

Recently, phonological problems have come to be regarded as the crux of the developmental dyslexic's difficulty in acquiring word recognition skills (e.g. Frith, 1985). It was noted earlier that many group and case studies of developmental dyslexics had found evidence of phonological problems. For example, Boder (1973) concluded that *dysphonetic* dyslexics far outnumbered *dyseidetic* dyslexics from an analysis of dyslexic reading and spelling errors. Moreover, the vast majority of her subjects (84%) suffered some phonological difficulties.

Many contemporary studies of developmental dyslexia have been influenced by dual route models of reading. As a result, definitions of phonological problems have tended to be largely theoretically driven. Phonological difficulties were equated with damage to the phonological route. It was expected that reading performance would then be characterised by a reliance upon "whole-word" reading, in which there was no advantage for regular over irregular words and the errors produced bore little phonological similarity to the target word. Therefore, such features, together with poor nonword naming, a skill which was thought to be wholly dependent upon the phonological route, were regarded as indicators of phonological difficulties.

It will be recalled that Jorm (1979), in claiming that developmental dyslexia resembled deep dyslexia, and Snowling (1983) in her defence of this claim, drew support from studies associating poor nonword naming with poor reading ability by Firth (1972) and Snowling (1981), respectively. However, other putative *symptoms* shared with deep dyslexia such as visual, derivational, and to some extent, semantic errors have since been found among younger normal children reading at the same level as the developmental dyslexics (e.g. Bryant & Impey, 1986). Consequently, it seems better to interpret these features as *symptoms* of reading level rather than of developmental dyslexia. Nonword naming problems, on the other hand, have survived such reading age comparisons (e.g. Bryant & Impey, 1986). Therefore, it was thought that this phenomenon might hold some clues as to the nature of the developmental dyslexics' difficulties. This hypothesis became increasingly plausible as evidence mounted which suggested that nonword naming problems could even span what had otherwise come to be regarded as distinct syndromes within the disorder. For example, both the developmental *phonological* dyslexic, H.M. (Temple & Marshall, 1983), and the developmental *surface* dyslexic, C.D. (Coltheart, Masterson, Byng, Prior & Riddoch, 1983) suffered severe nonword naming problems.

To illustrate the features of this particular difficulty some experimental investigations of nonword naming will be reviewed.

In 1981, Snowling compared the nonword naming ability of developmental dyslexics and their reading age controls. Both the dyslexic and the control group were subdivided into a "high ability" and a "low ability" group on the basis of reading age. The higher ability groups had a reading age of about 10 years 7 months and the lower ability groups, a reading age of around 8 years. Snowling discovered that the developmental dyslexics were worse than their reading age controls at reading bisyllabic nonwords (e.g. *yomter*, *slosbon*), despite being equally accurate at reading monosyllabic nonwords (e.g. *fer*, *sted*). Both the dyslexics and their controls were found to become better at reading bisyllabic nonwords when they attained a higher reading level. Snowling's conclusion was that the developmental dyslexics were suffering from a phonological impairment. Nevertheless, she emphasised that in spite of this, their decoding skills still showed some improvement with reading age.

In a later study, Frith & Snowling (1983) replicated the disproportionate inability of developmental dyslexics to read bisyllabic nonwords given their reading age. The dyslexics studied were about 11 years old but their reading age was approximately two years below this level. These dyslexics also tended to show a reduced, if not abolished, regularity effect when reading real words. The authors took this as confirmation of a reliance upon a lexical strategy in reading.

Other studies have succeeded in identifying nonword naming impairments among developmental dyslexics using monosyllabic stimuli e.g. Seymour & Porpodas (1980); Baddeley et al (1982); Holligan & Johnston (1988). The study by Seymour & Porpodas was especially noteworthy because these authors had augmented their assessments by measuring response latencies, a technique more commonly used at the time to measure adult performance. They found that developmental dyslexics with reading ages of approximately 7 years 8 months, were equally as accurate at naming monosyllabic words as their reading age controls. Seymour & Porpodas were able to demonstrate, however, that the dyslexic children were substantially slower than their controls in performing this task. The reaction times of both the dyslexics and the reading age controls showed a word length effect, although this effect was very much amplified among the developmental dyslexics. A word length effect is generally taken to indicate the use of an analytic strategy, which of course takes longer as the number of elements to be decoded increases. Indeed, Seymour & Porpodas interpreted their results as evidence of an operational, but damaged, grapheme -> phoneme translation system. Baddeley et al (1982) drew a similar conclusion from their study of developmental dyslexics reading at the ten year old level, who were both slower *and* less accurate than reading age controls at reading monosyllabic nonwords.

Snowling (1980) also proposed that developmental dyslexics might be impaired at utilising grapheme -> phoneme correspondence rules. In this early study, she did not directly investigate naming but instead looked at the ability to match monosyllabic nonwords across the visual and auditory modalities. Therefore, with the visual presentation of a nonword e.g. *snod*, the subject would be asked whether the spoken word that followed e.g. *sond*, was the same or different. This was the Visual-Auditory (V-A) condition which was thought to be closest to reading.

Other conditions included a reversal of the order of the modalities as well as within-modality comparisons. Dyslexic subjects with reading ages ranging from 7 to 10 years were only found to be worse than their reading age controls in the V-A condition. Snowling suggested that these cross-modality comparisons depended upon grapheme -> phoneme conversion which implied that the developmental dyslexics were impaired in this ability. However, in contrast to her 1981 study, where improvements were seen in nonword naming ability with reading age, the deficit in rapid matching skill remained relatively constant.

As was evident in the discussion of dual route reading models, it is not possible to equate phonological decoding skills solely with grapheme -> phoneme conversion. In fact, multiple levels of spelling-to-sound correspondence were indicated. Consequently, the status of the grapheme -> phoneme conversion system is unlikely to be the only determinant of nonword naming skills. Developmental dyslexics may also find it more difficult than their reading age controls to group letters together in order to assign the appropriate phonology to consonant clusters or vowel digraphs. Indeed, Snowling (1981) demonstrated that the ability of developmental dyslexics to read nonwords deteriorated as the phonological complexity of these stimuli increased. In particular, dyslexic children were more disadvantaged than their reading age controls by the presence of consonant clusters in the nonword stimuli. This ties in with Seymour & Porpodas' (1980) finding that the slope of the function relating word length to reaction time was steeper for dyslexics than for their reading age controls. A possible reason for this was the increased phonological complexity of these longer nonwords e.g. *stam* versus *praist*.

Further reports of nonword naming deficits relative to reading age have come from Bradley & Bryant (1981), Kochnower, Richardson & DiBenedetto (1983), Backman, Bruck, Hebert & Seidenberg (1984) and Siegel & Ryan (1988) among others. However, the literature also contains failures to replicate this effect e.g. Treiman & Hirsh-Pasek (1985); Johnston, Rugg & Scott (1988).

Treiman & Hirsh-Pasek (1985) studied a group of developmental dyslexics aged about 11 years 9 months, whose reading was approximately three years below this level. These dyslexics were matched with a group of younger normal readers on the basis of their reading of regular words. Tests showed that the dyslexics were as accurate as their reading age controls at reading nonwords and were affected to a similar extent by regularity in word reading. Both groups were also found to make equivalent numbers of "sound-preserving" (i.e. regularisation) errors e.g. pronouncing *done* to rhyme with *bone*), which lent further support to the authors' claim that these developmental dyslexics were not deficient in their use of spelling-to-sound rules since they possessed phonological decoding skills which were appropriate for their reading age. However, there were a few counter-indications which would be more easily reconciled with the usage of a visual reading strategy. For example, developmental dyslexics made more lexicalisation errors and more "meaning-preserving" errors e.g. *blood* -> 'bleed' than their reading age controls. Nevertheless, these did not overshadow the main finding concerning nonword naming and the authors concluded that developmental dyslexics need not suffer a general inability to utilise spelling-to-sound rules.

Treiman & Hirsh-Pasek examined the methodology of their study for factors which could have produced their unusual results. One possibility they suggested was that approximately 70% of their nonword stimuli were monosyllabic and may not have been sufficiently complex to elicit deficits in nonword naming relative to reading age controls (Snowling, 1981). However, Baddeley et al (1982) *did* reveal a nonword naming deficit among developmental dyslexics using monosyllabic stimuli, and so the above may not suffice as an explanation of Treiman & Hirsh-Pasek's results.

Another feature identified by Treiman & Hirsh-Pasek was that the nonwords had been presented in lists containing orthographically-similar regular and exception words, which often only differed from the nonwords by one or two letters. The availability of related orthographic structures may have promoted the use of a lexical analogy approach to nonword reading. Indeed, there is some preliminary evidence that orthographic priming of this type can influence developmental dyslexics' nonword pronunciation. In an unpublished study, Snowling & Williams used the priming procedure devised by Kay & Marcel (1981) to test a group of ten developmental dyslexics aged about 12 with a mean reading age of 9 years 6 months. The dyslexic children were worse at reading monosyllabic nonwords (e.g. *coth*) than their reading age controls, but the performance of each group improved when these nonwords were preceded by orthographically similar real words (e.g. *moth/both*), relative to a neutral prime (e.g. *bull*).

In the light of these results, one is led to consider how the pronunciation of a nonword might be affected by the nature of its orthographic neighbourhood. In fact, Frith & Snowling (1983), who found dyslexic children to be deficient at nonword naming, specifically chose to use only bisyllabic nonwords like *molsmit* and *slosbon* because they believed that these stimuli would have no close neighbours in the lexicon. It is possible that studies which have failed to find deficits in nonword naming employed stimuli which had many or very frequent orthographic neighbours, thus facilitating the use of a lexical analogy strategy. Support for this hypothesis has just emerged in a study by Treiman, Goswami & Bruck (1990). These authors manipulated the rime unit in monosyllabic nonwords and compared the pronunciation of nonwords with common rimes (e.g. tain, goach) with that of nonwords containing novel or infrequent rimes (e.g. goan, taich). It was clear that subjects ranging from first graders to college students were more accurate at reading the nonwords with the more common rime units. Treiman et al speculated that the use of grapheme -> phoneme correspondences may normally increase when nonwords with infrequent rimes have to be pronounced. Therefore, it may be that grapheme -> phoneme rules pose a particular problem for dyslexic children. On the other hand, if lexical analogy strategies are the norm (Glushko, 1979; Marcel, 1980), then it may be that developmental dyslexics are less efficient than their reading age controls at applying analogies when the lexical referents are more obscure. However, the description of the developmental dyslexic, J.M., by Snowling & Hulme (1989) indicates that even being able to spot an appropriate lexical analogy for a nonword does not guarantee accurate pronunciation of that nonword. It seems likely that there are many aspects to nonword decoding, any of which could be impaired in developmental dyslexia.

In 1988, Bruck reported that developmental dyslexics aged between 8 and 16 years were as accurate as their reading age controls at reading nonwords created by altering a letter in a real word. Thus, the orthographic neighbourhoods of these stimuli could well have exerted this effect. However, an additional factor was identified which could well have combined to produce this finding. All of the developmental dyslexics tested had been receiving intensive phonics-based remediation which may have enabled underlying deficiencies in the use of spelling-to-sound rules to be covered up on simpler nonword stimuli. Snowling (1981, 1983) had already voiced a similar opinion. In particular, she had suggested that remediation may have been responsible for the improvement seen in nonword naming ability with reading age in her 1981 study. An identical explanation may be given of the findings by Szeszulski & Manis (1987) who demonstrated that 10 year old developmental dyslexics were deficient in their ability to pronounce nonwords relative to reading age controls, whereas 13 year old dyslexics were not. The extra remediation no doubt experienced by the older dyslexics may have served to improve their decoding skills.

Sample differences may also contribute to the confusion over the severity of the nonword naming problem in developmental dyslexia. Evidence to support this conjecture emerged from two studies carried out by Johnston and her colleagues. Johnston, Rugg & Scott (1988) reported that groups of developmental dyslexics reading at the 7 and 9 year old level did not differ from their respective reading age controls in a nonword naming task. On the basis of the arguments presented above, one could point to the use of monosyllabic stimuli which were closely matched to real words as an explanation of this result. However, the same stimuli were used in a study by Holligan & Johnston (1988) which did find a nonword naming deficit among dyslexic children with reading ages of 7.

Although it seems reasonable to conclude that developmental dyslexics vary in their nonword naming ability, the prevalence of studies reporting nonword naming difficulties suggests that this task is problematic for a large proportion of dyslexic children. It would be productive if it could be established whether the prevalence of this difficulty in developmental dyslexia is due to the frequency of impairments to one particular cognitive process, or if it instead reflects the fact that success in the nonword naming task depends upon many cognitive operations, any of which may be deficient among dyslexic children. A more complex explanation of nonword naming deficits than merely phonological impairment, is indicated by studies which have described dyslexic children who have nonword naming deficits and yet exhibit regularity effects in their word reading e.g. Holligan & Johnston (1988); Johnston, Anderson & Duncan (1991).

Nevertheless, Wilding (1990) has argued strongly against the use of reading-related tasks in the study of cognitive impairments in developmental dyslexia. His view was that impairments identified in this way may be either causes or *consequences* of poor reading. Wilding suggested that the risk of this confound may be reduced by using extrinsic tasks. An additional benefit of such tasks may be that they might offer a more explanatory account of the causes of reading difficulties than can be provided by the theoretically motivated descriptions of reading patterns that have just been reviewed. This section will conclude with a discussion of two specific areas of phonological processing which have been linked to reading achievement through investigations employing extrinsic tasks, namely phonological awareness and phonological short-term memory.

(ii) *Studies of Phonological Awareness*

a) SENSITIVITY TO PHONEMES

The centrality of phonological awareness skills to the theories of Stuart & Coltheart (1988) and Seymour (1989, 1990) is testimony to the extent of the research linking such phonological skills with reading development. This body of converging evidence has accrued from longitudinal and training studies of beginning readers, as well as from comparisons of normal and disabled readers at various stages of development. Interest in the influence of phonological awareness upon reading development dates back to the early 1970's. It was proposed that with an alphabetic script, the acquisition of literacy skills may be dependent upon the ability to make an explicit analysis of spoken language (e.g. Mattingly, 1972; Rozin & Gleitman, 1977; Liberman & Shankweiler, 1979). For example, children who are able to discriminate between *pin* and *pen* do not necessarily know that each contains three separate phonemes. This type of explicit phonemic knowledge was believed to be important in order to fully grasp the grapheme -> phoneme correspondences hypothesised in the Dual Route Model of the time e.g. Coltheart (1978). Moreover, the establishment of such phonological decoding skills was seen as a fundamental part of reading acquisition (e.g. Guthrie & Seifert, 1977) and has since been conceptualised as a crucial step in the development of reading skills (e.g. Frith, 1985).

> If for the first stage of learning to read, the learning of rules relating letters or letter groups to the individual sounds (phonemes) of English words is crucial, it will be necessary that the child be first capable of analysing spoken words into their constituent phonemes. A child who is poor at such phonological analysis should therefore experience difficulties in learning to read.
>
> Coltheart (1983)

Liberman, Shankweiler, Liberman, Fowler & Fischer (1977) reported that half of the second grade children who scored in the lowest third of their class in a reading achievement test had failed a test of phonemic awareness the year before. In contrast, *none* of the children in the top third of the class at reading had failed this test, which involved tapping out the number of phonemes in a word. The predictive validity of phonemic segmentation tests was also suggested in a study by Share, Jorm, Maclean & Matthews (1984). These authors used a composite test reflecting both initial phoneme deletion and the complete segmentation of a word into its constituent phonemes. They tested children at school entry and demonstrated that performance on this test correlated very highly with reading achievement in kindergarten (0.66) and in first grade (0.62). Unfortunately, neither of these studies controlled for the effect of intelligence on both phonemic awareness and later reading achievement, making it difficult to be confident that their findings reflect phonemic awareness rather than simply general ability.

Fox & Routh (1980) selected 45 children from a first grade class who were all of average intelligence but varied in their level of reading attainment. Three groups were studied - average readers, children with mild reading difficulty and children suffering from severe reading disability. The authors found that the children who were reading normally or with mild difficulty had no problems in carrying out a task which involved segmenting syllables into phonemes, whereas the children with severe reading disability were extremely poor at this task. It was concluded that phonemic analysis was an important process in the initial stages of reading acquisition.

Thus, there appeared to be a relationship between phonemic awareness and reading ability. It seemed that the ability to analyse words into phonemes was responsible for success in reading acquisition; nevertheless, these studies had failed to establish that it was not reading acquisition itself which had promoted phonemic segmentation skills. In fact, children show little evidence of possessing phonemic segmentation skills before learning to read. Bruce (1964) investigated the ability of children aged between 5 and 7 years old to delete the initial, medial or final phoneme from spoken words. He discovered that the younger children found this task virtually impossible. It was only when children had achieved a mental age of around 7 years that they began to have some success in the task. Liberman, Shankweiler, Fischer & Carter (1974) reported a similar developmental sequence. None of the 4 year olds and only 17% of the 5 year olds in their study managed to tap out the phonemes in a word. However, by the age of 6, 70% of the children were correctly identifying the number of phonemes in words.

Furthermore, Ehri & Wilce (1980) demonstrated that the phonemic awareness of 9 and 10 year old children was influenced by their spelling knowledge. When these children were given phonologically similar but orthographically different words (e.g. *pitch* and *rich*), they tended to ascribe more phonemes to the longer words.

It was necessary, therefore, to determine whether the emergence of phonemic awareness at the start of reading acquisition was providential or a product of reading instruction. Fortunately, Morais and his colleagues were able to locate suitable conditions which would allow these two possibilities to be teased apart. They discovered that in certain agricultural areas of Portugal illiteracy was still the norm. However, in the area that they studied, Leiria, some people had been taught to read as adults either when they did their military service or when they went to work in a local factory. Morais, Cary, Alegria & Bertelson (1979) compared a group of these ex-illiterates with some fellow inhabitants of the area who had remained illiterate. They tested their ability to add and delete consonants at the beginning of words and nonwords, and found that the illiterates were very much worse at this task than the ex-illiterates. In fact, 50% of the illiterates failed on all of the nonword trials, whereas none of the ex-illiterates showed such a complete inability to perform these phonemic manipulations. This result contradicted the hypothesis that phonemic awareness emerges spontaneously as part of normal cognitive development.

Subsequent studies have confirmed and extended these findings. Morais, Cluytens, Alegria & Content (1986) replicated the earlier result while demonstrating that there was no difference between the illiterates and ex-illiterates in a musical segmentation task. Bertelson, De Gelder, Tfouni & Morais (1989) have carried out a study of comparable Brazilian adults and report that the performance of illiterates dropped to floor level when faced with a consonant deletion task, whereas ex-illiterates had very little difficulty with this task.

Of course, it is probable that literacy skills are not the only way in which the two groups differ, for example, intelligence, motivation and communication skills may also separate these subjects. Other studies have circumvented this problem by investigating subjects who are literate in either an alphabetic or a nonalphabetic script. Read, Zhang, Nie & Ding (1986) compared Chinese adults who by virtue of their age, had only been taught to read the traditional logographic characters, with those who had also learned the alternative alphabetic script Pinyin. Read et al tested these subjects on the consonant deletion task devised by Morais et al (1979). Analyses revealed that the performance of the logographic group was very similar to that of the Portuguese illiterates, whereas the alphabetic group resembled the ex-illiterates. The authors concluded that it was not learning to read *per se*, which promoted phonemic awareness, but rather learning to read an alphabetic script.

Mann (1986) contrasted the phonemic awareness of American and Japanese children in the first four grades of school because the Japanese children were learning to read the syllabic script Kana. She gave the children both a phoneme tapping and a consonant deletion task. The younger Japanese children were much worse at these phonemic tasks than their American contemporaries, which was consistent with the notion that experience with an alphabetic script leads to phonemic awareness. However, in apparent contravention of the unidirectionality of this notion, the performance of the Japanese children improved as they got older. Nevertheless, it is difficult to draw any firm conclusions from this result since some Japanese kana represent phonemes. Moreover, unlike logographic Chinese, Kana is a phonetic script and consequently reading instruction may indirectly draw attention to phonemes.

Finally, Alegria, Pignot & Morais (1982) examined the effects of *phonics* and *whole-word* methods of reading instruction upon phonemic awareness. They discovered that first graders receiving phonics instruction were far superior at reversing the order of phonemes in two-phoneme words than those receiving whole-word instruction. Unfortunately, no information was given about the relative reading abilities of the two subject groups and so it remains possible that this effect was really mediated by differing literacy skills.

Evidently learning to read an alphabetic script normally stimulates phonemic awareness. However, is this the full extent of the relationship between phonemic awareness and reading acquisition? Training studies have been used to determine whether improving phonemic awareness leads to greater success in reading. It is clear that even if an awareness of phonemes does not usually emerge prior to reading instruction, it is possible to improve phonemic segmentation skills at the preliterate stage by other methods e.g. Fox & Routh (1984); Content, Kolinsky, Morais & Bertelson (1986). However, as Content et al acknowledged, the skills which derive from training are unlikely to be the equivalent of phonemic awareness developed during reading acquisition. One obvious example would be the absence of orthographic influences such as those demonstrated by Ehri & Wilce (1980). Nevertheless, it is of great interest whether any sort of phonemic awareness can be shown to influence reading acquisition since a positive effect would mark phonemic awareness as a possible "dimension" of reading ability. Unfortunately, many of the training studies which have directly assessed outcome in terms of conventional reading performance have confounded phonemic awareness training with instruction about letter-sound correspondences e.g. Goldstein (1976); Williams (1980). However, Lundberg, Frost & Petersen (1988) concentrated upon giving their subjects a phonological training. These authors gradually taught a group of 6 year old Danish preschoolers to segment words into phonemes, while a control group received no training at all. After eight months of training, the experimental group was much better at manipulating phonemes than the controls, who initially had actually been better at such tasks. The effects of training could also be seen in later reading acquisition. When post-tests were administered during the following two years, the experimental group was found to be superior at reading and spelling words. This appeared to be a specific, rather than a general, educational effect since the experimental group was worse than the controls at a mathematics test. Although the control condition could have been improved by administering some form of nonphonological training to the subjects, this study provides convincing evidence that phonemic awareness is advantageous to reading acquisition.

It now seems possible that the relationship between phonemic awareness and reading development can be interactive. However, it remains true that the majority of preschoolers do not appear to be able to reflect upon the phonemic structure of speech prior to reading instruction. Furthermore, the existence of the subject R.E. (Campbell & Butterworth, 1985), suggests that literacy skills can still be acquired despite longstanding phonological difficulties. Consequently, predictions of later reading disability on the basis of poor phonemic awareness at the preschool level seem unlikely to be completely reliable. Nevertheless, this should not detract from the importance of such information in cross-sectional and longitudinal studies. In fact, it is to be lamented that so few studies have investigated whether dyslexic children have developed *phonemic* awareness which is commensurate with their reading ability. It will be important to establish if there are certain levels of insensitivity to phonemic knowledge which preclude normal reading development. However, these limits of performance may turn out to be identifiable only *after* explicit instruction on this topic at the preschool level, or when account is also taken of some measure of visual functioning such as visual memory.

b) Sensitivity to rhyme

Another reason for the shortcomings in the use of preschool phonemic awareness as a predictor of future reading is that the ability to isolate phonemes appears to be only one aspect of phonological awareness. Morais, Alegria & Content (1987) have proposed that phonological awareness is divided into three levels:

1. *Awareness of Phonological Strings*
   the ability to disregard meaning and to concentrate upon the phonological form of speech

2. *Phonetic Awareness*
   the awareness of speech as a sequence of phonetic segments or phones, which is highly influenced by perceptual or articulatory properties

3. *Phonemic Awareness*
   a more abstract awareness of speech as a sequence of phonemes[1] which is achieved by disregarding irrelevant phonetic variations and can be influenced by orthography

They further suggested that while phonemic awareness may depend upon exposure to an alphabetic script, phonetic awareness can in some cases precede the acquisition of literacy skills. As regards the awareness of phonological strings, Morais et al concluded that most people possess such awareness prior to learning to read. However, they drew a clear distinction between this ability and the segmental awareness characteristic of literate subjects. An alternative view has attributed a greater significance to this type of phonological awareness in reading development and is based on investigations of children's awareness of phonological segments which are larger than the phoneme. These studies will now be reviewed as they contain more substantial evidence of phonological impairments among developmental dyslexics, primarily because these studies have controlled for the effect of reading experience by using reading age comparisons.

In 1978, Bradley & Bryant demonstrated that a group of 10 year old developmental dyslexics differed from their younger reading age controls on the Bradley Auditory Organisation Test. This test involved grouping together three of four spoken monosyllabic words on the basis of a shared initial, middle or final phoneme and identifying the remaining word which did not conform to this grouping. This description makes the task seem like a test of phonemic awareness, but in reality, only the initial phoneme condition (e.g. *sun see sock <u>rag</u>*), could be said to depend upon phonemic awareness. The other two conditions could be solved

[1] a phoneme is a group of phones that speakers of a language consider to be variations of the same sound (Balmuth, 1982) e.g. the sound of t in *ten* and *stop* are examples of different phones but the same phoneme (Wagner & Torgesen, 1987)

on the basis of rhyme, since in the middle phoneme condition the words shared their last phonemes (e.g. *nod red fed bed*), and in the final phoneme condition the words shared their middle phonemes (e.g. *weed peel need deed*). Although both groups of subjects were reading at the seven and a half year old level, the developmental dyslexics were far worse than their reading age controls in all three conditions. This result did not appear to be due to differences in memory since the groups had been matched beforehand on their ability to remember similar lists of words. Both groups had particular difficulty with the initial phoneme condition, supporting earlier suggestions that phonemes are relatively inaccessible during the initial stages of reading development, and the dyslexics were especially disrupted by this condition. The developmental dyslexics' problem with rhyme was confirmed in an additional experiment in which subjects had to provide a rhyming word for each of ten spoken words (e.g. *dish*). Once more there was a relative deficit among dyslexic readers, 38% of whom failed to produce a rhyming word in one or more trials, compared to only 7% of the controls.

These results are especially striking given the age of the dyslexic subjects and the fact that neither of the tasks required the explicit segmentation or manipulation of phonemes which is normally associated with complexity in phonological awareness tests (Lewkowicz, 1980; Yopp, 1988).

Unlike phonemic awareness, sensitivity to rhyme generally emerges before reading instruction begins. Read (1978) reported that 5 year olds had no difficulty in identifying rhymes for a puppet called Ed who liked words which sounded like his name. Goswami & Bryant (1990) have emphasised the normal spontaneity with which a sensitivity to rhyme develops. For example, Chukovsky (1963) wrote of a two and a half year old child who composed a rhyming poem around the word *milk*, and Slobin (1978) described his 3 year old daughter's rhyming play:

"Eggs are beggs. Enough-duff. More-bore."

Nevertheless, Goswami & Bryant also note that there are considerable environmental inducements to become aware of rhyme. Children are well known to enjoy nursery rhymes and games involving rhyming sounds, and often receive a great deal of exposure to such material at the preschool stage. It is possible that this increases their awareness of rhyme. Indeed, MacLean, Bryant & Bradley (1987) published a study involving 65 three-year-olds whose knowledge of nursery rhymes at this stage correlated highly with their sensitivity to rhyme two years later. However, this result is ambiguous since nursery rhyme knowledge was assessed by asking the child to recite various nursery rhymes and hence was also a test of the child's verbal memory.

Among illiterates too, there is an appreciation of rhyme. Morais (1991) has studied an illiterate Portuguese poet who had entertained people for many years with rhyming poems of his own creation. His performance on tests of rhyme appreciation and production was 100%, and considerably superior to other illiterates tested who scored 66%. However, he could not be distinguished from other illiterates on tests involving phonemic segmentation. This case implies that a lifelong appreciation of rhyme need not lead to phonemic awareness.

Olson, Wise, Conners & Rack (1990) have recently presented data on mono- and di-zygotic twins which were consistent with genetic involvement in rhyming fluency. Their conclusions were based upon a test of rhyme generation, one of the less demanding tests of phonological awareness (e.g. Bradley & Bryant, 1978; Yopp, 1988). In fact, the performance of the 15-year-old disabled readers did not differ from that of their 10-year-old reading age controls on this test. Nevertheless, the idea that weak rhyming skills may be heritable in developmental dyslexia is very pertinent to the present discussion.

How does sensitivity to rhyme relate to phonemic awareness? Bertelson & De Gelder (1989) speculated that:

> rhyme decisions do not require analysis into segments proper and can be carried out at the level of syllables by appreciating some holistic sound identity or similarity

Accordingly, the illiterate poet was found to be superior to his fellow illiterates at manipulating syllables in phonological awareness tests. Experimental studies of preschoolers also endorse the view that rhyme and syllables are more naturally accessible than phonemes. Liberman et al (1974) reported that although none of the 4 year old children in their study could segment by phoneme, almost half of these children were able to segment by syllable. The theory that young children make rhyme judgements on the basis of some kind of holistic sound identity is consistent with a study by Lenel & Cantor (1981). In an auditory forced-choice rhyme selection task, 5 year old children were found to make more mistakes on an exemplar like *sun* when the incorrect choice shared some of its sounds, for example, rejecting *pin* was harder than rejecting *cat*.

The holistic and rudimentary nature of rhyming skills made claims that developmental dyslexics often find rhyme a problem particularly intriguing. Attempts were made, therefore, to establish whether young children's awareness of rhyme was predictive of their future reading ability. Bradley & Bryant addressed this question in a large-scale, longitudinal study of 403 children aged between four and five years. The study began before these children could read in order to avoid any confound with existing reading skills. In 1983, the authors reported that the children's initial performance on the Auditory Organisation Test had accounted for a significant proportion of the variance in their reading achievement over three years later. This result held even after controlling for differences in intelligence. This effect appeared to be specific to literacy since these early phonological skills were not predictive of later mathematical ability.

Thus, there appeared to be a link between preschoolers' sensitivity to rhyme and their later reading achievement, but was this link causal? Bradley & Bryant carried out a concurrent training study to investigate this issue. When the children were 6 years old, they selected 65 who had been poor at the Auditory Organisation Test and divided them into four training groups. Groups 1 and 2 received phonological training in rhyme and alliteration, but Group 2 also learned about letter-sound relationships. The other groups were controls, with Group 3 receiving training in conceptual categorisation, and Group 4 receiving no training at all. Analysis of results after two years of training revealed that rhyme and alliteration training had a preferential effect on later literacy skills which was independent of intelligence. However, the improvements due to this training only achieved significance over training in conceptual categorisation when combined with instruction in letter-sound correspondences. Therefore, despite being suggestive of a causal link between phonological awareness and reading achievement, Bradley & Bryant's results were certainly not unequivocal.

An additional problem with Bradley & Bryant's study was that it took place while the children were learning to read, making it difficult to discriminate the effects of training from those of reading instruction. Lundberg, et al (1988) argued that phonological training administered to prereaders would provide a better test of its causal influence upon reading. MacLean, Bryant & Bradley (1987) presented a longitudinal study of preschool awareness of rhyme and its correlation with early reading ability. Rhyme detection scores at age 3 were found to be significantly related to initial reading success over a year later, but had no relation to early arithmetic skills. When children who were beginning to read at this stage were compared with those who could not yet read, it was revealed that the year before, these children had also been better at detecting which of three words did not rhyme. However, initial rhyming ability was not related to the presence of letter recognition skills in these children, suggesting that such skills may be dependent upon other, possibly more visual factors.

c) Sensitivity to onsets and rimes

The relationship between early rhyming skills and later phonemic awareness is currently a controversial issue. Bryant, MacLean, Bradley & Crossland (1990) have outlined three models of the connection between phonological awareness and reading. They represented the stance of Morais et al (1987) as suggesting that rhyming skills do not make a direct contribution to reading. However, the view contained in the paper by Morais et al was rather different. Morais et al proposed that the absence of rhyming skills at the preschool level could derive from factors other than a phonological impairment, nevertheless they did believe that children who did not develop rhyming skills after appropriate stimulation were at risk of not attaining segmental awareness. The crucial prerequisite for normal reading was described as the capacity to *become* aware of even smaller phonological segments. Bryant and his colleagues have attributed a more distinctive role to rhyming skills in reading development (e.g. Bradley & Bryant, 1985; Goswami & Bryant, 1990; Bryant et al, 1990). Before considering this view it is necessary to introduce two structures which are now thought to be part of the phonological awareness puzzle, namely *onset* and *rime* units.

MacKay (1972) presented evidence arising from speech errors that the syllable has a hierarchical internal structure. He studied synonymic intrusion errors in which synonyms are mistakenly combined (e.g. *start* and *go*). MacKay noted the prevalence of combinations such as *sto* and the rarity of alternatives like *so*. He concluded that a split which preserved the integrity of both the initial consonant cluster and the remaining vocalic group was the most natural syllabic division. These units respectively became known as the "onset" and the "rime" e.g. in *start* the onset is *st* and the rime is *art*.

Treiman's work with adult subjects demonstrated the psychological reality of onset and rime units (e.g. Treiman, 1983; Treiman & Zukowski, 1988; Treiman & Chafetz, 1987). In 1985, she turned her attention to the saliency of these units in children's speech perception. In one experiment she focussed on the onset and tested initial consonant segmentation. She compared the difficulty of stimuli in which the onset was either a single consonant or a consonant cluster. Hence, subjects would have to segment either the complete onset or just part of the onset. Her subjects were aged between four and six years old and she was careful to make the experiment accessible to them. Treiman selected a relatively easy phoneme recognition task and, following Read (1978), asked the children to select "words" which a puppet with a favourite sound would like. The results showed that these children were much more accurate at recognising consonants (*s* or *f*) when they corresponded to the onset (e.g. *sem* or *fal*) than when they formed only a part of the onset (e.g. *sme* or *fla*). Treiman concluded that this was because the children perceived the onset as a cohesive unit making it difficult to segment.

Goswami & Bryant (1990) pointed out that Treiman's findings were not conclusive. They pointed out that her results could simply reflect the difficulty of segmenting *any* consonant cluster and may not be specific to the onset unit. Kirtley, Bryant, MacLean & Bradley (1989) presented an analysis of onset-rime segmentation which included the control conditions that Treiman's study had lacked. They tested a group of 64, five and a half year-olds using a version of the Auditory Organisation Test. The children were found to be better at categorising words on the basis of their initial sounds (e.g. *peg* *<u>land</u>* *pin pot*), than on the basis of their final sounds (e.g. *lip lap* *<u>beg</u>* *map*). In a second experiment, the authors investigated whether this result could have been due to the inaccessibility of all final sounds rather than to the salience of the onset. They made the following predictions. If final-sound categorisation is difficult by virtue of the sound's position alone, there should be no difference between the conditions *top* *<u>rail</u>* *hop* and *mop whip* *<u>lead</u>*. If onset-rime units are salient, however, then the *mop whip* *<u>lead</u>* condition should be more difficult since the similar words share only part of the rime. On the other hand, at the beginning of CVC words there should be no advantage in sharing more than one sound if the onset forms the basis of categorisations, so *doll deaf* *<u>can</u>* should be no more difficult than *<u>cap</u>* *doll dog*. The subjects in this experiment were 5, 6 and 7 year old children. Their performance confirmed the authors' predictions and verified that children of this age are sensitive to onsets and rimes.

There was evidence in the study by Olson et al (1990) that developmental dyslexics may have difficulty with onset-rime segmentation. The 15 year old dyslexic children were worse at manipulating onsets and rimes than younger controls who were also reading at the grade 6 level. The task used was a version of Pig latin in which the subjects heard a word and were instructed to move the initial phoneme from the beginning to the end of the word and to pronounce the result ending in *ay*. Thus, *plant* would become *lantpay* by virtue of phonemic segmentation. Interestingly, many subjects made errors reflecting onset-rime segmentation (e.g. *antplay*), which were consistent with the original Pig latin rules. The authors discovered that if these errors were also accepted as correct, the resulting compound measure of phonological awareness was more strongly related to word recognition and nonword naming than the original phonemic awareness score. Estimates of the heritability of this measure of phonological awareness were significant. Furthermore, Olson et al concluded that this type of phonological awareness, together with rhyming fluency, may be instrumental in the heritability of phonological decoding problems. However, Byrne (1987) has proposed that the use of orthographic images may be integral to the performance of tasks such as this which would somewhat confound these conclusions about phonological awareness.

Sensitivity to onset and rime units appears to have the potential to link the relatively holistic appreciation of rhyme that very young children seem to possess with the phonemic awareness demonstrated by older literate children. A developmental sequence from syllabic to phonemic awareness has already been indicated in studies such as Liberman et al (1974). The salience of the onset of a word may explain why several studies have been able to demonstrate "phonemic" awareness among very young children. For example, Calfee (1977) and Content, Kolinsky, Morais & Bertelson (1986) presented evidence that 4 and 5 year-olds could detect phonemes; their tasks, however, both involved attending to a single initial phoneme which of course, corresponded to the onset. One could speculate that sensitivity to the onset eases the development of a more phonemic level of awareness since the child gains experience of small units of sound.

More specifically, Goswami (1986, 1988) has outlined the means by which she believes an awareness of onset-rime units is related to reading acquisition. The evidence persuasively supports her argument. Goswami (1986) demonstrated that children aged between 5 and 7 years old could read new words through the use of analogies. This was previously thought to be a relatively mature reading strategy (e.g. Marsh, Friedman, Welch & Desberg, 1981). Children appeared to be utilising their appreciation of phonological similarities in making these analogies. Goswami's method was to identify groups of orthographically and phonologically similar words which the child could not read e.g. *beak*, *weak*, *leak*. One of these words was then chosen as a "clue" word (e.g. *beak*), and presented to the child along with its pronunciation. This item remained in view while the effect that this knowledge had on the child's ability to read various other words was tested. These other words were either "analogy" words (e.g. *weak* or *bean*), or a control word which had letters in common with the clue word but not in the same sequence (e.g. bask). It turned out that the children were most adept at making analogies between words like *beak* and *weak*. These words had the same final three letters and hence had common rime units. While the 6 and 7 year-olds sometimes would make analogies between *beak* and *bean* as well, such a strategy was rare among the 5 year-olds. In a later study, Goswami (1990) demonstrated that this result had not been due to phonological priming by showing that the clue word *head* was more likely to help children to read *bread* than *said*. Goswami (in press) reported that the basis of the successful analogies made by 7 year old olds, clearly corresponded to the linguistic onset and rime units. Children were more likely to use a common consonant cluster to link two words when this cluster formed the onset than when it appeared as part of the rime (e.g. *trim-trot* versus *wink-tank*). Furthermore, the addition of a common vowel to these words produced a greater increase in end analogies (e.g. *wink-pink*), than in beginning analogies (e.g. *trim-trip*), presumably because the former pair now share the entire rime unit. Therefore, Goswami concluded that children learn about orthography by noticing the commonalities between spelling and sound. They accomplish this by grouping words on the basis of the phonologically salient onset and rime segments. Goswami argued that such a strategy would be far more advantageous in the early stages of reading acquisition than the use of grapheme -> phoneme rules, since it would allow the "regularities" amongst words like *light*, *fight*, and *night* to be exploited. She speculated that the derivation of grapheme -> phoneme correspondence rules is a feature of later reading development.

Independent support for Goswami's theory has been presented in the form of a computerised method of reading instruction devised by Wise, Olson & Treiman (1990). These authors studied a group of 20 first graders who were around 6 years old. The children were trained in the pronunciation of CCVC or CVCC words through computer pronunciation of subword units obtained either by onset-rime or post-vowel segmentation. Training appeared to be more successful when onset-rime segmentation was used since novel words which had been introduced in this way were remembered better. Wise et al suggested that spelling-sound correspondences at the onset-rime level were easier to learn because of the phonological salience of onsets and rimes. However, the advantage for onset-rime segmentation was primarily related to the retention of information, rather than to the ease of blending the subword units.

The absence of a clear-cut advantage for onset-rime segmentation in the blending condition of the Wise et al study is consistent with the results of Fayne & Bryant (1981). These authors reported that neurologically impaired and learning disabled children who were aged between 7 and 14 years old, responded best to training in synthesis when CVC words were segmented into initial bigrams and final consonants (e.g. *co-p*). Performance in response to this post-vowel segmentation was significantly better to a consonant plus final bigram split which was equivalent to onset-rime segmentation (e.g. *c-op*). Wise et al have claimed that this was an artefact due to training with a very artificial stimulus set. Fayne & Bryant used only nine words and six nonwords, each of which contained the short 'o' vowel sound and were of the form CVC. As Wise et al have argued, with such stimuli the initial CV unit may have an advantage over the single consonant cluster because of its greater orthographic and phonological content. Nevertheless, the results of both Wise et al and Fayne & Bryant give reason to doubt that onset and rime units play a central role in the blending process. Indeed, Helfgott (1976) presented data suggesting that onsets and rimes may be more associated with the process of segmentation than with blending.

d) OVERVIEW

Taken together, the studies reviewed above indicate that deficiencies in phonological awareness exist among developmental dyslexics and justify the assumption that these deficiencies may be related to their failure to acquire literacy skills. However, it is hard to obtain an overall picture of dyslexic children's phonological capabilities from observations which are temporally isolated and highly specific in their interest. Studies of developmental dyslexics which contain comprehensive or longitudinal analyses of their phonological skills, regrettably, are scarce. When one of these rare studies does appear, it proves very illuminating. Snowling, Stackhouse & Rack (1986) studied seven *phonological* dyslexics, and, in addition to including reading age controls, the authors made comparisons of individual performance within the dyslexic group on a range of experimental tasks. Three of the dyslexic subjects were reading at the seven-year-old level and the rest had reading ages of ten or above. When nonword naming was tested, only one dyslexic at the higher reading level was found to perform within the normal range. This child's success was possibly due to receiving remediation in phonics. The presence of regularity effects was variable, and only two of the dyslexics with low reading ages did not show a normal effect for their reading age. One of these children was alone in having difficulties with input phonology as indicated by the Wepman Test of Auditory Discrimination. This problem seemed to have repercussions throughout the phonological system, as evidenced by the child's poor performance in tests of rhyme judgement, Auditory Organisation, initial sound identification, Spoonerism production, nonword repetition and auditory short-term memory. The only exception to emerge was that the subject was able to segment words by syllable, in common with the other dyslexics tested.[2] Another *phonological* dyslexic, K.F., who had a higher reading age, did not exhibit input phonology problems but was impaired on rhyming tests, making more errors than reading age controls on the Auditory Organisation test. Nevertheless, K.F. could segment by syllable, and his performance was perfect on Perin's (1983) Spoonerism task, which involved transposing the initial phonemes of a forename and a surname, e.g. David Bowie -> Bavid Dowie.

The overwhelming picture to emerge from this study was one of considerable individual variation in the phonological difficulties of children grouped as having a common reading problem. Nevertheless, there was some suggestion that all of the dyslexics experienced some difficulties with rhyme. In the case of K.F., however, these rhyming difficulties were accompanied by preserved phonemic segmentation skills. This finding is inconsistent with the hypothesis that phonemic skills are developmentally dependent upon a sensitivity to rhyme. Clearly, the developmental links between the various aspects of phonological awareness which have been described in this review deserve further investigation among both normal and impaired readers.

(iii) *Studies of Phonological Short-Term Memory*

Although it has been a fruitful approach, phonological awareness is not the only aspect of phonological processing to have been investigated in relation to developmental dyslexia. Wagner & Torgesen (1987) reviewed other contexts in which the relationship between phonological processing and reading has been addressed, namely the retrieval of phonological codes and phonetic recoding in

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[2] Ellis & Large (1987) have suggested that syllabic segmentation is an aspect of phonological awareness which is only weakly related to reading. The weakness of this relationship may reflect the rudimentary nature of syllabic awareness which was evident in the foregoing review.

working memory.[3] In support of the involvement of the former process in reading disability, studies such as those of Denckla & Rudel (1976) and Katz (1986) have shown developmental dyslexics to be slower at naming objects, colours, numbers, and letters than normal readers of the same age. Evidence for a link between phonetic recoding in working memory and reading disability stems from investigations of the phonological similarity effect in good and poor readers. Shankweiler, Liberman, Mark, Fowler & Fischer (1979) reported that 8-year-old poor readers did not show a phonological similarity effect to the same extent as their chronological age controls when recalling rhyming and nonrhyming letters in serial order. However, Holligan & Johnston (1988) demonstrated that if poor readers were given lists which were one item shorter than their individual spans, then they did exhibit a normal phonological similarity effect. When faced with too many items to remember, neither the poor readers *nor* their reading age controls showed differential recall of rhyming and nonrhyming letters. Thus, the original finding by Shankweiler et al was due to a result which is common in the literature, namely that developmental dyslexics have reduced memory spans relative to their chronological age controls (e.g. Johnston, 1982; Johnston, Rugg & Scott, 1987). In the study by Snowling et al (1986), the authors also measured the auditory short-term memory of their subjects and discovered that performance on the Digit Span subtest of the WISC-R was worse than would be expected from the children's general intellectual level. The dyslexics' short-term memory was more in line with their reading age than their chronological age.

Another test administered by Snowling et al was nonword repetition. Despite individual differences among the dyslexic subjects, there was a general weakness on this task relative to the reading age controls. For two of the dyslexics, this was due to articulation difficulties. Snowling concluded that the problems of the others reflected difficulties in the process of phoneme segmentation, which would be

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[3] for a description of working memory see Baddeley & Hitch (1974) and Baddeley (1989).

necessary to assemble a new motor articulation programme in order to repeat the nonword.

Recently, Gathercole & Baddeley (1989) have proposed that nonword repetition is superior to the classic digit-span measure as a test of auditory short-term memory. They make this claim on the supposition that nonword repetition does not rely upon explicit lexical support. However, Snowling & Chiat[4] disagreed with this strong claim and argued that derivational affixes have a predictable effect upon the prosodic structure of words which can be used to aid performance, e.g. *glistering*. Nevertheless, the residual contribution of auditory short-term memory to the performance of this task cannot be ignored. Gathercole & Baddeley (1990) suggested various impairments which might hamper nonword repetition, for example:

1/ reduced capacity of the phonological store leading to fewer items being stored (or all items being stored less richly) resulting in an inadequate memory trace

2/ the short-term memory trace may decay faster in these subjects

Baddeley (1979) enlarged upon the effects that reduced phonological capacity may have upon reading skill. A phonological decoding strategy, whereby letters are decoded into speech sounds and then blended together, would be less effective since an impaired phonological store would mean that fewer sounds could be retained. Indeed, Torgesen, Rashotte, Greenstein, Houck & Portes (1988) found that developmental dyslexics with poor memory spans were impaired on a sound blending task relative to both normal readers and dyslexic children without memory span problems. The discovery of such an impairment when the speech sounds to be blended were supplied by the experimenter is strong support for the view that short-term memory problems will cause difficulties for dyslexics in decoding, storing, and blending in nonword naming tasks.

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4 paper presented at the Open Meeting of the Cognitive Neuropsychology Interest Group, London, February, 1990.

Baddeley (1989) discussed the additional strain placed upon short-term memory capacity by tasks which require a combination of storage and processing (see also Wagner & Torgesen (1987)). He proposed that some tasks primarily regarded as measures of phonological awareness, for example the Auditory Organisation test or phoneme reversal, are of this form. Bradley & Bryant (1978) recognised that memory might influence performance in the auditory organisation task and attempted to control for this confound using a simple measure of memory span. However, Baddeley (1989) maintained that this would not have been an adequate reflection of the demands that a task such as the Auditory Organisation test placed upon auditory short-term memory.

Baddeley, Papagno & Vallar (1988) re-examined an Italian patient, P.V. (Vallar & Baddeley (1984)), who possessed an auditory-verbal span of only three items and was held to suffer an impairment to the phonological store. The original case study had illustrated that short-term storage could be dissociated from other phonological processing, specifically (i) discrimination of CV-syllables, e.g. *ba* versus *pa*, and (ii) visual rhyme judgement. Baddeley et al demonstrated that P.V. could repeat bi-syllabic nonwords but had difficulty with tri-syllabic nonwords and was completely unable to repeat nonwords with 4 or 5 syllables which were outwith her memory span. With auditory presentation, P.V. could not learn to associate bi-syllabic or tri-syllabic nonwords with word stimuli, whereas she was unimpaired in associating comparable meaningful stimuli. Her performance improved slightly with visual presentation, presumably because learning was enhanced by visual short-term storage. Baddeley et al interpreted these results as being consistent with the assumption that long-term learning requires short-term maintenance of the incoming material. These findings may have implications for understanding why some developmental dyslexics are failing to learn the relationship between orthography and spoken language.

Turning to the implications that short-term memory problems may have for long-term learning in developmental dyslexia, what has been discovered about the nature of long-term memory among dyslexic children? Using an cued recall task, Rack (1985) showed that 12- to 13-year-old dyslexics utilised orthographic coding in contrast to reading age controls who relied on phonological coding. Holligan & Johnston (1988) obtained similar results with 8-year-old developmental dyslexics. However, they also showed that the same subjects exhibited normal phonological similarity effects in a serial order recall task when the number of items to be recalled was adjusted to be within their impaired memory span. In view of the study by Baddeley et al (1988), short-term memory problems among the dyslexic children may have disrupted phonological coding, resulting in their apparent preference for orthographic coding.

A further aspect of long-term memory often impaired among developmental dyslexics is naming ability. Snowling, van Wagtendonk & Stafford (1988) reported that when compared with normal readers matched on receptive vocabulary, dyslexics were found to be worse at naming objects in response to either pictures or spoken definitions. Their performance was commensurate with their reading ability, and so may be a result of their limited reading experience. Alternatively, these findings may signify a difficulty associated with long-term phonological representations.

Finally, Gathercole & Baddeley's (1989) claim that short-term memory problems are detrimental to vocabulary development suggests that the poor vocabularies of some dyslexics may not simply be a consequence of their limited reading experience.

In conclusion, the work on auditory short-term memory has not been subject to the extensive investigation associated with phonological awareness. Nevertheless, Ellis & Large (1987) have recently indicated that memory span may be causally related to reading development, although they acknowledged that the relationship between these variables may well turn out to be interactive.

3.2 EVIDENCE LINKING VISUAL PROCESSING WITH NORMAL AND IMPAIRED READING DEVELOPMENT

Although phonological skills have been by far the most popular candidates for dimensions of reading ability, additional possibilities should not be overlooked. Visual perceptual skill is an alternative which has recently been much neglected. It is self-evident that even the possession of a fully operational phonological system would be insufficient to support literacy skills in a subject who could not retain the written representations of sounds due to a visual problem. Furthermore, the antithetic situation would also seem to hold. The existence of the developmental dyslexic, R.E. (Campbell & Butterworth, 1985), suggests that it is possible to acquire literacy skills despite severe phonological difficulties, apparently by reliance upon strong visual memory skills.

Frequently, visual skills have been taken for granted and it has been assumed that a child will possess visual abilities which will be sufficient to support reading acquisition. For example, Goswami (1986) has argued that children acquire knowledge about the spelling sequences in words through the use of analogies based upon their phonological awareness of onset and rime segments. This theory contains an implicit assumption that children will be capable of perceiving the visual similarity between words and be able to isolate and retain the nonredundant letter groups upon which this similarity rests.

The possibility that pre-existing visual skills may influence reading strategies has already been raised (e.g. Snowling, 1987), but is there any evidence that visual impairments may be implicated in developmental dyslexia? In fact, the theory that developmental dyslexics suffered from a visual impairment was actually pervasive in the literature for about thirty years following the publication of Orton's paper in 1937. In 1979, Vellutino reviewed the area and highlighted some serious methodological inadequacies which cast doubt upon this 'perceptual deficit' hypothesis. Nevertheless, reports of developmental dyslexics with what were considered primarily visual problems have appeared consistently in the literature. Boder (1973) classified 9% of the developmental dyslexics in her study as suffering from an essentially visual difficulty. Although Boder's work suggested that visual impairments may be less common than phonological difficulties in developmental dyslexia, this does not mean that the role of visual difficulties should be disregarded. Seymour (1986) has identified cases of *visual-processor* and *morphemic* dyslexia. These subjects demonstrated analytic weaknesses in tasks requiring comparison of letter arrays or problems in more holistic processes such as the instant recognition of words.

Evidence of visual impairments has been less forthcoming from group studies (for a review see Vellutino, 1979). This should not seem surprising if visual deficits are relatively less common than phonological ones. By taking a group average, difficulties which are suffered by only a few members of the group are likely to be concealed. Another methodological point concerns the experimental tasks which have been used. Vellutino (1979) and Wilding (1989, 1990) have argued that it is difficult to interpret performance on reading-based tasks which use words and letters as stimuli. One reason for this is the difficulty in determining whether dyslexic performance in such tasks reflects underlying problems or reading strategies adopted to compensate for their problems. For example, are dyslexics who utilise a laborious sounding-out strategy impaired in their ability to assign phonology, or in their ability to segment a letter string, in order to assign phonology effectively? To reiterate Ellis' (1985) comment upon the nature of *phonological* dyslexia, the explanation of a nonword naming deficit need not be a problem with phonological processing, it could equally well result from a difficulty with the visual segmentation of a letter string. Consequently, extrinsic tasks may be a valuable means of extending our knowledge about visual skills in developmental dyslexia, just as they have proved illuminating in relation to phonological processing.

Johnston, Anderson, Perrett & Holligan (1990) used extrinsic tasks to examine the visual and phonological segmentation skills of dyslexic children. They chose the Auditory Organisation Task as a test of phonological segmentation and the Children's Embedded Figures task to investigate visual segmentation skills. This latter test required the subject to locate a simple shape embedded within a more complex figure. The Embedded Figures test was selected because it was an aspect of visual segmentation which had already been implicated in developmental dyslexia. Goetzinger, Dirks & Baer (1960), Lovell, Gray & Oliver (1964) and Stuart (1967) had all reported that dyslexic children aged between 10 and 15 years old had difficulty with similar tasks. However, these studies assessed dyslexic performance relative to chronological age controls and so it was possible that the observed discrepancies between these groups merely reflected the limited reading experience of the dyslexic children. Johnston et al employed both reading age and chronological age comparisons in their study of ten and a half year old developmental dyslexics who were reading at the seven and a half year level. Overall, the dyslexic children were found to be impaired relative to the chronological age controls in both the visual and the phonological segmentation tasks. In fact, the developmental dyslexics performed at a similar level to their reading age controls on both tasks. Closer examination of the data revealed considerable individual differences. Eight of the 20 dyslexics performed more than two standard deviations below the mean of the chronological age controls on the visual segmentation task and seven were as severely impaired on the phonological task (five of whom were also members of the visually impaired group).

With regard to the developmental dyslexics' difficulties, both visual and phonological, there are at least two possible interpretations of such a result. The skills in question could improve conjointly with reading skill and so be a consequence of the developmental dyslexics' reading problems. Alternatively, the skills may be causally related to reading ability but the superior mental age of the dyslexic children may have enabled them to compensate for their difficulties and to bring their performance at least to the level of the reading age controls. This interpretational problem applies *equally* to the visual and auditory segmentation task.

In the case of phonological segmentation, there is a wide literature testifying to a reciprocal relationship between phonological skills and reading development. Unfortunately, at present, there is no comparable literature examining visual skills. Therefore, it is only possible to speculate that it seems likely that reading instruction would improve visual segmentation skills. On the other hand, the visual segmentation skills of three of the developmental dyslexics studied by Johnston et al, were above average for their chronological age. Thus, it appears that such skills are not purely a consequence of reading experience.

Vellutino (1979) was reluctant to view the early reports of difficulties with visual disembedding tasks as evidence of a visual deficit in developmental dyslexia. His objection was that these studies had not found problems with other visual tasks like the Block Design subtest of the WISC, or in tests of figure rotation and spatial orientation. However, the specificity of a deficit seems rather a spurious criticism and one that has not been raised in relation to studies of phonological problems. Johnston et al used the lack of an impairment on the Mooney Test, which tests visual synthesis, as evidence that the developmental dyslexics were suffering a segmentation problem. This result could be said to enhance rather than undermine their argument.

Treiman & Baron (1981) have proposed that auditory and visual segmentation skills are manifestations of a general perceptual capacity which has a characteristic maturational course. Their conception of the development of this capacity was derived from studies of visual perception (e.g. Ghent, 1956; Vurpillot, 1976). They suggested that young children were initially holistic perceivers and that the ability to analyse stimuli componentially developed only gradually. Treiman & Baron saw this as a visual parallel of the properties of phoneme perception, namely that although the identification of a spoken word involves the perception of phonemes, this does not necessarily entail phenomenological awareness of the phonemes themselves. Vurpillot (1976) commented that young children viewed line-drawings of objects as very rigid configurations. It was not until they were about 6 years of age that they were able to use a secondary level of perceptual organisation whereby a line or group of lines could also be independently perceived as part of a substructure.

Kolinsky, Morais, Content & Cary (1987) examined the development of these latter *postperceptual* visual processes. They employed a version of the 'part-probe' task which consisted of a set of six-segment figures paired with various three-segment parts. The subjects were asked to say whether they could find the part within the larger figure. Kolinsky et al reported that preschool children and some first graders found this task extremely difficult. Second graders, on the other hand, were much more successful. The authors also used this task to test unschooled adults and discovered that they performed at a similar level to the preschool children. This led Kolinsky et al to conclude that the ability to make componential analyses of visual stimuli developed as a result of educational instruction. The nature of this instruction was not specified, although it did not appear to be reading instruction since some of the unschooled adults were described as ex-illiterates. However, neither the literacy achievements of this group nor the nature of the reading instruction that they received was described.

Unfortunately, it is debatable whether this rather abstract task is strictly comparable to the Embedded Figures tasks used in the studies referred to previously. The figures in the part-probe task were geometric line-drawings which may not have had the same holistic properties as pictures of recognisable objects. In a later study, Kolinsky (1989) found that the ability of young children to analyse shapes into parts was influenced by the nature of the shape itself. Parts of open shapes like arrows were easier to perceive than parts of closed shapes like triangles.

Elkind, Koegler & Go (1964) investigated children's perception of figures in which the parts also depicted objects e.g. line-drawings of fruits arranged to form the shape of a man. They concluded that young children can sometimes see the parts of a figure although this depended very much upon the nature of the stimuli. However, the simultaneous perception of the wholes and parts of complex visual stimuli did not appear to develop until around 8 or 9 years of age.

Further research will be necessary before it can be established whether visual segmentation skills are causally related to reading development. At present visual segmentation problems would seem to have the potential to disrupt decoding skills in word recognition and have been associated with the reading difficulties of some dyslexic children. It may be that by studying visual segmentation skills in reading it will be possible to provide a more comprehensive account of reading acquisition.

CHAPTER 4

STUDY ONE

4.1 INTRODUCTION

In the series of experiments which follows, the question of heterogeneity within the dyslexic population was explored. The approach taken was to study a larger than average sample of dyslexic children. This was felt to be vital if an adequate assessment of heterogeneity was to be made. For example, children suffering from what are regarded as less frequent problems, such as visual impairments, would be more likely to be represented in a sizeable group.

The hypothesis that reading ability can be dimensionally defined was pursued from the perspective of identifying cognitive processes which are impaired among developmental dyslexics. Such processes would constitute putative dimensions of reading ability since impairments to these processes would be associated with poor reading ability. Although causality could not be established in such a study, it was felt that the results would provide useful pointers for future longitudinal and training studies. Experimental tasks were chosen to assess some of the cognitive processes which were discussed in Chapter 3. Phonological processes were assessed using tests of nonword naming, rhyme judgement, auditory organisation, phoneme deletion and auditory digit span. This varied selection of tests was employed because it was thought to be important to establish whether there were associations and dissociations in dyslexic performance, on different phonological tasks. An assessment of visual processing was made using the Visual Embedded Figures Task, a test of visual segmentation. This particular visual skill was chosen because the idea of focussing on the visual features within a perceptual whole seemed applicable to the reading process; since whatever theoretical stance one adopts, some graphemic parsing of the letter string is necessary.

An additional reason for investigating visual segmentation skills was their apparent correspondence with the segmental aspects of the phonological awareness tests (i.e. rhyme judgement, auditory organisation and phoneme deletion). Treiman

& Baron (1981) have put forward a theory of perceptual development in which they suggest that both visual and auditory perception may be initially holistic in nature and then gradually become more analytic. In a study of dyslexic children, Johnston et al (1990) revealed that these children were impaired on both a phonological and a visual segmentation task. Johnston et al speculated that developmental dyslexics may be delayed in their general perceptual development. It was decided to test this hypothesis in the present study using the phonological and visual segmentation tasks mentioned above. An added feature of the present study was the inclusion of a test of tactile segmentation which extended the investigation of dyslexic children's perceptual skills to the tactile modality.

4.2 SUBJECTS

(i) *Developmental Dyslexics*

This sample consisted of children who attended what are known as Reading Units set up in Edinburgh by Lothian Regional Council. These children had been identified as suffering "specific reading difficulties" and had already received learning support in their individual Primary Schools located around the city. They are children of average or above average ability and have been judged to be sufficiently motivated to benefit from the remedial opportunities provided by the Reading Units.

The children attend the Reading Units during the latter stages of their Primary School education, and are taught in small groups of 3 or 4 by an experienced teacher. They receive approximately 5 hours of tuition in reading, spelling and other related activities per week. This instruction is tailored to suit individual strengths and weaknesses, and in so doing, draws upon both "Look-and-Say" and "Phonics" methods.

The sample contained 41 developmental dyslexics with a mean chronological age of 10.7 years (see Table 1). Using the Word Recognition Test of the British

TABLE 1

SUBJECTS:
Mean Chronological Age, Reading Age, Spelling Age, I.Q. and Digit Span
(standard deviations in brackets)

ATTRIBUTE	READING GROUP		
	READING AGE CONTROLS	DEVELOPMENTAL DYSLEXICS	CHRONOLOGICAL AGE CONTROLS
CHRONOLOGICAL AGE	7.6 (0.3)	10.7 (0.7)	10.7 (0.8)
READING AGE	8.2 (0.6)	8.0 (0.8)	11.8 (1.5)
SPELLING AGE	8.1 (0.8)	8.0 (0.8)	11.2 (1.1)
I.Q.	110.5 (11.8)	107.9 (13.3)	112.8 (11.9)
SCALED DIGIT SPAN	10.0 (1.8)	7.6 (2.4)	9.6 (2.6)

Ability Scales (Elliott, Murray & Pearson, 1979), their mean reading age was found to be 8.0 years. On average, the developmental dyslexics had a reading age which was 32 months behind their chronological age; however, this deficit varied in severity among the subjects, ranging from 15 to 55 months. The Schonell Graded Word Spelling Test B (Schonell, 1971) showed that the mean spelling age of the sample was 8.0 years. On average, the group's spelling age was 35 months behind chronological age, although this deficit ranged from 10 to 60 months among the subjects.

A "short form" of the WISC-R (Wechsler, 1976) was used to assess the I.Q. of the sample. This was derived from the work of Maxwell (1959) who carried out a factor analysis of the correlation matrix for the subtests of the WISC. He concluded that the Vocabulary and Similarities subtests gave a relatively pure measure of a child's "verbal" ability, and that the Object Assembly and Block Design subtests best described "performance" ability. Therefore, Verbal and Performance Scores can be prorated from the scaled scores in these associated subtests, and these scores summed to estimate I.Q. In the present study, this gave a mean I.Q. Score of 107.9 for the group. Only those developmental dyslexics who were calculated to have an I.Q. greater than 85 (equal to 1 standard deviation below the mean in the WISC-R) were included in the sample.

The developmental dyslexics' short-term memory was tested using the Digit Span subtest of the WISC-R (Wechsler, 1976). The average raw score for the group was 9.3 which when adjusted for chronological age became a scaled score of 7.6 (the scaled score norms are such that 10 is the average score with a standard deviation of 3).

(ii) *Reading Age Controls*

The 41 children in this sample were drawn from four state Primary Schools. Two of the schools were in Edinburgh and were schools which some of the developmental dyslexics attended. The other two schools were in Fife. The method of reading instruction in these schools was broadly similar, in that the pupils' initial exposure to reading was through "Look-and-Say". This method was gradually supplemented and then replaced by "Phonics" by Primary 3 at the latest.

The children selected to form this control group had experienced no difficulties in learning to read and had achieved a level of reading skill commensurate with that of the developmental dyslexics in the normal time-scale of reading development. These children had a mean chronological age of 7.6 years (see Table 1). Their reading age was generally slightly in advance of their chronological age, the mean for the group being 8.2 years. Spelling age also tended to be higher than chronological age with a mean spelling age for the group of 8.1 years. The mean I.Q. Score was 110.5, and only those children achieving a score greater than 85 were included in the sample. The reading age controls as a group produced a raw score of 8.7 on the Digit Span test and a scaled score of 10.0. All of the above measurements were obtained using the same tests as had been given to the developmental dyslexic group.

(iii) *Chronological Age Controls*

The 41 children in this sample were selected from four state Primary Schools with similar characteristics to those attended by the reading age controls.

The children who formed this control group, like the reading age controls, had experienced no difficulties in learning to read. Their mean chronological age was 10.7 years (see Table 1), and their average I.Q. Score was 112.8. The group had a mean reading age of 11.8 years and a mean spelling age of 11.2 years, which reflected the level of achievement that would be expected from normal readers of equivalent age and ability to the developmental dyslexics. The chronological age controls achieved a raw score of 11.2 in the Digit Span test which translated to a scaled score of 9.6. All of these measurements were obtained using the standardised tests which had been given to the developmental dyslexic and reading age control groups.

(iv) *Reading Group Comparisons*

To assess the reading age comparison, an analysis of variance was performed on reading age as a function of **groups** (developmental dyslexics and reading age controls). There was no main effect of groups, ($F(1,80)=1.81$, $p>0.05$). Similar analyses were carried out for I.Q. and spelling age. Once again, there was no main effect of groups, ($F<1$, in both tests). Therefore, the reading age controls seemed to adequately fulfil their function of providing a match for the developmental dyslexics in terms of reading age, I.Q. and spelling age.

The chronological age comparison was evaluated by subjecting chronological age to an analysis of variance as a function of **groups** (developmental dyslexics and chronological age controls). There was no main effect of groups, ($F<1$). In a similar analysis of I.Q., there was also no main effect of groups, ($F(1,80)=3.07$, $p>0.05$). Therefore, the chronological age controls seemed to adequately fulfil their function of providing a match for the developmental dyslexics in terms of both chronological age and I.Q.

An analysis of variance was also performed to assess the relative short-term memory capabilities of the reading groups using scaled scores in the Digit Span test. There was one between-subjects factor, **groups** (developmental dyslexics, reading age and chronological age controls). A main effect of groups was found, ($F(2,120)=12.48$, $p<0.0005$). Newman-Keuls tests[1] revealed that there was no difference between reading age and chronological age controls in this "age-adjusted" test, however the scaled scores of the developmental dyslexics were significantly below those of the other two groups. This suggested that the dyslexic group's memory span was lower than would be expected for their age. To investigate this finding further the developmental dyslexics' raw scores in the Digit Span test were compared with those of their reading age controls. The data were subjected to an analysis of variance with one between-subjects factor, **groups** (developmental

[1] All Newman-Keuls tests were evaluated using a 5% significance level.

dyslexics and reading age controls). The effect of groups did not achieve significance, ($F(1,80)=1.91$, $p>0.05$), indicating that the short-term memory capabilities of the developmental dyslexic group were equivalent to those of normal readers who were three years their junior.

4.3 NONWORD NAMING TASK

(i) *Materials*

The stimuli were constructed by Johnston, Rugg & Scott (1988) and consisted of 24 pseudohomophones and 24 ordinary nonwords (see Appendix 1). The items were derived according to Taft's (1982) criteria: two visually similar words with differing pronunciations of the vowel sounds were selected e.g. *bear* and *near*. The vowel digraph in both words was replaced i.e. replacing "ea" with "ai" would give the pseudohomophone, *bair*, and the ordinary nonword, *nair*. The mean frequency for the words used to generate the pseudohomophones was 528 (s.d. 1426), and for the words used to generate the remaining nonwords, 659 (s.d. 1277), according to the Grade 3 norms of Carroll, Davies & Richman (1971). Johnston et al demonstrated that there was no significant difference between these mean frequencies.

(ii) *Procedure*

Each stimulus was written in the middle of a separate index card using a lower case script similar to that employed in the early stages of reading tuition. The children were told that they were going to see some "made-up" words and that they should try and read these out as quickly but as carefully as they could. The stimuli were presented in blocks, the nonwords were presented first, followed by the pseudohomophones. Responses were taped for later analysis.

(iii) *Results*

Accuracy

The results were expressed in terms of percentage accuracy according to nonword type (see Table 2). Tests for homogeneity-of-variance (Cochran's C and the Bartlett-Box F) showed that variance was inhomogeneous between the reading groups and so an arcsine transformation was performed on the data (as recommended by Winer (1971) when basic observations are proportions). Since this was found to have homogenised the variance, a two-way analysis of variance could be carried out with one between-subjects factor, **groups** (developmental dyslexics, reading age and chronological age controls), and one within-subjects factor, **nonword type** (pseudohomophones and ordinary nonwords). There were significant main effects of both groups ($F(2,120)=71.26$, $p<0.0005$) and nonword type ($F(1,120)=61.61$, $p<0.0005$). The interaction between groups and nonword type was also significant ($F(2,120)=6.65$, $p<0.003$). Newman-Keuls tests showed that developmental dyslexics were worse than both their chronological age and their reading age controls at naming nonwords (see Figure 3). However, the developmental dyslexics showed a pattern of performance which was similar to that of their reading age controls, in that they read pseudohomophones better than ordinary nonwords. The chronological age controls were better at nonword naming than the reading age controls and exhibited a developmentally more mature pattern, responding with equal accuracy to the two types of nonword.

Error Analysis: Lexicalisation errors

The number of lexicalisation errors (e.g. *loase*-> "lose") that each subject made was converted into a percentage of their total errors (see Table 3). Tests for homogeneity-of-variance (Cochran's C and the Bartlett-Box F) showed that variance was inhomogeneous between the reading groups. As this problem was unresponsive to transformation, the chronological controls were dropped from the analysis. Once more the tests for homogeneity-of-variance showed that variance was inhomogeneous

TABLE 2

NONWORD NAMING TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	ORDINARY NONWORDS e.g. *coe*	PSEUDOHOMOPHONES e.g. *loe*
READING AGE CONTROLS	53.46 (17.87)	68.50 (17.18)
DEVELOPMENTAL DYSLEXICS	44.51 (14.33)	57.22 (15.02)
CHRONOLOGICAL AGE CONTROLS	82.93 (10.86)	85.57 (11.45)

FIGURE 3
NONWORD NAMING TASK:
Interaction of Groups and Nonword Type

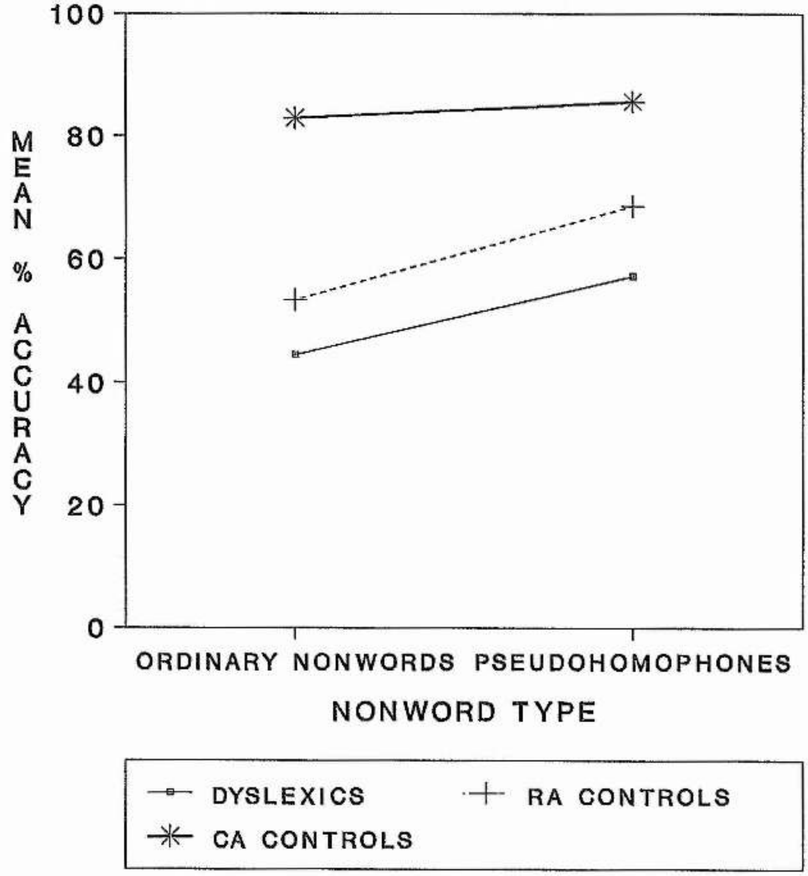


TABLE 3

LEXICALISATION ERRORS IN THE NONWORD NAMING TASK:
Mean Number Of Lexicalisation Errors As A Percentage of Total Errors In Each Condition
(standard deviations in brackets)

READING GROUP	CONDITION	
	ORDINARY NONWORDS	PSEUDOHOMOPHONES
READING AGE CONTROLS	53.07 (19.95)	34.02 (21.79)
DEVELOPMENTAL DYSLEXICS	45.84 (13.71)	33.06 (15.53)
CHRONOLOGICAL AGE CONTROLS	40.03 (29.01)	13.14 (20.18)

between the reading groups and transformation did not improve this situation. The significance of the inhomogeneity in the above tests using the original data was 0.02 for nonword naming and 0.04 for pseudohomophone naming. A circumspect analysis of variance was attempted since analysis of variance is reputedly relatively robust in the face of moderate departures from homogeneity (see Winer, 1971). There was one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and one within-subjects factor, **nonword type** (pseudohomophones and ordinary nonwords). The main effect of nonword type was significant ($F(1,80)=34.19$, $p<0.0005$) but the effects of groups ($F(1,80)=1.98$, $p>0.05$) and groups by nonword type ($F(1,80)=1.33$, $p>0.05$) did not achieve significance. Both groups made a higher proportion of lexicalisation errors when naming the ordinary nonwords than when naming the pseudohomophones. In a similar analysis of the data from the chronological controls, the main effect of nonword type was also significant ($F(1,40)=26.81$, $p<0.0005$), with the chronological age controls showing the same pattern as the other two reading groups.

Correlational Analyses

A battery of tests produces a large number of correlations. Rather than report all of these, the approach taken in the present chapter (and in the chapter to follow), has been to consider each test in turn and to examine how that test correlated with selected relevant variables. The intercorrelations were examined group by group and the significance of these Pearson Product Moment correlations was assessed using two-tailed tests. Where intercorrelations were only reported for selected groups, they were not significant for the other groups. Where correlations appeared to be mediated by a third variable, for example, reading age, this variable was partialled out. In order to provide a concise account of the intercorrelations, the results were reported in the discussion sections. This seemed appropriate since it was originally intended that this information should play a subsidiary role to the main analysis, rather than forming the basis of conclusions.

(iv) *Discussion*

It was established that this group of developmental dyslexics was impaired at naming nonwords relative to both the chronological age *and* reading age controls. There was some individual variation, however, within the dyslexic group. Closer inspection of the data revealed that ten of the dyslexic children were particularly impaired at nonword naming. These children's level of performance was more than one standard deviation below the mean of their reading age controls, and two of these children obtained a score which was more than two standard deviations below the mean of the reading age controls. On the other hand, twelve of the dyslexic children obtained scores which were above the mean of the reading age controls, and one of these children scored more than one standard deviation above this mean. Therefore, 30% of the sample were reading nonwords with a degree of success that was above average when compared with the reading age control group.

In terms of the qualitative nature of their performance, the developmental dyslexics resembled the reading age controls. Both groups exhibited a similar advantage for naming pseudohomophones over nonhomophonic stimuli. This pattern of performance contrasted with the data from the chronological age controls who responded to both types of nonword with equal accuracy.

This finding is consistent with other reports in the literature. Pring & Snowling (1986) discovered that the advantage for pseudohomophonic over nonhomophonic stimuli decreased with age in a priming experiment. This result was in terms of reaction time, and although this pattern was not significant for the accuracy scores the tendency was in the same direction. However, Seymour (1986) noted considerable individual variation among children with reading ages of twelve and suggested that the *pseudohomophone effect* in nonword naming was associated with readers who exhibit less efficient phonological processing and consequently tend to seek lexical support to augment their decoding. While in the present study there was little individual variation in the absence of a pseudohomophone effect among the chronological age controls, this may have been due to the relative simplicity of the monosyllabic nonwords being utilised in the study. The results of the error analysis, on the other hand, revealed substantial variation in the incidence of lexicalisation errors amongst the chronological age control group. Although the developmental dyslexics seemed to make a higher proportion of lexicalisation errors than their chronological age controls, they also exhibited considerable individual variation on this measure.

The reading age and chronological age controls showed a negative correlation between reading age and the proportion of lexicalisation errors made when naming pseudohomophones (*reading age controls*: $r(39)=-0.35$, $p<0.03$; *chronological age controls*: $r(39)=-0.36$, $p<0.03$). The reading age controls exhibited an additional positive correlation between reading age and the proportion of lexicalisation errors made in naming *ordinary* nonwords ($r(39)=0.42$, $p<0.007$). At least for the reading age controls, it appeared that those subjects who made lexicalisation errors in response to ordinary nonwords tended to be successful readers, whereas those who made lexicalisation errors in response to pseudohomophones tended to have lower reading ages. The developmental dyslexics, in contrast, exhibited an *association* between the proportion of lexicalisation errors that they made in response to pseudohomophones and ordinary nonwords ($r(39)=0.34$, $p<0.03$). Furthermore, the dyslexic group showed no significant correlation between reading age and the proportion of lexicalisation errors which they made in response to either type of nonword (*ordinary nonwords*: $r(39)=-0.27$, $p>0.05$; *pseudohomophones*: $r(39)=-0.14$, $p>0.05$).

While the developmental dyslexics appeared to utilise a strategy which was appropriate for their reading age, it must be borne in mind that they were still less accurate than their reading age controls in the nonword naming task. Whatever the nature of the dyslexic children's difficulty, the use of the strategy characterised by lexicalisation errors did not appear to be related to reading success amongst these children. Apparently, something prevented the dyslexic children from exploiting their use of this strategy as effectively as the reading age controls.

Skill at naming ordinary nonwords was correlated with reading age in the dyslexic group ($r(39)=0.39$, $p<0.02$) and in the reading age control group ($r(39)=0.57$, $p<0.0005$). For the reading age and chronological age controls, the more their reading age tended to be in advance of their chronological age, the more accurate they were at naming nonwords (*reading age controls*: $r(39)=0.42$, $p<0.007$; *chronological age controls*: $r(39)=0.31$, $p<0.05$). No such relationship was found in the data from the developmental dyslexics ($r(39)=0.28$, $p>0.05$). This suggested that nonword naming ability was closely associated with reading achievement. With normal readers, the relationship between reading age and chronological age tends to reflect reading skill, however with the dyslexic children the relationship of these variables is less indicative of their level of reading ability.

4.4 AUDITORY RHYME JUDGEMENT TASK

(i) *Materials*

The stimuli were constructed by Reid (1988) and consisted of 60 word-pairs forming a 2x2 factorial design (see Appendix 2). All of the words had four letters. The mean frequency of the words appearing first in the pair was 158 (s.d. 263), and 107 (s.d. 211) for those appearing in the second position.

There were four types of 15 word-pairs, randomised in the final list:

1. **Rhyming and Orthographically Similar** e.g. *bake-cake*
   The mean frequencies for the first and second items of these word-pairs were 203 (s.d. 360) and 207 (s.d. 375), respectively.

2. **Rhyming and Orthographically Different** e.g. *paid-fade*
   The mean frequencies for the first and second items of these word-pairs were 69 (s.d. 64) and 58 (s.d.75), respectively.

3. **Nonrhyming and Orthographically Similar** e.g. *post-cost*
   The mean frequencies for the first and second items of these word-pairs were 305 (s.d. 332) and 105 (s.d. 115), respectively.

4. **Nonrhyming and Orthographically Different** e.g. *poor-sort*
   The mean frequencies for the first and second items of these word-pairs were 55 (s.d.47) and 58 (s.d.113), respectively.

All of the above frequencies were calculated using the Grade 3 norms of Carroll et al, 1971).

(ii) *Procedure*

The experimenter read out the word-pairs one at a time and the children were asked to respond "yes" or "no" to each word-pair, according to whether or not they thought that the two words had rhymed. The children were instructed to look down at the desk during the test to prevent lip movement cues being utilised to aid performance. Items were repeated at the subject's request.

(iii) *Results*

Unfortunately, analysis of the rhyme judgement test was complicated by the inclusion of homophones in the original test. Obviously, it is unacceptable to include homophones in conditions requiring orthographic similarity between the members of a word-pair, such as *pear-year*. In this example, the criterion of orthographic similarity is violated in an auditory rhyme judgement task if the subject interprets the first word as *pair*. Therefore, four word-pairs from Condition 2 and three word-pairs from Condition 3 were excluded from the analysis (see Appendix 2). A second problem was encountered when mean frequencies were calculated for each condition. As can be seen from the materials section, Conditions 1 and 3 contain items with approximately 4-times the mean frequency of the items included in Conditions 2 and 4. Although it is hard to gauge the exact significance of such a difference, there is certainly the potential for a confound between frequency and orthographic similarity. Nonetheless, it was decided to go ahead with the analysis of the reduced stimulus set whilst bearing this confound in mind.

Percentage accuracy in each of the four conditions was calculated for every subject (see Table 4). Tests for homogeneity-of-variance (Cochran's C and the Bartlett-Box F) showed that variance was inhomogeneous between the reading

TABLE 4

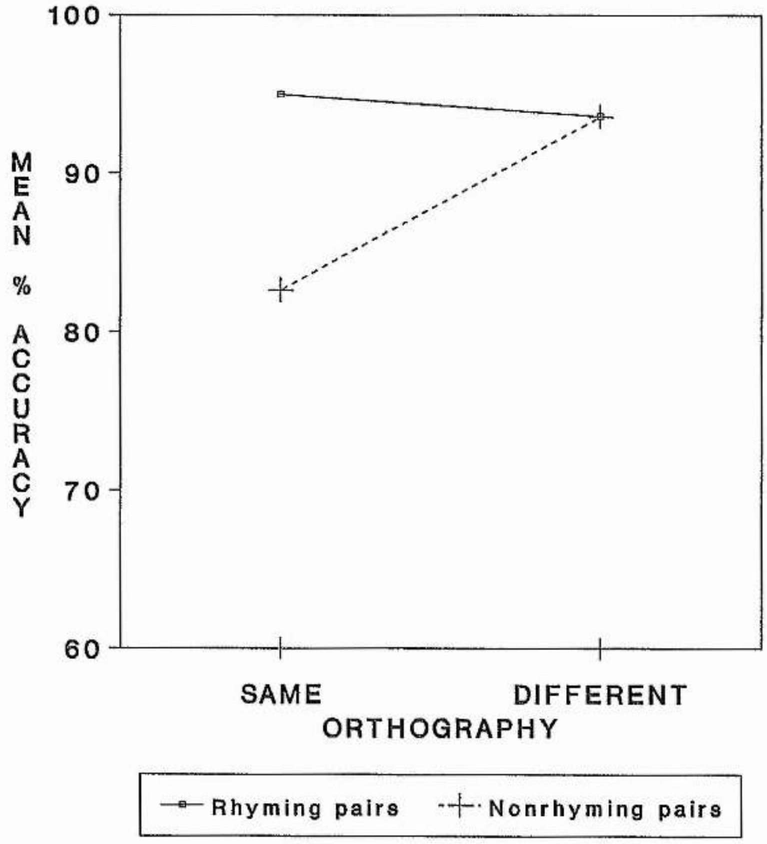
AUDITORY RHYME JUDGEMENT TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	CONDITION			
	RHYMING		NONRHYMING	
	SIMILAR ORTHOGRAPHY	DIFFERENT ORTHOGRAPHY	SIMILAR ORTHOGRAPHY	DIFFERENT ORTHOGRAPHY
READING AGE CONTROLS	94.96 (7.57)	92.24 (11.42)	82.11 (20.88)	93.01 (8.29)
DEVELOPMENTAL DYSLEXICS	91.54 (10.65)	92.91 (8.75)	78.66 (24.58)	89.76 (16.61)
CHRONOLOGICAL AGE CONTROLS	98.37 (3.88)	95.57 (7.36)	86.99 (15.60)	97.89 (5.66)

groups and so an arcsine transformation was performed on the data. This did not homogenise the variance sufficiently well to include the chronological age controls in the analysis. The original data from the remaining two reading groups did not satisfy the homogeneity-of-variance assumption either, and so also had to be subjected to an arcsine transformation which homogenised the variance for all conditions except for Condition 4. Since analysis of variance is reputedly relatively robust in the face of moderate departures from homogeneity, and the significance level of both Cochran's C and the Bartlett-Box F was greater than 0.025, a circumspect analysis of variance was attempted using the transformed data. There was one between-subjects factor, **groups** (developmental dyslexics and reading age controls), and two nested within-subjects factors, **rhyme** (rhyming and nonrhyming word-pairs) and **orthography** (orthographically similar and dissimilar word-pairs). Significant main effects of rhyme ($F(1,80)=10.40$, $p<0.003$) and orthography ($F(1,80)=16.04$, $p<0.0005$) were found, but there was no main effect of groups ($F(1,80)=1.07$, $p>0.05$), showing that the dyslexic children judged rhyme appropriately for their reading age. The interaction between rhyme and orthography was also significant ($F(1,80)=13.10$, $p<0.002$), but none of the other interaction terms reached significance: groups by rhyme ($F<1$); groups by orthography ($F(1,80)=1.43$, $p>0.05$); groups by orthography by rhyme ($F<1$)). Newman-Keuls tests revealed that the rhyme by orthography interaction was due to both developmental dyslexics and their reading age controls being misled by orthographic similarity when responding to nonrhyming word-pairs. Where word-pairs rhymed, orthographic similarity did not seem to influence judgements (see Figure 4). For example, with nonrhyming word-pairs like *post-cost* and *poor-sort*, both reading groups made most errors to those of the *post-cost* type. With rhyming word-pairs, there was no effect of orthographic similarity and word-pairs like *bake-cake* and *paid-fade* were responded to with equal accuracy.

Investigation of the chronological age controls' results showed the same pattern but a higher degree of accuracy. In an identical analysis to that outlined

FIGURE 4
AUDITORY RHYME JUDGEMENT TASK:
*Interaction of Rhyme and Orthography**



* Data from Dyslexics and RA Controls

above, but using only the data from the chronological age controls, significant main effects were found of orthography ($F(1,40)=10.12$, $p<0.004$) and rhyme ($F(1,40)=8.34$, $p<0.007$). The interaction rhyme by orthography again reached significance ($F(1,40)=24.05$, $p<0.0005$), and Newman-Keuls tests showed that chronological age controls were also only misled by orthographic similarity when responding to nonrhyming word-pairs.

It will be recalled that there was a confound between orthographic similarity and frequency in this experiment, orthographically similar words being more frequent than orthographically dissimilar words. If frequency was exerting an effect upon rhyme judgement, the expectation would presumably be that rhyme judgements to more frequent words would be easier. In fact, the results are contrary to this expectation, for when there was a significant difference in the case of nonrhyming items, performance was worse for orthographically similar (or more frequent) word-pairs. Therefore, it is possible to argue that in the absence of this confound between frequency and orthographic similarity the effects reported above would have been even more marked.

(iv) *Discussion*

There was no difference between the developmental dyslexic and reading age control groups in their ability to judge whether two spoken words rhymed. Variation was apparent within the dyslexic group when the data were examined at the level of the individual. Three of the dyslexic children were found to have obtained perfect scores in the test. At the same time, four other dyslexic children in the group were performing at a level which was more than two standard deviations below that of their reading age controls, and the performance of one of these dyslexic children was at chance.

The developmental dyslexics as a group exhibited an identical pattern of performance to their reading age controls in the Rhyme Judgement Task. Neither group showed an effect of orthographic similarity in response to word pairs which rhymed i.e. Condition 1 (e.g.*bake-cake*) and Condition 2 (e.g. *paid-fade*) were responded to with equal accuracy. An effect of orthographic similarity was seen in response to word pairs which did not rhyme. Both groups were less accurate in Condition 3 (e.g. *post-cost*) where the nonrhyming words were orthographically similar, than they were in Condition 4 (e.g. *poor-sort*) where there was a consistent difficulty with word pairs in which rhyme and orthography conflicted. An identical effect was displayed by the chronological age controls in a separate analysis, despite their accuracy levels being close to ceiling.

This result contrasted with previous studies that have found developmental dyslexics to be impaired relative to their reading age controls in tests of rhyming skills. For example, Bradley & Bryant (1978) reported that dyslexic children had difficulty manipulating rhyme in the context of the Auditory Organisation Task and a Rhyme Production Task.

In a previous study of auditory rhyme judgement, Rack (1985) also failed to find any difference between small groups of developmental dyslexics and their reading age controls who were reading at the ten and a half year-old level. However, the performance of Rack's subjects was close to ceiling in this task (similar to the performance of many of the children in the present study, in particular the chronological age controls). Group differences did emerge when Rack examined reaction time, developmental dyslexics being slower than reading age controls. From this he concluded that developmental dyslexics were able to make auditory rhyme judgements but were less efficient at doing so. A further group difference was revealed by this analysis, suggesting that the dyslexic children made more use of an orthographic code than their reading age controls. In the rhyme judgement task, the developmental dyslexics took longer to identify rhyming word-pairs when they were orthographically dissimilar (e.g. *head-said*) than when they were orthographically similar (e.g. *head-dead*). The reading age controls did not show this effect. Rack observed that, although nonsignificant, the trends in error rates to rhyming pairs were in keeping with these conclusions. With nonrhyming pairs, Rack found that the groups did not differ in terms of either accuracy or reaction time.

Rack's findings concerning the interactions between rhyme and orthography are in contrast to the results under discussion here. The auditory rhyme judgement task in the present study revealed that the developmental dyslexics were able to cope with this type of test as accurately as their reading age controls. The dyslexic children, in common with their reading age and chronological age controls, were disrupted when orthographic information conflicted with phonological information in judgements about nonrhyming pairs. While this could be indicative of an orthography effect dependent upon stored knowledge about the spellings of the stimuli, such a conclusion is not unequivocal in the present study due to the greater phonological similarity of the orthographically similar nonrhyming pairs (e.g. *lost-post*) than the orthographically dissimilar nonrhyming pairs (e.g. *boil-safe*). Rack did control for this factor by making the stimuli in the nonrhyming and orthographically dissimilar condition be of the form *cash-posh* rather than *boil-safe*. The absence of an orthography effect with the rhyming pairs supports the possibility that the effect with the nonrhyming pairs was subject to the influence of phonological information. However, in a recent unpublished study of auditory rhyme judgement by Johnston in which the phonological similarity of the nonrhyming pairs was controlled for by substituting word pairs like *side-loud* for *poor-sort*, the results obtained were very like the present findings. No difference in accuracy was found between good and poor readers reading at the eight year old level, and the only effect of orthographic similarity was with nonrhyming pairs.

Since Morais, Bertelson, Cary & Alegria (1986) have shown that rhyming skills were 20% worse among adult illiterates, it seems reasonable to conclude that reading acquisition may improve rhyming skills. This may account for the tendency for the dyslexic children and their reading age controls to be worse than their chronological age controls at rhyme judgements. The similarity of the performance of the developmental dyslexic and reading age control groups conflicts with reports that dyslexic children suffer a lack of facility with rhyme which is out of step even with their reading age (e.g. Bradley & Bryant, 1978). However, Yopp (1988) and Stanovich et al (1984) have suggested that tests of rhyming skills are one of the least taxing measures of phonological awareness. It is possible that in tests of auditory rhyme judgement, accuracy measurements may not be sufficient to differentiate the rhyming skills of dyslexics and their reading age controls, especially among those dyslexics who are reading at a level of eight years, or above. Certainly, in the present study, such scores showed no correlation with reading age, spelling age or nonword naming ability. Therefore, more analytical measures of processing efficiency may be required if group differences between developmental dyslexics and their reading age controls are to emerge in this relatively simple task. On the other hand, the present study illustrated that it was possible to identify *individual* dyslexic children who were severely impaired at auditory rhyme judgement using accuracy scores alone.

4.5 AUDITORY ORGANISATION TASK

(i) *Materials*

This was based on a version of Bradley & Bryant's (1978) test which was devised by Holligan (1987), (see Appendix 3). The test consisted of three conditions which each had eight trials. All of the trials contained four monosyllabic, 3-letter words, and in each trial one of these words differed from the others. The conditions took the following form:

1. **Initial Phoneme Different** *e.g. bud bun bus rug*
2. **Middle Phoneme Different** *e.g. dot cot pot bat*
3. **Final Phoneme Different** *e.g. fat sat pat bad*

The trials for each condition were blocked and presented in the above order. The position of the target word was counterbalanced, appearing twice in each serial position for every condition.

(ii) *Procedure*

A memory-pretest was administered to each subject. This consisted of four lists of words which the subject had to repeat in the same order. Each list contained four monosyllabic words (e.g. *jam big kiss bell*) which were read out by the experimenter at a rate of one word per second. Subjects succeeded in a trial *only* if they repeated all four of the words correctly.

The main part of the test was preceded by three practice trials, each of which typified a condition. All practice and experimental trials were read out by the experimenter at a rate of one word per second. The subjects were told to listen carefully to the words and to say which word was the odd one out but they were not told explicitly what to look for. They were also instructed to look down at the desk during the test to prevent them from using the experimenter's lip movements to aid their performance. The trials could be repeated up to three times if the child was unsure of the answer and on the third repetition the child was encouraged to guess.

(iii) *Results*

The results from the memory-pretest consisted of the percentage of trials repeated correctly by each child. An analysis of variance was conducted on these data with one between-subjects factor, **groups** (developmental dyslexics, reading age and chronological age controls). There was no main effect of groups ($F < 1$), and it was concluded that the groups did not differ in performance on this memory test.

Next, percentage accuracy was assessed for each of the conditions in the Auditory Organisation task (see Table 5). Tests for homogeneity-of-variance (Cochran's C and the Bartlett-Box F) showed that variance was inhomogeneous between the reading groups and so an arcsine transformation was performed on the data. This did not homogenise the variance sufficiently well to include the chronological age controls in the analysis. The original data from the remaining two reading groups did not satisfy the homogeneity-of-variance assumption either, and so also had to be subjected to an arcsine transformation which homogenised the

TABLE 5

AUDITORY ORGANISATION TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	INITIAL CONDITION	MIDDLE CONDITION	FINAL CONDITION
READING AGE CONTROLS	35.37 (17.43)	59.15 (20.54)	62.20 (21.92)
DEVELOPMENTAL DYSLEXICS	50.30 (25.39)	62.50 (20.54)	63.11 (23.38)
CHRONOLOGICAL AGE CONTROLS	57.01 (31.75)	77.44 (20.58)	83.54 (19.25)

variance for all conditions except for Condition 1. Since analysis of variance is reputedly relatively robust in the face of moderate departures from homogeneity, and the significance level of both Cochran's C and the Bartlett-Box F was greater than 0.04, a two-way analysis of variance was attempted with the transformed data. There was one between-subjects factor, **groups** (developmental dyslexics and reading age controls), and one within-subjects factor, **position** (initial, middle and final phoneme). Significant main effects of groups ($F(1,80)=4.56$, $p<0.04$) and position ($F(2,160)=21.95$, $p<0.0005$) were found. The interaction groups by position did not reach significance ($F(2,160)=2.23$, $p>0.05$). Developmental dyslexics were found to perform best overall but showed a similar pattern of performance to their reading age controls. Newman-Keuls tests revealed that both reading groups were less accurate in Condition 1, where the initial phoneme was different, and performance did not differ between Conditions 2 and 3 where the middle and final phonemes differed. In an identical analysis to that outlined above, but using only the data from the chronological age controls, a significant main effect of position was also found ($F(2,80)=17.61$, $p<0.0005$). A Newman-Keuls test showed that the chronological age controls were exhibiting exactly the same pattern of performance as the developmental dyslexics and their reading age controls.

(iv) *Discussion*

The developmental dyslexics were found to be *more* accurate than their reading age controls in this phonological test. Nevertheless, they tended to be less accurate than their chronological age controls, although this comparison could not be tested statistically.

As the Auditory Organisation Task has a large rhyming component to it, this result appeared to conflict with the outcome of the last experiment. It was also unexpected that only the chronological age controls exhibited a correlation between their performance in the Auditory Organisation and Rhyme Judgement Tasks ($r(39)=0.43$, $p<0.006$). The Auditory Organisation Task, however, does contain additional features which were not shared by the Rhyme Judgement Task. For example, one third of the trials were based on a judgement of alliteration rather than rhyme, and this did appear to be a source of advantage for the developmental dyslexics over the reading age controls. However, there was a rather wide variation among the scores in this condition, in both the dyslexic and chronological age control groups. It may be that success in this condition depended upon strategic variables which were more likely to be invoked by children with a higher mental age.

The correlational analyses revealed an association between performance in the Auditory Organisation Task and raw scores in the Digit Span subtest of the WISC-R for the reading age controls ($r(39)=0.38$, $p<0.02$) and the chronological age controls ($r(39)=0.43$, $p<0.007$). However, for the dyslexic children this relationship occurred only for the condition of the Auditory Organisation Task in which the middle phoneme differed ($r(39)=0.40$, $p<0.02$).

The finding that the developmental dyslexics did not suffer a deficit in this task, and in fact were more accurate than their reading age controls, does not correspond with the results of previous studies. Bradley & Bryant (1978) found that a group of dyslexic children with a reading age of seven and a half years, was worse than a group of reading age controls at the Auditory Organisation Task. The findings of Johnston et al (1990) were more in line with the results of the present study. Johnston et al found that their group of developmental dyslexics performed at the same level as their reading age controls, and, as in the Bradley & Bryant study these groups had a mean reading age of seven and a half years.

In the present study, all the reading groups found the initial phoneme condition the most difficult. However, in the study by Johnston et al only the reading age and chronological age controls found this condition the most difficult. Despite displaying the same tendency as the other reading groups, in statistical terms the dyslexic children were found to respond equally accurately to all three conditions. Bradley & Bryant (1978) on the other hand, reported that their developmental dyslexics were at a particular disadvantage in the initial phoneme condition. Although there was a tendency for this condition to be the most difficult for the reading age controls as well, the significance of this tendency was not reported. One unfortunate aspect of the Bradley & Bryant study was that the reading age controls made very few errors in the test and may have been exhibiting a ceiling effect. This would make it difficult to draw any conclusions from the group by condition interaction.

Examination of individuals' results in the present experiment revealed that 14 dyslexic children did not make the highest proportion of their errors in the initial condition (the equivalent numbers of reading age and chronological age controls were 6 and 11, respectively). It is possible that the intensive remediation that the dyslexic children had received made them more conscious of the initial phoneme in a word than normal children with the same reading age. Alternatively, there was evidence in the Rhyme Judgement Task that the dyslexic children were able to use orthographic information. It may be that they favour such a strategy to a greater extent than their reading age controls when their attention is not directed explicitly to the rhyming (or alliterative) nature of the task. The simple monosyllabic stimuli in this experiment would facilitate their use of such a strategy.

Analysis of individual results also revealed that in spite of the overall superiority in accuracy shown by the dyslexic children over the reading age controls, there was considerable variation in performance within the dyslexic group. It transpired that six of the dyslexic children performed more than one standard deviation below the mean of the reading age control group. Therefore, it appears probable that some of the dyslexic children were very impaired at this task despite the group result.

Nevertheless, these findings do not fit well with the hypothesis that the Auditory Organisation Task taps impairments which are characteristic of the majority of dyslexic children (e.g. Bradley & Bryant, 1978, 1983). Furthermore, only the chronological age controls exhibited a significant correlation between performance in the Auditory Organisation Task and any of the measures of literacy; their performance on this task correlated only with their spelling age ($r(39)=0.34$, $p<0.04$).

4.6 PHONEME DELETION TASK

(i) *Materials*

There were 48 stimuli forming a 2x2x2x2 factorial design. The stimuli were selected to explore the influence of the following factors on phoneme deletion performance:

1. **Lexicality** comparing phoneme deletion from words and nonwords containing four phonemes.

2. **Position** comparing phoneme deletion from the beginning (e.g. *flat*) or end (e.g. *desk*) of a stimulus - mean frequencies for the words contained in this comparison were 266 (s.d. 246) and 317 (s.d. 257), respectively.

3. **Split Type** comparing phoneme deletion which involved splitting a consonant blend (e.g. *skep*) with phoneme deletion which involved splitting a consonant from a vowel (e.g. *lext*) - mean frequencies for the words contained in this comparison were 267 (s.d. 242) and 317 (s.d. 262), respectively.

4. **Orthography** comparing phoneme deletion where the resulting segment is consistent in terms of both orthography and phonology (e.g. *hard*) with phoneme deletion which leaves an inconsistent segment (e.g. *work*)[2] - mean frequencies for the words contained in this comparison were 299 (s.d. 215) and 284 (s.d. 287), respectively.

All of the above frequencies were calculated using the Grade 3 norms of Carroll et al, 1971).

Each item was chosen so that removal of the designated sound resulted in a nonword. See Appendix 4 for the complete list of stimuli. The stimuli were randomised in four different versions of the test and application of these tests was roughly balanced among the subjects.

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[2] The manipulation in this condition, of course, applied primarily to the lexical stimuli but an attempt was made to match the nonwords very closely to these stimuli.

(ii) *Procedure*

After the nature of the test had been explained to them with the help of an example, subjects were instructed to look down at the desk in order to prevent them from using the experimenter's lip movements to aid their performance. Each stimulus was read out by the experimenter and the child was asked to repeat it to ensure that they had heard correctly. The experimenter then asked what would be left if a particular sound was taken away from the stimulus. For example, *flat*:

> "Say flat .... What would be left if you took away the /f/ sound ?"

The subject's response was noted by the experimenter.

There were eight practice trials. The first four of these involved deletions from words and exemplified various combinations of the position and split type conditions. The final four practice trials were used to prepare the subjects for deleting sounds from nonwords. These were followed by the experimental trials. The only feedback on accuracy that the subjects received was during the practice trials. The experiment was administered in two halves in order to reduce any effects of fatigue which might have arisen due to the demands of the task.

(iii) *Results*

The results were expressed as percentage correct for each subject for all the cells in the factorial design (see Table 6). Tests for homogeneity-of-variance (Cochran's C and the Bartlett-Box F) showed that variance was inhomogeneous between the reading groups and so an arcsine transformation was performed on the data. This did not homogenise the variance sufficiently well to include the chronological age controls in the analysis. The original data from the remaining two reading groups satisfied the homogeneity-of-variance assumption for all but two of the cells. An arcsine transformation did not correct the inhomogeneity in these cells.

<u>TABLE 6</u>

PHONEME DELETION TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

STIMULUS TYPE	READING GROUP*	CONSISTENT ORTHOGRAPHY				INCONSISTENT ORTHOGRAPHY			
		BEGINNING DELETIONS		END DELETIONS		BEGINNING DELETIONS		END DELETIONS	
		C/C SPLIT	C/V SPLIT	C/C SPLIT	C/V SPLIT	C/C SPLIT	C/V SPLIT	C/C SPLIT	C/V SPLIT
WORDS	RA	60.16 (35.13)	88.62 (23.11)	78.86 (25.56)	88.62 (19.16)	50.41 (35.06)	83.74 (21.24)	74.80 (27.67)	77.64 (29.72)
	DD	50.41 (31.51)	75.61 (28.89)	71.54 (32.97)	74.80 (31.43)	50.41 (37.36)	69.11 (35.27)	65.85 (36.70)	63.01 (30.39)
	CA	92.68 (13.97)	96.75 (10.01)	95.12 (11.93)	95.12 (11.93)	91.87 (20.79)	88.62 (17.65)	93.50 (15.31)	85.37 (19.79)
NONWORDS	RA	56.50 (35.14)	88.62 (24.28)	69.92 (30.33)	81.71 (24.10)	48.78 (37.89)	87.81 (23.28)	72.76 (29.29)	69.11 (33.45)
	DD	43.09 (33.95)	72.36 (30.64)	62.20 (32.50)	69.51 (28.85)	41.87 (35.58)	69.76 (29.88)	66.26 (34.26)	62.20 (35.56)
	CA	86.18 (21.05)	96.75 (10.01)	93.50 (13.37)	92.68 (15.83)	80.89 (27.27)	92.68 (13.97)	88.62 (20.90)	93.09 (14.42)

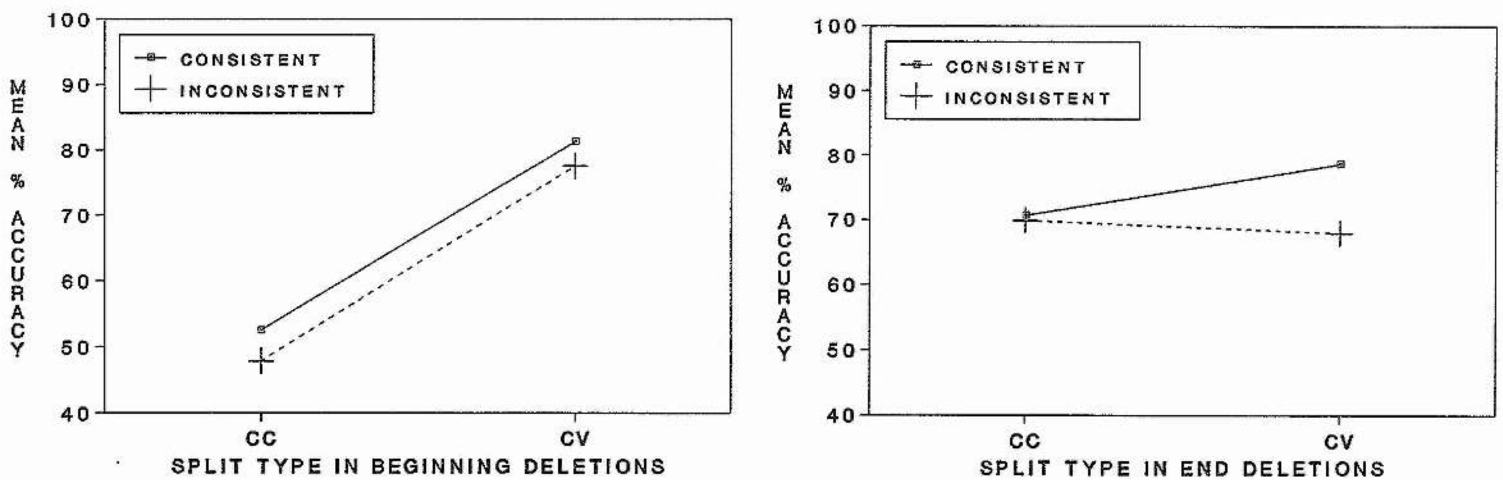
* RA = Reading Age Controls; DD = Developmental Dyslexics; CA = Chronological Age Controls.

Nevertheless, since analysis of variance is reputedly relatively robust in the face of moderate departures from homogeneity, and the significance level of both Cochran's C and the Bartlett-Box F was greater than 0.001, a circumspect analysis of variance was attempted using the original data. There was one between-subjects factor, **groups** (developmental dyslexics and reading age controls), and four nested within-subjects factors: **lexicality** (words and nonwords), **position** (beginning and end), **split type** (consonant-blend or consonant-vowel) and **orthography** (consistent and inconsistent). All main effects were significant - groups ($F(1,80)=7.45$, $p<0.009$); lexicality ($F(1,80)=8.49$, $p<0.006$); orthography ($F(1,80)=9.63$, $p<0.004$); position ($F(1,80)=13.02$, $p<0.002$); split type ($F(1,80)=71.45$, $p<0.0005$). The effects of groups and lexicality did not feature in any of the interactions and so were interpreted at this level. It was found that, overall, developmental dyslexics were worse at the Phoneme Deletion task than their reading age controls but both groups found it easier to delete phonemes from words than from nonwords. The only interactions to reach significance were position by split type ($F(1,80)=45.98$, $p<0.0005$) and orthography by position by split type ($F(1,80)=4.06$, $p<0.05$). Newman-Keuls tests of simple main effects on the latter interaction showed that phoneme deletion accuracy differed between consistent and inconsistent stimuli only when the deletion involved splitting the end consonant from a vowel, with more errors being made on the inconsistent stimuli i.e. *small* was more difficult than *blass* (see Figure 5). Deletion from the beginning of a stimulus followed a clear pattern, being more accurate when the deletion involved splitting a consonant from a vowel, as compared to splitting up a consonant blend i.e. *cost* was easier than *skep*. There was no such effect of split type when deletion was from the end of the stimulus. However, it was noted that subjects were less accurate at splitting up a consonant blend at the beginning of a stimulus than at the end of a stimulus i.e. *skep* was more difficult than *ferm*.

The remaining interactions were all nonsignificant: groups by lexicality ($F<1$); groups by orthography ($F<1$); groups by position ($F<1$); groups by split

FIGURE 5

*PHONEME DELETION TASK: Interaction of Orthography, Position and Split Type**



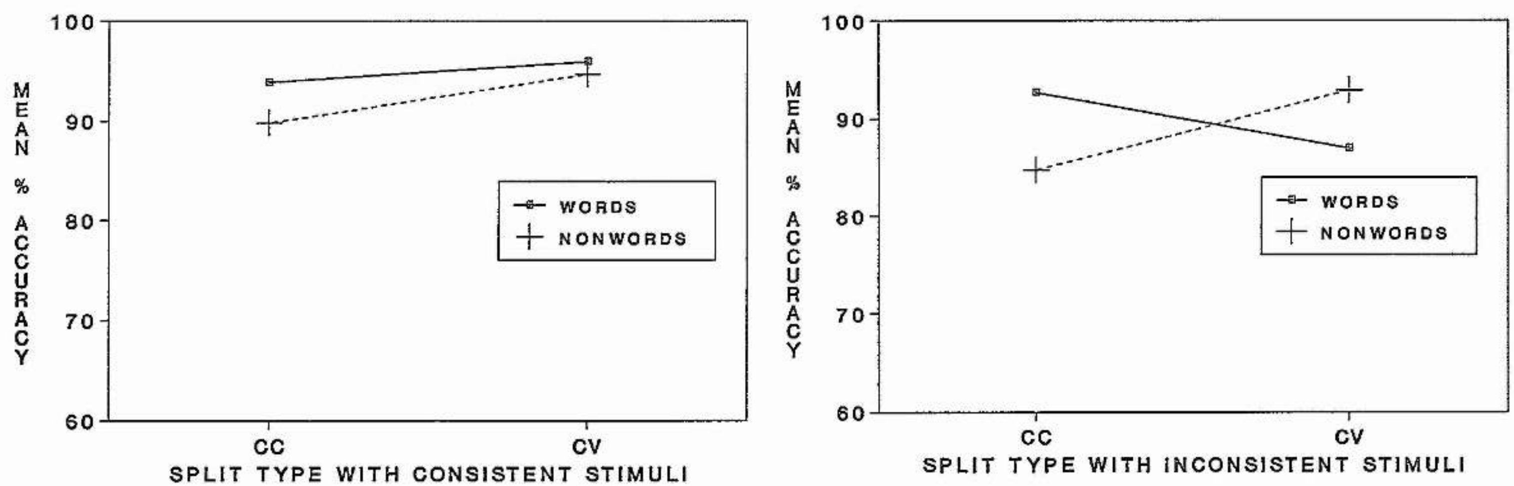
* Data from Dyslexics and RA Controls

type ($F(1,80)=2.56$, $p>0.05$); lexicality by orthography ($F(1,80)=2.45$, $p>0.05$); lexicality by position ($F(1,80)=1.29$, $p>0.05$); lexicality by split type ($F(1,80)=1.11$, $p>0.05$); orthography by position ($F<1$); orthography by split type ($F(1,80)=2.87$, $p>0.05$); groups by lexicality by orthography ($F<1$); groups by lexicality by position ($F(1,80)=2.22$, $p>0.05$); groups by lexicality by split type ($F<1$); groups by orthography by position ($F<1$); groups by orthography by split type ($F<1$); groups by position by split type ($F<1$); lexicality by orthography by position ($F<1$); lexicality by orthography by split type ($F<1$); lexicality by position by split type ($F(1,80)=1.05$, $p>0.05$); groups by lexicality by orthography by position ($F<1$); groups by lexicality by orthography by split type ($F<1$); groups by lexicality by position by split type ($F<1$); groups by orthography by position by split type ($F(1,80)=1.28$, $p>0.05$); lexicality by orthography by position by split type ($F<1$); groups by lexicality by orthography by position by split type ($F<1$).

In an identical analysis to that outlined above but using only the data from the chronological age controls, a significant main effect was found of orthography ($F(1,40)=12.47$, $p<0.002$). None of the other main effects achieved significance - lexicality ($F(1,40)=2.04$, $p>0.05$); position ($F<1$); split type ($F(1,40)=2.11$, $p>0.05$). The interactions lexicality by split type ($F(1,40)=11.88$, $p<0.002$) and lexicality by orthography by split type ($F(1,40)=5.50$, $p<0.03$) were found to be significant. Newman-Keuls tests on the latter interaction revealed that the chronological age controls exhibited a differential effect of the type of split only with inconsistent nonwords, when they were more accurate at splitting a consonant from a vowel than at splitting up a consonant blend i.e. *snol* was easier than *koasp*. For inconsistent *words* there was a nonsignificant tendency in the opposite direction, in that splitting a consonant from a vowel tended to be more difficult than splitting a consonant blend (see Figure 6). This was reminiscent of the result obtained with the developmental dyslexics and reading age controls. The interaction position by split type also reached significance ($F(1,40)=5.45$, $p<0.03$). Newman-Keuls tests indicated that accuracy to the two types of split differed when the split occurred at

FIGURE 6

*PHONEME DELETION TASK: Interaction of Lexicality, Orthography and Split Type**



* Data from CA Controls

the beginning of a stimulus, but not when the split occurred at the end. When deleting phonemes from the beginning of a stimulus, subjects were more accurate at splitting a consonant from a vowel than at splitting up a consonant blend. This pattern was broadly similar to the interaction of these variables found in the developmental dyslexic and reading age control data, although position and split type showed no interaction here with orthography. None of the other interactions achieved significance - lexicality by orthography ($F<1$); lexicality by position ($F(1,40)=1.62$, $p>0.05$); orthography by position ($F<1$); orthography by split type ($F<1$); lexicality by orthography by position ($F(1,40)=1.11$, $p>0.05$); lexicality by position by split type ($F<1$); orthography by position by split type ($F<1$); lexicality by orthography by position by split type ($F<1$).

(iv) *Discussion*

The discussion of the Phoneme Deletion Task will follow Section 4.7.

4.7 SPELLING TASK

(i) *Materials*

These were the stimuli used in the Phoneme Deletion Experiment (see Appendix 4).

(ii) *Procedure*

This spelling test was always administered after the Phoneme Deletion task in case the subject was biased towards an orthographic approach in the phonological segmentation task. The stimuli were read out to the subject one at a time. The subject was asked to repeat the item before writing it down, to check that they had heard it correctly. The subject wrote their answer in a little booklet, taking a new page for each item.

(iii) *Results*

The results of the spelling test were expressed in terms of percentage accuracy (nonwords being marked correct if they were phonologically regular representations of the sound or if they were based on an analogy with an irregular word). The group means and standard deviations can be seen in Table 7. Tests for homogeneity-of-variance (Cochran's C and the Bartlett-Box F) showed that variance was inhomogeneous between the reading groups and so an arcsine transformation was performed on the data. Since this was found to have homogenised the variance, an analysis of variance could be carried out with one between-subjects factor, **groups** (developmental dyslexics, reading age and chronological age controls) and one within-subjects factor, **lexicality** (word and nonword spelling). There were main effects of groups ($F(2,120)=81.34$, $p<0.0005$) and lexicality ($F(1,120)=134.00$, $p<0.0005$). There was also a groups by lexicality interaction ($F(2,120)=29.23$, $p<0.0005$). Using a Scheffe test it was determined that all groups showed an advantage for spelling real words as compared to nonwords. This effect of lexicality, however, was significantly greater for the chronological age controls than for the developmental dyslexics and their reading age controls. The lexicality effects exhibited by the dyslexic children and the reading age controls did not differ significantly (see Figure 7). The chronological age controls were much more accurate in their spelling than the developmental dyslexics and their reading age controls. Overall, the reading age controls were also more accurate than the developmental dyslexics.

(iv) *Discussion*

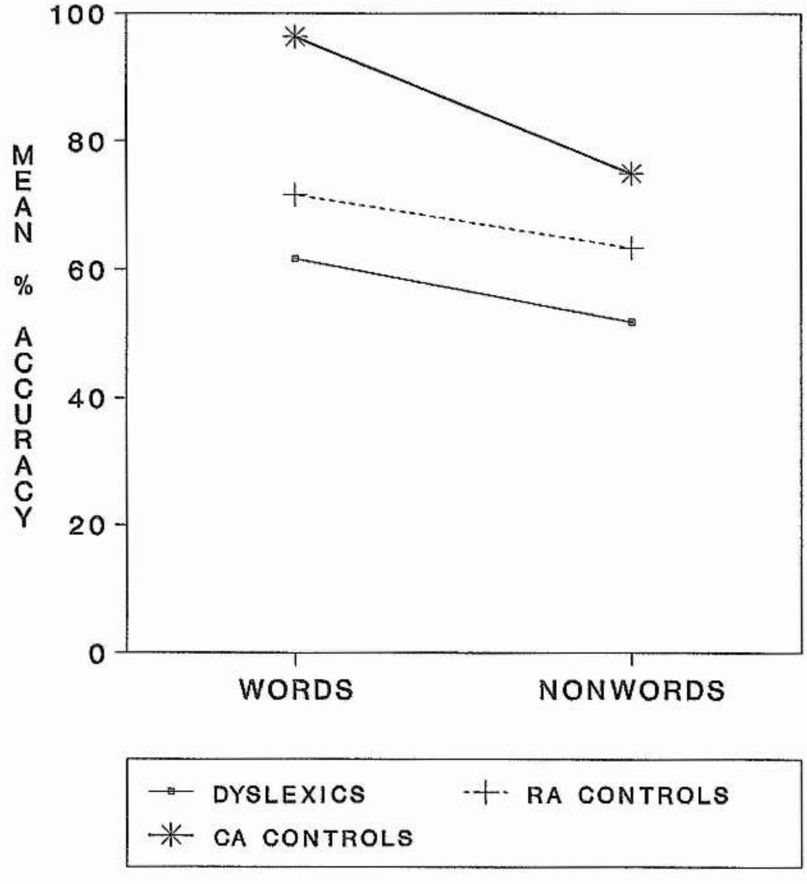
The developmental dyslexics were found to be impaired for their reading age at deleting phonemes from auditory stimuli. This skill is thought to be strongly dependent upon learning to read in an alphabetic orthography (Morais et al, 1979; Read et al, 1986). Consequently, it might seem surprising that the developmental dyslexics were impaired for their reading age on this task, especially since these

TABLE 7

SPELLING TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	WORDS	NONWORDS
READING AGE CONTROLS	71.65 (17.06)	63.31 (14.04)
DEVELOPMENTAL DYSLEXICS	61.65 (19.37)	51.83 (15.62)
CHRONOLOGICAL AGE CONTROLS	96.34 (5.98)	74.87 (9.63)

FIGURE 7
SPELLING TASK:
Interaction of Groups and Lexicality



dyslexic children had been receiving intensive phonics remediation. However, there is equally strong evidence that preschool performance on tests of phoneme deletion is predictive of subsequent ability to read words and nonwords (e.g. Stanovich et al, 1984; Yopp, 1988). Therefore, the performance of the dyslexic group may be indicative of an underlying deficit which is contributing to their reading difficulties.

The results of the Spelling Task revealed a similar pattern in that the developmental dyslexics were impaired at spelling words and nonwords relative to both their chronological age controls *and* their reading age controls. This was unexpected given the close spelling age match between the dyslexic and reading age control groups.[3] The performance of the chronological age controls was also superior to that of the reading age controls.

Seven of the dyslexic children were severely impaired at the Phoneme Deletion Task, scoring more than two standard deviations below the mean of the reading age controls. On the other hand, there were fifteen dyslexics who scored above the mean of the reading age controls, and two of these children scored more than one standard deviation above that mean. It would appear that there were considerable individual differences in phoneme deletion ability amongst the dyslexic children and it would be misleading to conclude that they all suffered a deficit for their reading age on this task.

Overall, the pattern of performance that the developmental dyslexics exhibited was indistinguishable from that of the reading age controls. Both groups were more accurate at deleting phonemes from words than from nonwords. However, it was noteworthy that the chronological age controls showed no such advantage for words, in common with the nine year old children studied by Stuart (1990). This contrasted with the spelling task, in which the chronological age controls exhibited a greater lexicality effect than either the developmental dyslexics or the reading age controls. This was unexpected and perhaps suggested that the

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[3] Lundberg & Hoien (1990) proposed that such results generally reflect regression to the mean.

chronological age controls were beginning to utilise more complex orthographic patterns in their spelling as a result of their increasing lexical knowledge. This transition may at first be detrimental, producing rather strange, analogy-based spellings for subparts of the letter-string e.g. /**n** ɒ **lp**/->knowlp (by analogy with *knowledge*?).

The lexicality effect in the Phoneme Deletion Task amongst the two younger reading age groups may reflect their level of spelling knowledge. Several authors have demonstrated that spelling knowledge is often utilised in phonemic segmentation tasks (Ehri & Wilce, 1980; Perin, 1983; Stuart, 1990). If so, this would suggest that both the developmental dyslexics and their reading age controls were able to use this knowledge to advantage in the Phoneme Deletion Task. Spelling knowledge may not yet be sufficiently abstract or automatic to enable these groups to deal as accurately with novel sound sequences as they do with the sounds in real words. The chronological age controls, on the other hand, may have already achieved this level of automaticity and this may account for their failure to show a lexicality effect. Why then do the chronological age controls exhibit a lexicality effect in the Spelling Task? It may be that the process of constructing a *written* representation of a letter string brings additional concerns into play, which are secondary to a more abstract awareness of the phonemic units of sound.

In order to investigate the issue of orthographic influences, the stimuli in the present study were designed such that the segment which remained after deletion was either consistent in its phonology and orthography (e.g. *hard*), or inconsistent (e.g. *work*). All the groups in the study performed more accurately on deletions which left a consistent segment. This suggests that even the developmental dyslexics were able to utilise their spelling knowledge to aid their performance in this phonological task. A trend was evident, particularly for the dyslexic children and their reading age controls, suggesting that this *consistency* effect was greater for lexical than nonlexical stimuli, but this effect failed to attain significance. Nevertheless, that such an effect could be found in response to nonlexical stimuli seems worthy of further investigation. One might have expected the children to have constructed nonlexical spellings which were all *regular* in their orthography. Therefore, the effect of inconsistent orthography amongst the nonlexical stimuli was intriguing. Campbell (1985) has shown that children's nonword spelling can be primed by previously occurring spelling patterns, and she concluded that children can use their knowledge of real word spellings to generate nonword spellings. This may account for the consistency effect in response to the nonlexical stimuli in the present study, especially since the nonwords were closely matched in their orthography and phonology to real words. Indeed, there was evidence of *analogy-based* spellings in the data from all of the groups e.g. **/snɒl/** -> snall; **/prɛth/** -> preath; **/gaɪnd/** -> gind.

Phoneme Deletion performance was shown to correlate with spelling age for the reading age controls ($r(39)=0.50$, $p<0.002$) and the chronological age controls ($r(39)=0.46$, $p<0.003$) but not for the developmental dyslexics ($r(39)=0.27$, $p>0.05$). For the reading age controls, however, this correlation was no longer significant after reading age was partialled out ($r(38)=0.20$, $p>0.05$). Nevertheless, a close association emerged in all the reading groups between phoneme deletion skills and the ability to spell the actual stimuli used in this experiment. For the lexical stimuli, these correlations failed to achieve significance after partialling out reading age (*reading age controls*: $r(38)=0.19$, $p>0.05$; *developmental dyslexics*: $r(38)=0.17$, $p>0.05$; *chronological age controls*: $r(38)=0.16$, $p>0.05$). However, with the nonlexical stimuli the correlation between spelling and phoneme deletion was more robust amongst the developmental dyslexics ($r(39)=0.53$, $p<0.0005$) and their reading age controls (*after partialling out reading age*: $r(38)=0.44$, $p<0.003$). Correlations were run for each subject in these two groups, on the correspondence between the accuracy of responses to individual stimuli in the Phoneme Deletion and Spelling Tasks. These indicated that only approximately 20% of the subjects in both the dyslexic and reading age control groups showed significant correlations between their responses to the stimuli in the two experiments. Therefore, for the majority of these subjects, it was not the case that being able to spell an item accurately was associated with successful phoneme deletion from that stimulus. Conversely, being unable to spell a stimulus did not necessarily bear any relationship to whether phoneme deletion from that stimulus would be successful. Thus, it seemed that the original correlation between performance in the Phoneme Deletion and Spelling Tasks reflected a more abstract relationship between these two variables. It also seems unlikely that the difference in the ability of the dyslexic and reading age control groups to spell the stimuli in the Phoneme Deletion Task could provide a complete account of their differing performances in that task.

The consistent-inconsistent distinction appeared to be particularly relevant when deletions were from the ends of the stimuli. The developmental dyslexics and their reading age controls both found it more difficult to split the end consonant from a vowel with inconsistent stimuli than with consistent stimuli. One possible explanation of this is that the vowel is largely the source of the inconsistency and so difficulties may arise when an *inconsistent* vowel is exposed by the deletion e.g. *small*. This may contrast with similar deletions which leave a consistent vowel e.g. *class*, and also with deletions from an inconsistent stimulus which involve splitting up a consonant digraph which do not involve the vowel e.g. *salt*.

The chronological age controls on the other hand, showed an interaction between orthography and split type which was also subject to the influence of lexicality. It is interesting that the chronological age controls were showing differential effects for lexical and nonlexical stimuli in this instance, despite the absence of an overall lexicality effect. It may be that children at this reading level tend to analyse the phonemic units in an unfamiliar phonological string in a way which reflects the *regularities* of English orthography, more than when they analyse the phonemic units in words that they are familiar with. This may account for the above interaction since in deletions from the end of inconsistent nonwords, accuracy was greater when splitting a consonant from a vowel than when splitting up a consonant blend (i.e. *snol* was easier than *gind*).

To return to more phonological concerns, all of the groups were more accurate at deletions from the beginning of stimuli which involved splitting a consonant from a vowel (e.g. *hard*), than at those which involved splitting a consonant digraph (e.g. *skep*). This was true for both lexical and nonlexical stimuli. When deletion was from the end of the stimuli, the children were equally accurate at both these types of splits. These findings were consistent with the salience that has been attributed to onset and rime units in phonological segmentation (e.g. Treiman, 1985; Kirtley et al, 1989; Goswami & Bryant, 1990). All groups of children found it easier to delete a phoneme which corresponded to the whole onset of the stimulus (e.g. *cost*) than a phoneme which was only part of the onset unit (e.g. *flat*). Furthermore, splitting up a consonant digraph was found to be harder at the beginning of a stimulus (when the digraph corresponded to the onset) than at the end of a stimulus. This replicates an unpublished study by Bruck which was reported by Bruck & Treiman (1990). The finding that the dyslexic children were as sensitive to the onset unit as their reading age controls contrasts with the results of a study by Olson, Wise, Conners & Rack (1990) who studied a group of fifteen and a half year-old developmental dyslexics with a mean reading age of ten years. These authors found evidence that the dyslexic children were impaired in a test which involved onset-rime segmentation. Although the evidence was mixed, there were also indications that this type of phonological segmentation ability might account for some of the heritable variance in word recognition and nonword naming skills.

The dyslexic children and their reading age controls exhibited a greater ability to delete phonemes from the end than from the beginning of stimuli. Similar results have also been reported by Fox & Routh (1975) and Content et al (1982). The interpretation given of such results by Goswami & Bryant (1990) was that young children find it easier to stop articulating before the end of a word than to commence at a new point in the sound stream. Goswami & Bryant speculate that the former process need not require phonological awareness at all. Interestingly, the chronological age controls did not exhibit this effect.

Although it was impossible to compare the results of the chronological age controls directly with those of the other reading groups, they did appear to achieve a higher average score in this test and to be less variable in their performance than the reading age controls. Moreover, the chronological age controls did not exhibit an overall lexicality effect. These findings were suggestive of quantitative and qualitative developmental changes in phoneme deletion skills.

In all of the groups, phoneme deletion performance correlated with reading age (*reading age controls*: $r(39)=0.53$, $p<0.0005$; *developmental dyslexics*: $r(39)=0.34$, $p<0.04$); *chronological age controls*: $r(39)=0.37$, $p<0.02$). This result was in keeping with the claims by authors such as Morais et al (1979) and Read et al (1986) that reading instruction in an alphabetic orthography produces a great improvement in phonemic awareness. Unfortunately, the nature of the present study does not allow for the developmental course of the relationship between these variables to be properly assessed. However, the finding that some of the dyslexic children were worse than their reading age controls at Phoneme Deletion suggests that this task may tap an underlying impairment which is contributing to these cases of reading failure. This would be consistent with claims by authors such as Liberman et al (1977), Fox & Routh (1980), Lundberg et al (1980) and Share et al (1984) that phonological awareness prior to reading instruction is a good predictor of later reading ability.

Yopp (1988) concluded that tests of phoneme deletion were measuring a "compound phonological awareness" since they require multiple operations to be performed and consequently created a greater memory load. From Yopp's analysis, it appears that more direct tests such as the Yopp-Singer Test of phoneme segmentation would provide a less contaminated measure of the phonemic awareness of developmental dyslexics. The impaired phoneme deletion skills of the current sample of dyslexic children may have arisen because they lack automaticity at the phonemic level of segmentation. This may place a strain on their short-term memory and depress overall performance when complex manipulations of phonemic units are required. Alternatively, the phoneme deletion problems of the developmental dyslexics may derive from the fact that the Phoneme Deletion Task requires the manipulation of subword segments. In contrast, tests like the Auditory Organisation Task require comparison of a list of *words* for which there may be considerable lexical support. This point may also relate to the lexicality effect found in the Phoneme Deletion Task since it may be easier to maintain a familiar word in memory while performing the deletion task, than a nonword which is an unfamiliar phonological sequence.

The correlational analysis revealed that the developmental dyslexics' performance in the Phoneme Deletion Task correlated with their scores in the Auditory Rhyme Judgement Task ($r(39)=0.39$, $p<0.02$). This result was rather unexpected since such skills have been thought to reflect quite different aspects of phonological awareness (see Morais et al, 1987), and the reading age controls showed no such association between their performance in these tasks. Moreover, the developmental dyslexics were impaired for their reading age on the Phoneme Deletion Task but not on the Rhyme Judgement Task. The correlation might suggest that low levels of rhyming skill were detrimental to the development of phonemic awareness. Certainly, all 4 of the developmental dyslexics who were impaired at rhyme judgement performed below the average of the reading age controls in the Phoneme Deletion Task. Low levels of phonemic awareness, on the other hand, did not appear to entail poor rhyming skills since only 3 of the 7 dyslexic children who were severely impaired at phoneme deletion were below average relative to the reading age controls at auditory rhyme judgement.

For the developmental dyslexics, phoneme deletion performance was a correlate of the ability to name ordinary nonwords ($r(39)=0.34$, $p<0.03$), but this relationship dropped below significance after reading age was partialled out ($r(38)=0.24$, $p>0.05$). The reading age controls also displayed a correlation between these variables ($r(39)=0.50$, $p<0.002$), which did not seem to be completely mediated by reading age (*after partialling out reading age*: $r(38)=0.29$, $p<0.04$). The association between phoneme deletion and pseudohomophone naming appeared closer and remained strong after reading age had been partialled out (*reading age controls*: $r(38)=0.50$, $p<0.002$); *developmental dyslexics*: $r(38)=0.41$, $p<0.006$). The chronological age controls exhibited no correlations between their phoneme deletion skills and their naming of either type of nonword.

4.8 VISUAL EMBEDDED FIGURES TASK

(i) *Materials*

The test materials used were compiled by Witkin, Oltman, Raskin & Karp (1971). There were two cardboard, cut-out forms, a "tent" shape (a triangle) and a "house" shape (a rectangle with a triangle fixed to the top left-hand side). Each of the forms had an accompanying series of four discrimination plates showing the form with three other related shapes, and also a series of complex figures with 11 and 14 items respectively. These complex figures were of recognisable objects which children would be likely to see as organised Gestalten. The forms were hidden within these figures and location of the shape involved the perceptual disembedding of the shape from the surrounding context. See Appendix 5 for examples.

(ii) *Procedure*

Before attempting each set of experimental figures, the subjects were trained on identifying the particular cut-out form in a display of isolated shapes. The importance of correct shape, size and orientation was emphasised. This was followed by practice items to familiarise the children with the disembedding task. First of all, the subjects were asked what was shown in the picture, to promote viewing of the picture as a whole, then they were asked to find the shape within the picture. They were allowed to fit the cardboard cut-out over the shape to reinforce the idea of the task and care was taken to point out that the shape in the drawing could be the same as the cardboard cut-out despite containing different colours and lines. The experimental procedure devised by Witkin et al (1971) was followed except that all children attempted all items until they failed five items in a row (the usual procedure is to start children at a level in the test deemed appropriate for their age, however, since it was thought that this might not apply to the developmental dyslexics, all subjects commenced at the first item). The series of figures associated with the "tent" shape were easier and preceded the more complex "house" shape series. When the hidden form was located, the children traced around it with a paintbrush for the experimenter to see. During the experimental items, the children were shown the cut-out form only if they explicitly asked to see it, or failed three consecutive items.

(iii) *Results*

Percentage accuracy was assessed for the test as a whole (see Table 8). An analysis of variance was conducted on these data with one between-subjects factor, **groups** (developmental dyslexics, reading age and chronological age controls). There was a main effects of groups ($F(2,120)=27.52$, $p<0.0005$). Newman-Keuls tests showed that reading age controls were the least accurate at this task, followed by the developmental dyslexics who were significantly worse than their chronological age controls.

(iv) *Discussion*

The developmental dyslexics were found to be impaired relative to their chronological age controls at disembedding shapes from complex backgrounds. While it is probable that visual segmentation skills improve with reading skills, it seems equally likely that other activities both within and outside the classroom also enhance these skills. For example, as Kolinsky et al (1987) note, visual puzzles like "spot-the-difference" or "find-the-hidden-figure" are common childhood endeavours.

TABLE 8

VISUAL EMBEDDED FIGURES TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	MEAN % ACCURACY
READING AGE CONTROLS	46 (19)
DEVELOPMENTAL DYSLEXICS	58 (17)
CHRONOLOGICAL AGE CONTROLS	74 (15)

Therefore, the finding that developmental dyslexics were impaired for their chronological age at the visual segmentation task may not simply be a product of their limited reading experience.

In contrast to the results of Johnston et al (1990), the dyslexic children were more accurate than their reading age controls at this task. Nevertheless, analysis at the level of the individual gave reason to suggest that some dyslexic children suffered severe visual segmentation problems. Three of the dyslexic children obtained a score on the most difficult part of the test which was more than one standard deviation below that of their reading age controls, whereas none of the chronological age controls performed this badly. Eleven other dyslexics performed below the mean of the reading age controls but only two chronological age controls produced such low scores.

Dealing with the developmental dyslexics as a group, their performance on the Visual Embedded Figures Task correlated with accuracy in the conditions of the Auditory Organisation Task which were tests of rhyming skills, namely the middle condition ($r(39)=0.42$, $p<0.008$) and the final condition ($r(39)=0.31$, $p<0.05$). This was consistent with the results of Johnston et al (1990) who found a relationship between performance on the Auditory Organisation and Visual Embedded Figures Tasks amongst a group of dyslexic children and their chronological age controls aged ten and a half. Analysis of the data from the chronological age control group in the present study, revealed a correlation between performance on the Visual Embedded Figures Task and overall accuracy in the Auditory Organisation Task ($r(39)=0.38$, $p<0.02$). This relationship appeared to be highly dependent, however, upon performance in the Digit Span subtest of the WISC-R (*after partialling out Raw Digit Span Score*: $r(38)=0.22$, $p>0.05$). This could indicate that both tests were drawing upon attentional skills for this particular group. On the other hand, the reading age controls showed a correlation between their visual segmentation and rhyme judgement abilities ($r(39)=0.36$, $p<0.03$). This association failed to achieve significance once chronological age had been partialled out ($r(38)=0.23$, $p>0.05$), suggesting perhaps that it was mediated by attentional or more general maturational factors.

An additional point of interest was that the visual segmentation skills of the developmental dyslexics correlated with their ability to spell words ($r(39)=0.38$, $p<0.02$). It seems possible that some developmental dyslexics with good visual segmentation skills may be able to note visual patterns within words more accurately and that this may be advantageous to the spelling process. There was no such relationship for nonword spelling, which may be more reliant upon phonological skills at this level of ability.

The chronological age control group's performance in the Visual Embedded Figures Task correlated with their scores in all four of the subtests of the WISC-R.[4] Among the developmental dyslexics and their reading age controls there was a significant relationship with only one of the performance subtests, namely Block Design, which shares many of the segmental aspects of the Visual Embedded Figures Task (*reading age controls*: $r(39)=0.40$, $p<0.02$; *developmental dyslexics*: $r(39)=0.54$, $p<0.0005$). However, the dyslexic group's performance on the Block Design subtest did not differ significantly from that of the chronological age control group. There was also an association between the reading age controls visual segmentation skills and their score on the Vocabulary subtest of the WISC-R, a test of expressive vocabulary ($r(39)=0.49$, $p<0.002$).

4.9 TACTILE EMBEDDED FIGURES TASK

(i) *Materials*

The test was designed to be a tactile equivalent of the Visual Embedded Figures Task. The target shape was the raised outline of a square made from strips of balsa wood and mounted on a wooden board. The discrimination, practice and

4 *Raw Vocabulary Score*: $r(39)=0.45$, $p<0.004$; *Raw Similarities Score*: $r(39)=0.50$, $p<0.002$; *Raw Block Design Score*: $r(39)=0.58$, $p<0.0005$; *Raw Object Assembly Score*: $r(39)=0.50$, $p<0.002$).

experimental items were constructed in the same way, and took a similar format to those used in the visual test. However, the experimental (and practice) items contained the shape hidden inside a geometric figure as opposed to an outline of a familiar object. The two practice and eleven experimental figures can be seen in Appendix 6. The geometric format drew upon the work of Thurstone (1944) but most of his designs were unsuitable for this type of test, and so figures which would be more appropriate for use with children in the tactile modality were designed to form a series of increasing difficulty.

(ii) *Procedure*

The figures were concealed from the child at all times behind a thick velvet curtain. The child slipped one or both hands underneath the curtain to explore the figures which were secured to the desk top as they were presented. The procedure was similar to that in the visual test. The child was helped to trace round the target square, and then had to discriminate this square from selections of similar shapes mounted separately on the same board in order to familiarise them with its shape, size and orientation. This was followed by the practice trials to acquaint the child with the disembedding task. The child was instructed to trace round the outline of the figure before attempting to find the hidden square, and to indicate the location of the square by tracing round its edges with their finger. It was explained that the square might have lines within it and that they should not be put off by this. All the experimental items were presented to each child. During the experimental trials, the child was allowed to retrace the target square only if they specifically requested to, or failed on three consecutive items.

(iii) *Results*

The results were expressed as percentage correct (see Table 9). An analysis of variance was conducted on the data with one between-subjects factor, **groups** (developmental dyslexics, reading age and chronological age controls). A main

TABLE 9

TACTILE EMBEDDED FIGURES TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	MEAN % ACCURACY
READING AGE CONTROLS	22.39 (16.65)
DEVELOPMENTAL DYSLEXICS	43.90 (23.44)
CHRONOLOGICAL AGE CONTROLS	48.56 (24.02)

effect of groups was found ($F(2,120)=17.07$, $p<0.0005$). Newman-Keuls tests showed that developmental dyslexics performed at a similar level to their chronological age controls on this task, and that the performance of both of these groups was superior to that of the reading age controls.

(iv) *Discussion*

The developmental dyslexics performed at the same level as their chronological age controls. Moreover, the distribution of these groups' scores was very similar. The reading age controls were significantly less accurate at locating the hidden figures, suggesting that the tactile skills involved in this task improve with chronological age.

It is reassuring to find that the developmental dyslexics can perform at a level appropriate for their chronological age in this task since it implies that the impairments that have already been found reflect specific areas of difficulty rather than a general depression of performance in the dyslexic group.

The finding that the performance of the dyslexic children was appropriate for their age in this sensory modality could have important remedial implications. Hulme (1981) reported that manual tracing improved dyslexic children's recall of visually presented letters and nonverbal forms. He suggested that developmental dyslexics generally relied upon a visual memory code for recall. Manual tracing provided an equivalent source of information to describe the forms which could combine with the visual information to aid recognition.

Although Hulme's experiment was limited to short-term retention, he quoted studies testifying to the durability of motor memory.[5] The success of multisensory teaching methods appeared to confirm the effectiveness and durability of kinaesthetic learning. Schevill (1978) argued that tactile learning led to better alphabetic recognition and to better serial ordering and retention of the distinctive features of letters. Fernauld (1943) developed the Fernauld Tracing Technique and advocated

[5] See also Baddeley (1975).

that children be taught by requiring them to trace written words with their fingers. Each word was traced in a single movement with concurrent vocalisation of the word. Then the child attempted to write the whole word from memory. In the case of error or interruption the child had to begin once again. This procedure was repeated until the spelling of the word could be reproduced correctly from memory. This and similar methods have been widely used with developmental dyslexics and have been claimed to be highly successful (see Cotterell, 1970).

Among the dyslexic children, performance in the Tactile Embedded Figures Task correlated with reading age ($r(39)=0.48$, $p<0.003$). There was also an association between this task and spelling age ($r(39)=0.43$, $p<0.007$) but this relationship did not reach significance after reading age was partialled out ($r(38)=0.16$, $p>0.05$). It may be that some literacy skills are being consolidated via written language for the dyslexic children with good tactile skills. The Tactile Embedded Figures Task also correlated with the dyslexic children's performance in the middle condition ($r(39)=0.38$, $p<0.02$) and the final condition ($r(39)=0.34$, $p<0.03$) of the Auditory Organisation Task. It will be recalled that a similar relationship existed for this group's performance on the Visual Embedded Figures and Auditory Organisation Tasks.

The only correlates of the Tactile Embedded Figures Task among the reading age controls were the raw scores for the performance subtests of the WISC-R: Block Design ($r(39)=0.46$, $p<0.003$) and Object Assembly ($r(39)=0.42$, $p<0.007$). The scores obtained by the chronological age controls on the Tactile Embedded Figures Task correlated with their age ($r(39)=0.58$, $p<0.0005$), their raw scores on the Digit Span subtest of the WISC-R ($r(39)=0.38$, $p<0.02$) and their nonword spelling accuracy ($r(39)=0.33$, $p<0.04$). An additional correlation with the Auditory Organisation Task just missed significance ($r(39)=0.31$, $p<0.052$).

Performance on the Visual and Tactile Embedded Figures Tasks correlated significantly in both the dyslexic group ($r(39)=0.48$, $p<0.002$) and the chronological age control group ($r(39)=0.51$, $p<0.002$). An association between visual and tactile performance in similar tasks was also reported by Axelrod & Cohen (1961) in a study of adult subjects. They attributed this to a reliance upon visualisation of the solution of the tactile figures on the basis of the retrospective accounts given by their subjects. This is one possible explanation of the correlation found in the present study because the children would sometimes spontaneously give the geometric name of the shape that they felt or make a visual analogy about its appearance e.g. "it's like a bow-tie!".

Nevertheless, the difference in the level of accuracy shown by the developmental dyslexics in the two tasks may be attributable to there not being the same spontaneous perception of the overall figure as a gestalt in the tactile modality as exists in the visual modality. Difficulty in segmenting a meaningful picture into its parts may have caused some dyslexic children particular problems. Indeed, the common factor accounting for the correlation between the tests may not be the segmental aspects of these tasks but an extrinsic element, such as the attentional skills required in order to search for the hidden figure.

4.10 SUMMARY DISCUSSION

The performance of the control subjects on the experimental tasks in this section was consistent with there being a developmental improvement in segmental abilities across sensory modalities (see Treiman & Baron, 1981). Where statistical comparison of the results of the reading age and chronological age controls was feasible, the performance of the chronological age controls was always superior to that of the younger reading age controls. When a direct comparison could not be made statistically the trend of the means was also in this direction.

Intercorrelations among the various experimental tasks within each reading group, however, were varied and at times mediated by factors such as reading age or short-term memory. Consideration of the data from the developmental dyslexics yielded evidence against the theory that there is one general perceptual ability underlying segmental analysis in the auditory, visual and tactile modalities, since the dyslexic children exhibited differential impairments in these sensory modalities. On the other hand, examination of the dyslexic children's performance *within* the auditory modality also revealed differential impairments. The dyslexics as a group had less difficulty with the Auditory Organisation and Rhyme Judgement Tasks than with the Phoneme Deletion Task. This pattern of impairment was consistent with there being a development from holistic to more analytical skills (Treiman & Baron, 1981), and with the possibility that the dyslexic group might be developmentally delayed in relation to auditory processing. It also highlighted the probability that comparison across modalities will be complicated by issues of task comparability. In particular, if segmentation skill is to be compared across modalities, the present findings imply that it would be necessary to ensure that the experimental tasks required a similar degree of analysis. At present, the fact that the dyslexic group as a whole were not impaired for their reading age on the Visual Embedded Figures Task, may suggest that this task like the Auditory Organisation Task, tapped a more holistic level of segmentation, rather than implying that impairments to the dyslexic group's segmentation skills for reading age were confined to the auditory modality.

Despite the positive correlation between rhyme judgement and phoneme deletion skills amongst the dyslexic group as a whole, there were two subjects within this group who displayed superior phoneme deletion to rhyme judgement skills. This finding appeared to conflict with any theory which contends that phonemic perception is developmentally contingent upon the more holistic perception of rhyming segments. Of course, these two dyslexic children were impaired for their chronological age at the Phoneme Deletion Task, so it was interesting to note that three reading age controls showed a similar advantage for phoneme deletion over rhyme judgement. Seymour (personal communication) has also recently found similar dissociations between phonemic and rhyming skills among beginning readers in Primary 1. So far these subjects would appear to be the exception to the rule and their performances perhaps reflect motivational factors or the influence of a particular instructional regime. Nevertheless, the issues of developmental contingency and the specificity of training in different aspects of phonological awareness merit more detailed investigation.

Further research will be necessary to establish whether a general segmental ability forms part of perceptual development. In the present study, the chronological age controls did perform at a higher level than the reading age controls but this may have reflected general developmental factors such as gains in short-term memory capacity or attentional skills. Furthermore, tactile segmentation skills appeared to be dissociable from segmentation skills in the auditory and visual modalities as far as developmental dysfunction is concerned, although auditory and visual segmentation skills showed a closer association with each other. The strongest evidence for a development from holistic to analytical processing came from the auditory modality, where the dyslexic group gave indications that they suffered a developmental delay at a relatively holistic level of processing. However, there appeared to be individuals within both the dyslexic and reading age control groups who exhibited dissociations between holistic and analytical levels of auditory processing. The issue of task demands emerged as an important factor. Golinkoff (1978) proposed that the complexity of phonological awareness tasks could be gauged by taking into account the following factors: the degree of analysis required, the operation to be performed and the number of units to be manipulated. Such factors will need to be taken into account in future research which aims to compare segmentation skills across sensory modalities. Until experimental tasks in the various modalities are comparable, experimental findings will remain rather difficult to interpret. For the moment, this section will proceed with a more general discussion of the performance of the reading groups in the experimental tasks.

The nonword naming skills of the group of developmental dyslexics under scrutiny here were not commensurate with their level of competence at word recognition. In common with the majority of investigations of this issue[6], a

[6] See Olson et al (1990) for a summary of these studies.

nonword naming deficit for reading age was identified. The only segmentation task in which the dyslexic children were as severely impaired was in the Phoneme Deletion Task. In accordance with the findings of Lenchner, Gerber & Routh (1990), who studied 9 year old poor decoders, the phoneme deletion skills of the present dyslexic group correlated significantly with their nonword and pseudohomophone naming (although the relationship with nonword naming may have been mediated by reading age). Lenchner et al tested other phonemic tasks such as phoneme tapping and segmentation but found that phoneme deletion was the strongest correlate of pseudoword decoding. In a study of kindergartners, Yopp (1988) found a Phoneme Deletion Task to be highly correlated with learning to read artificial words with novel spelling-to-sound correspondences (explaining 45% of the variance). Yopp demonstrated that a rhyme judgement task was less related to learning in this criterion task (explaining only 22% of the variance). Lenchner et al (1990) concluded that the relationship with decoding was closest when the phonemic awareness task involved more than simply a passive awareness of phonemes, since they argued that nonword decoding required the segmentation, manipulation and blending of phonemes. It follows that it would be instructive to investigate whether this result was really reflecting commonalities between nonword naming and these particular types of phonemic processing, or more fundamentally, the memory load which such processing is likely to impose. This latter suggestion would be similar to Yopp's (1988) conclusion about the similarity between the phonological tasks which loaded on what she called the *Compound Phonemic Awareness* Factor. Then again it may be that the more complex tasks stand a greater chance of picking up many individual problems within the group which affect any one of the subskills like segmentation or blending which are involved in such a complex operation.

Data were available for a subgroup of 20 of the present dyslexic sample concerning their reading of regular and irregular words. The irregular words conformed to the *exception* word criteria of Waters, Seidenberg & Bruck (1984). These items had irregular pronunciations but were not orthographically irregular.

Both nonword naming deficits and the absence of the normal advantage for regular over irregular words[7], are generally thought to be parallel indicators of phonological deficiencies in word recognition (but see Holligan & Johnston (1988) and Johnston, Anderson & Duncan (1991) for apparent dissociations between these measures amongst dyslexic children). Data concerning the regularity effect for the present sample would obviously be of great interest bearing in mind that a nonword naming deficit has already been identified. The nonword and pseudohomophone naming accuracy of the subgroup of dyslexic children did not differ significantly from that of the sample as a whole ($t<1$, in both cases). It transpired that this subgroup did not exhibit a regularity effect for either high or low frequency words. Johnston et al (1991) demonstrated that children reading normally at the 8-year-old level did show a significant advantage for regular words in response to these stimuli. Therefore, this subgroup of the present dyslexic sample were performing at a level which was incommensurate with their reading age in both the nonword naming and regularity tasks.

In the present study, the dyslexic group's performance in the Rhyme Judgement and Auditory Organisation Tasks was not impaired for their reading age. While there was a correlation between the Rhyme Judgement and Phoneme Deletion Tasks amongst the dyslexic children, this correlation was not present in the data of the reading age controls. It seems likely that in the dyslexic group a problem in the Rhyme Judgement Task is indicative of phonological difficulties whereas in the younger reading age control group, other factors may be contributing to the variance in this task, such as limited exposure to nursery rhymes (see MacLean, Bryant & Bradley, 1987). In fact, the reading age controls exhibited a correlation between chronological age and their rhyme judgement skills. The nature of the phonological skills common to the Rhyme Judgement and Phoneme Deletion Tasks would appear to merit further exploration. It has already been noted that good phonemic

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7 See Chapter 1 for a description of *regularity effects* in relation to word recognition.

processing is rarely found amongst subjects with poor rhyming skills (although it is not impossible). However, rhyming and phonemic skills are not usually reported to be highly correlated (see Stanovich et al, 1984; Yopp, 1988). It may be that in groups of children where phonological difficulties are prevalent, the relationships between tasks which normally appear to tap relatively distinct levels of phonological processing become more apparent.

It should be borne in mind that the developmental dyslexics were impaired for their chronological age at the Rhyme Judgement and Auditory Organisation Tasks despite being at least as competent as their reading age controls. It would appear that normally as children attain higher levels of reading skill, their ability in phonological tasks improves even in tasks which seem to be aimed at relatively implicit and holistic aspects of phonological awareness. This may not be purely a reflection of increasing phonological skills since orthographic effects have been discovered in phonological awareness tasks such as rhyme judgement e.g. Holligan & Johnston (1988), phoneme deletion e.g. Stuart (1990), and of course, the findings of the present study also support this conclusion. Phoneme deletion performance was found to correlate with accuracy at spelling the word and nonword stimuli in the Phoneme Deletion Task for all of the reading groups in the present study. This did not appear to be a one-to-one relationship for the majority of the subjects. The likelihood would seem to be that orthographic knowledge refines performance on tests of phonological awareness. Indeed, Ehri & Wilce (1987) argued that spelling training improves young readers' ability to divide words into their phonemic constituents. Ehri (1987, 1991) claimed that letters provide visual *phonemic* symbols for words. Although the dyslexic children did appear to utilise an orthographic strategy to the same extent as their reading age controls in these experiments, the Spelling Task revealed that the reading groups may not have been as adequately matched on their ability to spell the stimuli in the Phoneme Deletion Task as would be suggested by their spelling ages.

It should be stressed that even the phonological task which caused the most difficulty for the dyslexic group as a whole, namely the Phoneme Deletion Task, could only explain a small proportion of the variance in nonword and pseudohomophone naming ability (6% and 17% of the variance, respectively, after reading age had been partialled out). Other factors, be they visual, attentional, memory related or as yet unidentified, would seem to be exerting an influence and need to be specified if greater insight into the reading process is to be achieved. The association evident in the developmental dyslexic group between reading age and performance on the Tactile Embedded Figures Task was intriguing and would seem to be worth pursuing in more detail, perhaps in relation to remediation.

Visual skills, in particular, may be relevant to the difficulty encountered by some dyslexic children given the very severe deficits that were suffered by some of the children in the sample. The relationships between the Visual Embedded Figures Task and spelling accuracy would seem to be of particular interest and may relate to the identification and retention of orthographic patterns which occur within words. In addition, there was a high negative correlation between scores on the Visual Embedded Figures Task and the presence of a regularity effect amongst the aforementioned subgroup of 20 dyslexics from the present sample ($r(18)=0.54$, $p<0.02$). That is, the better their visual segmentation skills were, the less they exhibited an advantage for regular over irregular words in their reading. Olson et al (1985) reported a negative correlation between the presence of regularity effects and orthographic skill amongst a group of disabled readers. Johnston et al (1991) have demonstrated further, that a subgroup of dyslexic children with good visual segmentation skills actually displayed an advantage for *irregular* words in their reading. This subgroup of dyslexics displayed a greater proficiency in reading visually distinctive words containing risers and descenders (e.g. *plate*) and this may relate to their enhanced processing of irregular words. This would appear to provide support for the conclusions of Olson et al (1985), who proposed that their results derived from the enhanced processing of irregular words by children with orthographic strengths.

Pring & Snowling (1986) have already shown that a nonword's orthographic similarity to a real word can influence decoding ability. They demonstrated in their priming experiment that normal readers at both the 8 and 10 year old levels were faster at reading pseudohomophones which differed from their lexical targets by only one grapheme (e.g. *neer*), than those which differed by two graphemes (e.g. *kneer*). Pring & Snowling suggested that young children, in particular, supplement their use of spelling-to-sound rules by making auditory and visual analogies when decoding. As the authors point out, it would be fascinating to investigate the prevalence of this strategy amongst developmental dyslexics. In the present study, the developmental dyslexics and their reading age controls showed pseudohomophone effects of equal size in the Nonword Naming Task, implying that both groups used auditory analogies to the same extent. The use of more visually-based analogies awaits investigation.

The experimental programme in this chapter yielded evidence that the dyslexic group as a whole were impaired for their reading age in three tasks - Nonword Naming, Phoneme Deletion and Spelling. However, this gives a rather artificial impression of the range of impairments which the developmental dyslexics suffered. With the exception of the Tactile Embedded Figures Task, examination of individual performance in the experimental tasks revealed both dyslexic children who were impaired for their reading age and dyslexic children who were not. The relative proportion of such children varied considerably between the experimental tasks. In the Nonword Naming, Phoneme Deletion and Spelling Tasks impairments were prevalent amongst the dyslexic group, but nevertheless, children whose performance was consistent with their reading age were identified. In the Rhyme Judgement, Auditory Organisation and Visual Embedded Figures Tasks impairments were less frequent but did afflict some of the dyslexic children very severely. The heterogeneity underlying the performance of the dyslexic group was striking. The impression was not, however, that this heterogeneity was manifest in homogeneous subgroups of children with similar and restricted impairments. Instead, impairments appeared to have variable associations. As was mentioned earlier, it did not appear to be the case that performance in the various phonological segmentation tasks corresponded to performance in the visual segmentation task. Nor did it seem that those children who suffered phonological impairments were impaired in all the phonological tasks, or that such children were not impaired in the visual task. The relative balance of cognitive skills and impairments would appear to be a key issue. Not only in terms of which impairments reliably co-occur or dissociate, but also how the system as a whole is galvanised in order to learn to read. Johnston et al (1991, in press) have tackled this issue in relation to the reading patterns found in children with varying visual and phonological segmentation skills. Future longitudinal research is needed to determine whether such results reflect causal relationships which are shaping the course of reading acquisition.

CHAPTER 5

STUDY TWO

5.1 INTRODUCTION

The experimental work in this chapter was designed to consolidate some of the findings from Chapter 4, and to explore in more detail certain of the issues which were raised in that chapter, using a new sample of developmental dyslexics. In addition, the inquiry was extended to investigate long-term memory processes in developmental dyslexia.

A replication of the earlier results with regard to the Nonword Naming and Visual Embedded Figures Tasks was undertaken. In the case of the Nonword Naming Task assessment of performance was broadened to include measurements of speed of processing.

A new phonological segmentation task was designed in order to test the dyslexic children's sensitivity to onset and rime units. This type of phonological segmentation was of interest because Treiman (1991) has suggested that such units form an intermediate stage between the more holistic awareness of syllables and the more analytical awareness of phonemes. In the previous chapter, the majority of the dyslexic sample were found to be impaired for their reading age on the Phoneme Deletion Task which tested phonemic awareness, but few were deficient for their reading age on the Rhyme Judgement and Auditory Organisation Tasks which required a more holistic awareness of phonology. It was argued in Chapter 4 that task demands may interact with levels of phonological awareness to determine the difficulty of any particular test of phonological awareness. Therefore, sensitivity to the relatively holistic onset-rime level of phonological segmentation was examined in the present chapter using the unit deletion paradigm which had revealed the phonemic impairments in Chapter 4.

The correspondence between phonological and orthographic segments was also examined with regard to onset and rime units. Goswami (1986, 1988) has suggested that phonological sensitivity to onsets and rimes leads children to notice that words which rime have spelling patterns in common. Thus, a corresponding *visual* awareness of onset and rime spelling units may be promoted. This could be linked to the salience which Patterson & Morton (1985) have attributed to bodies or rime units in adult word recognition. Treiman & Chafetz (1987) have demonstrated that adults were more accurate in a lexical decision task when words were split according to their onset and rime units (e.g. cr//isp), than according to post-vowel segmentation (e.g. cri//sp). These issues were thought to be of relevance to the present study given that some of the developmental dyslexics in Chapter 4 had been found to suffer severe visual segmentation problems. Therefore, a task similar to the one used by Treiman & Chafetz (1987) was incorporated into the present experimental programme in order to test whether developmental dyslexics would show preference for certain types of sublexical units. In an attempt to make this task less artificial, the units were highlighted in different colours rather than separated by lines so as to avoid disrupting the overall shape of the word.

The discovery that the developmental dyslexics in Chapter 4 tended to be impaired for their chronological age on the Digit Span subtest of the WISC-R replicated numerous reports in the literature which suggest that developmental dyslexics suffer phonological short-term memory problems (e.g. Vellutino, 1979; Torgesen & Houck, 1980; Ellis & Miles, 1981). Dyslexic children would also appear to be typically unable to draw upon the requisite long-term representations in order to read words which should be familiar to them. It is interesting to note, therefore, that there has been a revival of the hypothesis that long-term learning depends upon short-term storage (e.g. Baddeley, Papagno & Vallar, 1988). Consequently, it was felt that an examination of dyslexic performance on a long-term memory task would be very pertinent.

The repetition memory paradigm was selected as it would enable comparison of the extent to which the performance of dyslexic children and their controls was facilitated by the repetition of the experimental items. A phonological decision task containing nonlexical stimuli formed the basis of this experiment. This task was favoured over the standard lexical decision task because it should require the subjects to utilise their decoding skills in order to consider the *sound* of each item. The "learning" of these stimuli was assessed in the Repetition Memory Task by the measurement of accuracy and reaction times, and in addition, the subjects' recognition of the experimental items was later tested in the Recognition Memory Task.

5.2 SUBJECTS

(i) *Developmental Dyslexics*

The developmental dyslexics in this sample were drawn from the same type of population as those described in Chapter 4; in fact, 8 developmental dyslexics participated in both studies.

There were 20 developmental dyslexics in the current sample whose mean chronological age was 11.1 years (see Table 10). The Word Reading test from the British Ability Scales (Elliott et al, 1979) was once again used to assess word recognition skills, and the mean reading age was found to be 7.9 years. Therefore, as was the case for the developmental dyslexics studied in Chapter 4, the group's mean reading age was approximately three years behind the average chronological age, although this deficit ranged in severity from 19 to 53 months among the individuals in the group. The mean spelling age of the sample was found to be 7.9 years using the Schonell Graded Word Spelling Test B (Schonell, 1971). Thus, the developmental dyslexics exhibited a spelling deficit similar in magnitude to their deficit in reading; however the severity of this deficit ranged between 23 and 60 months among the subjects.

The scaled score from the vocabulary subtest of the WISC-R (Wechsler, 1976) was used to estimate the I.Q. of the subjects. This was felt to be a valid

TABLE 10

SUBJECTS:
Mean Chronological Age, Reading Age, Spelling Age, Vocabulary Score and Digit Span
(standard deviations in brackets)

ATTRIBUTE	READING GROUP	
	READING AGE CONTROLS	DEVELOPMENTAL DYSLEXICS
CHRONOLOGICAL AGE	7.7 (0.3)	11.1 (0.7)
READING AGE	8.0 (0.6)	7.9 (0.8)
SPELLING AGE	8.2 (0.7)	7.9 (0.9)
SCALED VOCABULARY SCORE	10.4 (1.7)	9.9 (1.5)
SCALED DIGIT SPAN	9.9 (1.5)	7.5 (2.0)

approximation of I.Q. since Wechsler (1976) reported that the vocabulary subtest scores correlated more highly with Full-Scale I.Q. than those of any other subtest. Furthermore, equating vocabulary scores should be a very stringent match of I.Q. considering the contribution of reading, especially independent reading, to the consolidation and expansion of vocabulary. The developmental dyslexics' mean scaled score in the vocabulary subtest was 9.9, and all subjects achieved a scaled score of 8 or above.

When tested using the Digit Span subtest of the WISC-R (Wechsler, 1976), the developmental dyslexics achieved a mean raw score of 9.4, which translated to an average scaled score of 7.5.

(ii) *Reading Age Controls*

The 20 children in this sample were drawn from one of the state Primary Schools in Fife described in Chapter 4, using similar selection criteria.

The mean chronological age for the group was 7.7 years. All the following measurements involved the same tests that had been used with the developmental dyslexic group. The sample's reading age tended to be a couple of months ahead of their chronological age, with the mean reading age of the group being 8.0 years. The group's spelling age was slightly better, being on average six months above their chronological age, the mean for the group was 8.2 years. The mean scaled vocabulary score was 10.4, and all members of the sample scored 8 or above on this test. The reading age controls produced a mean raw score of 8.8 in the Digit Span test and this corresponded to a mean score of 9.9 when adjusted for chronological age.

(iii) *Reading Group Comparisons*

To evaluate the reading age comparison, an analysis of variance was performed on reading age as a function of **groups** (developmental dyslexics and reading age controls). There was no main effect of groups, $F<1$. When scaled vocabulary scores and spelling age were subjected to a similar test, once again, there was no main effect of groups, $F(1,38)=1.00$, $p>0.05$, and $F(1,38)=1.32$, $p>0.05$, respectively. Therefore, this sample seemed to provide an adequate control for the developmental dyslexics in terms of reading age, scaled vocabulary score and spelling age.

The scaled scores from the Digit Span subtest were also subjected to an analysis of variance in order to compare the short-term memory capabilities of the two reading groups. There was one between-subjects factor, **groups** (developmental dyslexics and reading age controls) which was found to be significant, $F(1,38)=17.55$, $p<0.0005$. A Newman-Keuls test indicated that the performance of the developmental dyslexics was significantly worse than that of the reading age controls in this "age-adjusted" test. Another similar analysis of variance was carried out on the raw scores from the Digit Span test. The analysis contained one between-subjects factor, **groups** (developmental dyslexics and reading age controls) but this effect did not achieve significance, [$F(1,38) = 1.45$, $p>0.05$]. Thus, the developmental dyslexics were exhibiting the same short-term memory capabilities as normal readers who were over three years younger.

5.3 NONWORD NAMING TASK

(i) *Materials*

Sixteen pairs of pseudohomophones and their control nonwords were selected. These were a subset of the stimuli used for the study of nonword naming in Chapter 4. In addition, eight filler nonwords were included in order to break up the repetition of orthographic patterns occurring among these closely matched stimuli (see Appendix 7). The Grade 3 norms of Carroll et al (1971) indicated that the mean frequency of the words from which the three types of nonwords were derived were as follows - pseudohomophones, 706 (s.d. 1731); control nonwords, 849 (s.d. 1503); filler nonwords, 316 (s.d. 731).

(ii) *Procedure*

An Amstrad Portable Personal Computer (512K RAM) and a MicroVitec CUB colour monitor (12-inch display) were used to present stimuli and collect response data. A verbal response unit was interfaced to the PC via an analogue sensitivity controller, allowing adjustment to accommodate the normal speaking voice level of individual subjects.

Each of the stimuli letters was designed using software written for the PC on a matrix of 20 (x) by 30 (y) pixels. This allowed explicit control over the style of the font used. All letters were in lower-case and based on those typically found in early reading materials. Additionally, an asterisk character was designed for use as a fixation point. Reaction time resolution was limited to 1/100ths of a second by the PC's internal clock. The associated stimuli and response data for each subject were stored in on-line disk files for later analyses. The entire experimental session was also recorded on audio-cassette tape for accuracy analysis.

Subjects were seated 0.6m from the computer display, with the microphone directly in front of them. (At this distance, letters displayed on the monitor subtended a visual angle of approximately 2 degrees). All stimuli appeared centred on the monitor display, and were preceded by a central fixation point (asterisk) for 0.5 seconds. Presentation of subsequent stimuli was controlled by the experimenter pressing the space-bar on the computer console.

The 40 stimuli were pseudo-randomised in three alternative lists, and care was taken to ensure that pseudohomophones and their control nonwords were always separated by at least four items in each list. In both reading groups, the three alternative lists were each administered to equivalent numbers of subjects. All subjects participated in the same six practice trials. The children were told that they were going to see some "made-up" words on the screen and that they had to try and make them disappear by saying them out loud. They were asked to do this as quickly but as carefully as they could. They were also instructed not to say anything until they had decided on their response, in order to prevent them from triggering the voice key prematurely.

(iii) Results

The statistical package MINITAB (PC release 7; Minitab Inc., California) was programmed to compute the cell arithmetic mean accuracy scores and geometric mean reaction times from the raw data files produced in the experiment.

Accuracy

The results were expressed in terms of percentage accuracy according to nonword type (see Table 11). A two-way analysis of variance was carried out with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and one within-subjects factor, **type** (pseudohomophone, control and filler nonwords). There were significant main effects of both groups ($F(1,38)=4.57$, $p<0.04$) and type ($F(2,76)=5.83$, $p<0.005$) but the interaction groups by type did not reach significance ($F<1$). Overall, the developmental dyslexics were found to be worse at nonword naming than their reading age controls. Nevertheless, their performance was qualitatively similar to that of their reading age controls and Newman-Keuls tests showed that both groups were more accurate at naming pseudohomophones than either type of ordinary nonword. The two types of ordinary nonwords produced similar levels of accuracy in the subjects.

Error Analysis: Lexicalisation Errors

Only those errors which were made in the carefully matched pseudohomophone and control nonword conditions were included in this

TABLE 11

NONWORD NAMING TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	NONWORD TYPE		
	CONTROL e.g. *coe*	PSEUDOHOMOPHONE e.g. *loe*	FILLER e.g. *blie*
READING AGE CONTROLS	57.19 (20.81)	63.44 (23.23)	53.38 (21.75)
DEVELOPMENTAL DYSLEXICS	44.38 (20.47)	49.69 (20.02)	42.06 (19.49)

analysis. The number of lexicalisation errors that each subject made in each condition was converted into a percentage of their total errors in that condition (see Table 12). The data were subjected to a two-way analysis of variance with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and one within-subjects factor, **type** (pseudohomophone and control nonwords). There was a main effect of type ($F(1,38)=20.13$, $p<0.0005$). However, the effects of groups ($F(1,38)=1.21$, $p>0.05$) and the interaction groups by type ($F(1,38)=1.57$, $p>0.05$) failed to reach significance. Therefore, the results show that both reading groups made a higher proportion of lexicalisation errors when naming ordinary nonwords than when naming pseudohomophones.

Reaction Time

Only reaction times to correct responses were analysed. One subject from each reading group had to be excluded due to their low accuracy in the filler word condition, as this had made it impossible for any reliable average of their reaction times to be calculated.

The analysis of reaction time data is methodologically complex. Summarising these data by measures of central location, such as the arithmetic mean, can be misleading for they reflect every stimulus anticipation and lapse of attention. Moreover, reaction time data tends to be positively skewed by its very nature and this complication becomes magnified when children are used as subjects. In this situation, the median is often preferred for its resistance to atypical values and skew (e.g. Milner, 1986). Nevertheless, Miller (1988) has qualified this with a set of provisions as to the circumstances in which this measure should be used. He pointed out that sample median reaction times are likely to overestimate the true population values. So long as one is comparing experimental conditions biased in the same way, this is not a problem. However, difficulties arise when experimental conditions contain varying

TABLE 12

LEXICALISATION ERRORS IN THE NONWORD NAMING TASK:
Mean Number Of Lexicalisation Errors As A Percentage of Total Errors In Each Condition
(standard deviations in brackets)

READING GROUP	CONDITION	
	CONTROL NONWORDS	PSEUDOHOMOPHONES
READING AGE CONTROLS	65.03 (25.11)	39.68 (21.14)
DEVELOPMENTAL DYSLEXICS	53.45 (22.82)	39.16 (19.88)

numbers of trials (as in the present experiment), since median bias becomes more extreme as the number of scores the calculation is based upon decreases. To avoid introducing this statistical artifact into the present analysis, the average speed to each type of nonword was derived for each reading group by taking the geometric mean reaction time. This measure was selected for its capacity to cope with positively skewed data. The derivation of this property of the geometric mean is evident from its calculation. This involves finding the antilogarithm of the arithmetic mean of the logarithms of the data set, a transformation which should make the distribution of a positively skewed data set more symmetrical.

The results for each reading group are summarised in Table 13, by taking the arithmetic mean of the geometric mean reaction times to each type of nonword.[1] Tests for homogeneity of variance (Cochran's C and the Bartlett-Box F) showed that variance was inhomogeneous between the reading groups and so a logarithmic transformation was performed on these data (as recommended by Winer (1971) for reaction time data). As this was found to have homogenised the variance, a two-way analysis of variance could be carried out on the transformed data with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and one within-subjects factor, **type** (pseudohomophone, control and filler nonwords). Main effects were found of both groups ($F(1,36)=5.66$, $p<0.03$) and type ($F(2,72)=11.39$, $p<0.0005$). However, the interaction of groups by type did not achieve significance ($F(2,72)=2.65$, $p>0.05$). The basis of the groups effect was that the developmental dyslexics were slower to respond than their reading age controls in the Nonword Naming Task. In spite of this, the reading groups exhibited a similar pattern of performance, as revealed by Newman-Keuls tests; subjects responded significantly faster to the pseudohomophones than to either type of the

[1] It is assumed that the skew in the data has been largely dealt with by taking the geometric mean and so the arithmetic mean can once again be used for averaging the data.

TABLE 13

NONWORD NAMING TASK: ***Geometric Mean Reaction Time (msecs.)***
(standard deviations in brackets)

READING GROUP*	NONWORD TYPE		
	CONTROL e.g. *coe*	PSEUDOHOMOPHONE e.g. *loe*	FILLER e.g. *blie*
READING AGE CONTROLS	2070 (1342)	1874 (1259)	3221 (3358)
DEVELOPMENTAL DYSLEXICS	3486 (2271)	2727 (1165)	3396 (1725)

* n=19 in both reading groups

ordinary nonwords, and response times to the control nonwords were significantly faster than those to the filler nonwords.

(iv) Discussion

The developmental dyslexic group were found to suffer a nonword naming deficit relative to their reading age controls. This result replicated the finding in Chapter 4 in terms of accuracy, and extended the description of the dyslexics' impairment to include speed of processing. In spite of their nonword naming problems, the dyslexic children once again showed the same pattern of performance as their reading age controls. Both groups responded faster and with greater accuracy to the pseudohomophones than to the nonhomophonic nonwords. Thus, despite altering the method of presentation by mixing the pseudohomophones and control nonwords in a single stimulus list, the results of Chapter 4 were replicated.

The discovery that the dyslexic children were slower to respond than their reading age controls in this task could imply that the dyslexics were making more use of a phonic *sounding-out* strategy in this task. This may not necessarily mean that the reading age controls were not sounding out, but they may have been better able to employ larger sublexical units in this process. On the other hand, the slow responses of the dyslexic children could perhaps reflect a lack of automaticity in the decoding process. Certainly in terms of the qualitative comparisons contained in the nonword naming tests in this study, the dyslexic children were indistinguishable from their reading age controls.

In terms of nonword naming accuracy, five dyslexic children were above average for their reading age and one of these children scored more than one standard deviation above that average. At the other end of the scale, one dyslexic child was extremely poor at naming nonwords and performed more than two standard deviations below the mean of the reading age controls. This was outwith the range of scores produced by the reading age controls. He read only one ordinary nonword correctly but managed to read seven of the pseudohomophones.

Amongst the reading age controls, as in Chapter 4, accuracy at naming nonwords correlated with reading age (*control nonwords:* $r(18)=0.52$, $p<0.02$; *pseudohomophones*: $r(18)=0.57$, $p<0.01$) and spelling age (*control nonwords:* $r(18)=0.51$, $p<0.03$; *pseudohomophones*: $r(18)=0.57$, $p<0.09$). In addition, nonword naming speeds were correlated with reading age (*control nonwords:* $r(17)=-0.59$, $p<0.009$; *pseudohomophones*: $r(17)=-0.52$, $p<0.03$), and rather more strongly with spelling age (*control nonwords:* $r(17)=-0.68$, $p<0.002$; *pseudohomophones*: $r(17)=-0.62$, $p<0.006$). The better readers and spellers named the stimuli faster. The developmental dyslexics also exhibited an association between their accuracy at naming control nonwords and their reading age ($r(18)=0.87$, $p<0.0005$) and spelling age ($r(18)=0.72$, $p<0.0005$), although the association with spelling age did not reach significance once reading age was partialled out ($r(17)=0.15$, $p>0.05$). As in Chapter 4, accuracy at naming pseudohomophones did not relate significantly to either reading or spelling age. In common with the reading age controls, the better spellers among the dyslexic children named control nonwords faster than the poorer spellers ($r(17)=-0.48$, $p<0.04$).

Analysis of the lexicalisation errors made by the reading age controls in response to pseudohomophones revealed that, as in the previous chapter, the better readers in this group made the lowest proportion of lexicalisation errors ($r(18)=0.52$, $p<0.02$). In addition, it was evident that the better spellers also made a lower proportion of lexicalisation errors when naming the pseudohomophones ($r(18)=0.59$, $p<0.008$). Large proportions of lexicalisation errors in response to pseudohomophones tended to be associated with inaccuracy in naming these stimuli, but this relationship just missed significance ($r(18)=-0.44$, $p>0.05$). Reading age controls who made a high proportion of lexicalisation errors in response to pseudohomophones also tended to have longer response latencies in naming both pseudohomophones ($r(17)=0.57$, $p<0.02$) and control nonwords ($r(17)=0.50$, $p<0.03$). These findings seemed consistent with the indications in Chapter 4 that subjects who made high proportions of lexicalisation errors when naming pseudohomophones tended to have poorer literacy skills. The reading age controls showed no significant relationship between reading age or spelling age and the proportion of lexicalisation errors made in response to the control nonwords.

Amongst the developmental dyslexics, high proportions of lexicalisation errors in pseudohomophone naming were associated with lower spelling ages ($r(18)=-0.45$, $p<0.05$). However, lexicalisation errors made in response to the control nonwords were not related significantly to spelling age ($r(18)=-0.42$, $p>0.05$). The developmental dyslexics displayed no significant association between reading age and the proportion of lexicalisation errors in response to either pseudohomophones ($r(18)=-0.32$, $p>0.05$) or control nonwords ($r(18)=-0.26$, $p>0.05$). In addition, the dyslexic children showed a negative correlation between raw scores in the Digit Span subtest of the WISC-R and the proportion of lexicalisation errors made in response to pseudohomophones ($r(18)=-0.63$, $p<0.004$). This could suggest that short-term memory problems lead to inaccuracies in the process of sounding-out and blending, which limit their success with decoding.

5.4 SEGMENT DELETION TASK

(i) Materials

The stimuli formed a 2x2x2 factorial design and were selected to enable investigation of the following conditions:

1. Lexicality	comparing segment deletion from words and nonwords e.g. *spent* vs. *stent*
2. Segmentation	comparing segment deletion involving onset-rime and post-vowel segmentation e.g. *blond* vs. *blond*
3. Position	comparing segment deletion from the beginning and end of stimuli e.g. *blast* vs. *blast*

There were 22 words and 22 nonwords, all of the form CCVCC (see Appendix 8). Lexical and nonlexical items each contained two subgroups of stimuli and these stimuli were matched both within and across lexicality in terms of their phonetic content. The two lexical subgroups had mean word frequencies of 36 (s.d. 88) and 23 (s.d. 27) respectively (as calculated using the Grade 3 norms of Carroll et al, 1971). These subgroups allowed segmentation and position to be balanced within the categories of lexicality. The segmentation condition was further controlled in that the experiment was administered in two halves, the second half featured the same stimuli and deletion from the same position but involved the alternative type of segmentation i.e. if the deletion were *stamp* in the first half, it would become *stamp* in the second half. This meant that each stimulus was investigated under both onset-rime and post-vowel segmentation and hence formed its own control. Two different versions existed of the final 88 item test in order to control for the effect of position. So, if *stamp* were included in one version as outlined above, it would appear in the second version as *stamp* and *stamp*.

(ii) *Procedure*

The stimuli were randomised in each half of the two test versions and the presentation of these alternative versions was balanced among the subjects. The two halves of the test were presented on different days and all subjects were allowed a rest in the middle of each half of the test to prevent fatigue effects. The subjects were told to listen carefully to the sounds in the "words" that were read out because they were going to be asked what would be left after some of the sounds were taken away. They were also instructed to look down at the desk throughout the test to prevent them from using the experimenter's lip movements to aid their performance. At the outset, the subjects were given an illustrative example by the experimenter and then they attempted eight practice items. The first four practice items involved deletions from words and contained various combinations of segmentation and position conditions. The idea of deleting sounds from "made-up" words was explained and practiced using the last four items. The subjects received feedback on accuracy only during this practice session. All practice and experimental trials had the following form e.g. *blunt*:

> "Say 'blunt' .... What would be left if you took away the /blu/ sound ?"

The subjects response was noted by the experimenter.

(iii) *Results*

Each subject's percentage accuracy for every cell in the factorial design was calculated (see Table 14). An analysis of variance was carried out with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and three within-subjects factors: **lexicality** (words and nonwords); **segmentation** (onset-rime and post-vowel); **position** (beginning and end). There were main effects of lexicality ($F(1,38)=9.10$, $p<0.006$), segmentation ($F(1,38)=105.47$, $p<0.0005$) and position ($F(1,38)=9.15$, $p<0.005$). However, the effect of groups was not significant ($F(1,38)=1.32$, $p>0.05$) and did not feature in any of the significant interactions, indicating that the developmental dyslexics performed this task at an equivalent level and in a similar manner to their reading age controls. The effect of lexicality did not appear in any significant interactions either, showing that subjects were more accurate at deleting segments from words than from nonwords. The only interaction to reach significance was that of segmentation by position

TABLE 14

SEGMENT DELETION TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	WORDS				NONWORDS			
	ONSET-RIME		POST-VOWEL		ONSET-RIME		POST-VOWEL	
	BEGINNING	END	BEGINNING	END	BEGINNING	END	BEGINNING	END
READING AGE CONTROLS	89.09 (14.33)	48.64 (29.83)	24.09 (23.65)	47.27 (25.13)	84.55 (15.63)	46.36 (30.92)	22.73 (24.05)	38.64 (20.41)
DEVELOPMENTAL DYSLEXICS	84.55 (19.14)	51.82 (27.21)	17.73 (24.23)	35.00 (24.19)	80.60 (20.51)	54.70 (26.93)	9.56 (17.57)	29.55 (21.25)

($F(1,38)=73.78$, $p<0.0005$). Newman-Keuls tests revealed that, overall, subjects were more accurate at onset-rime segmentation than at post-vowel segmentation (see Figure 8). In addition, subjects showed an advantage for deleting the onset as opposed to the rime under onset-rime segmentation (i.e. *blond* better than *blond*). With post-vowel segmentation the opposite pattern prevailed, subjects were more accurate at deleting the end rather than the beginning segment (i.e. *blond* better than *blond*). Although this result may have partly reflected the difficulty of articulating a consonant blend in isolation, there was a marked advantage for deletions which left the initial consonant blend or onset unit (e.g. *blond*). Such deletions were performed significantly more accurately than those which left either the final consonant blend (e.g. *blond*) or the "initial consonant blend+vowel" segment (e.g. *blond*). None of the other interactions were significant - groups by segmentation ($F(1,38)=2.04$, $p>0.05$); groups by lexicality ($F<1$); groups by position ($F<1$); segmentation by lexicality ($F(1,38)=2.82$, $p>0.05$); lexicality by position ($F<1$); groups by segmentation by lexicality ($F(1,38)=1$, $p>0.05$); groups by segmentation by position ($F<1$); groups by lexicality by position ($F(1,38)=2.68$, $p>0.05$); segmentation by lexicality by position ($F(1,38)=1.38$, $p>0.05$); groups by segmentation by lexicality by position ($F<1$).[2]

(iv) *Discussion*

The discussion for the Segment Deletion Task will follow Section 5.5.

5.5 SPELLING TASK

(i) *Materials*

These were the 22 words and 22 nonwords used in the Segment Deletion Task in this chapter (see Appendix 8).

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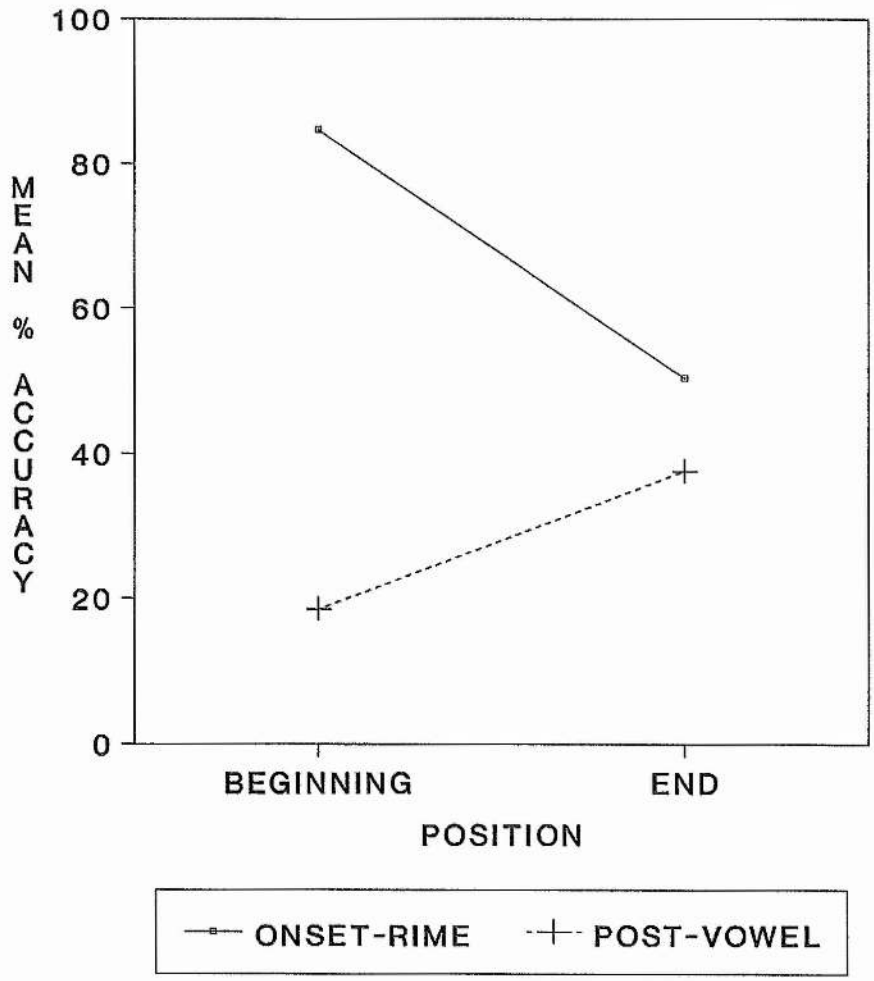
[2] In an additional analysis, the effect of the alternative stimulus lists was investigated and found not to be significant (see Appendix 11).

FIGURE 8
SEGMENT DELETION TASK:
Interaction of Segmentation and Position



(ii) *Procedure*

This test was always carried out after the Segment Deletion Task. The experimental items were presented to the child in the same order as they had received them in the first part of the Segment Deletion Task. Thus, the stimuli were administered in one of two randomised orders. The procedure for presentation of the stimuli and collection of the data were as described for the Spelling Task in Chapter 4.

(iii) *Results*

The results were expressed in terms of percentage accuracy for word and nonword items (see Table 15). A two-way analysis of variance was conducted with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and one within-subjects factor, **lexicality** (words and nonwords). None of the effects achieved significance in this analysis - groups ($F<1$); lexicality ($F(1,38)=3.45$, $p>0.05$); groups by lexicality ($F<1$).

(iv) *Discussion*

In the Segment Deletion Task, the developmental dyslexic group were able to delete both onset-rime and post-vowel segments as accurately as the reading age controls. The dyslexic groups' ability to spell the experimental stimuli used in this task was also commensurate with the performance of the control group, and so was consistent with both reading and spelling age. It will be recalled that in Chapter 4, the dyslexic group was found to be worse than the reading age controls in a similar spelling task, despite the apparent match on spelling age between these two groups. The present results may reflect sample differences or perhaps originate from the use of new stimuli for the Segment Deletion Task in this chapter. None of the new experimental items contained a mismatch between their orthography and phonology. Moreover, all of the new

TABLE 15

SPELLING TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	WORDS	NONWORDS
READING AGE CONTROLS	76.13 (21.47)	79.32 (22.34)
DEVELOPMENTAL DYSLEXICS	71.36 (13.44)	74.32 (17.15)

items had short vowels which meant that vowel digraphs were avoided, although each item did contain a consonant digraph at beginning and end.

The phonological segments to be manipulated in the Segment Deletion Task were most comparable to those occurring in the Rhyme Judgement and Auditory Organisation Tasks in Chapter 4, although the manipulation itself was based on the Phoneme Deletion Task. The findings of Chapter 4 were replicated in that the dyslexic group did not appear to be insensitive to the more holistic phonological aspects of speech. Furthermore, these dyslexic children were as able as their reading age controls to cope with the demands of the deletion task. Nevertheless, it remains a possibility that the size and number of the units to be manipulated could have influenced the processing load in the deletion task. Thus, the manipulation of onset and rime units may be less disruptive to the performance of the dyslexic children than the manipulation of phonemes which are smaller and more numerous.

When individual results were examined, it was apparent that four of the dyslexic children did have considerable difficulty with segment deletion, since they scored more than one standard deviation below the mean of their reading age controls. Only one dyslexic child scored more than one standard deviation above the mean of the reading age controls and it appeared that the distribution of the dyslexic's results was slightly negatively skewed relative to the data from the reading age controls.

The qualitative aspects of the reading groups' performance in this task were very similar. Both of the groups were more accurate at deleting onset-rime segments than post-vowel segments, confirming recent work which indicates that onset and rime units have a particular salience for both children and adults (e.g. Treiman, 1983, 1985; Kirtley et al, 1989). Furthermore, it has been established that developmental dyslexics also find these units salient. A recently published study by Bruck & Treiman (1990) contained a similar finding. These authors were particularly interested in the onset unit and compared various permutations of deleting phonemes from onset clusters with the deletion of actual singleton and cluster onset units. They discovered that dyslexic children were worse than their spelling age controls at deleting the first and the second consonants in cluster onsets but were as accurate as controls at deleting the entire onset unit.

The position of the segment to be deleted was shown to be important. This may have reflected articulatory factors relating to the difficulty of articulating the terminal consonant cluster in the post-vowel segmentation condition. For example, when the first sound of a terminal consonant cluster is a preconsonantal nasal, this is usually vocalised as part of the vowel and may be hard to reproduce in isolation (see Read, 1986). However, the advantage for onset-rime segmentation remained when deletions leaving larger, more easily articulated segments, were considered. That is, deleting the onset in the onset-rime segmentation condition, which required pronunciation of the remaining rime segment (e.g. *spent*), was easier than deleting the terminal consonant cluster in the post-vowel segmentation condition, which required pronunciation of the remaining 'initial consonant cluster + vowel' segment (e.g. *spent*).

As in Chapter 4, the developmental dyslexics and their reading age controls found it easier to delete segments from words than nonwords, which could have been due to the extra demands of maintaining the unfamiliar phonological sequences in memory while performing the deletion. In the last chapter it was also suggested that such lexicality effects may derive from a lack of automaticity in applying an orthographic strategy to novel sound sequences. The reading groups performance in the Spelling Task was indicative of a phonological approach since neither group exhibited an advantage for spelling words, if anything, there tended to be an advantage for nonwords.

The reading age controls' performance in the Segment Deletion Task was related to reading age ($r(18)=0.71$, $p<0.002$) and spelling age ($r(18)=0.72$, $p<0.0005$). Segment deletion performance in this group was also associated with accuracy at naming pseudohomophones ($r(18)=0.62$, $p<0.005$) and control nonwords ($r(18)=0.54$, $p<0.02$), but these relationships failed to achieve significance once reading age was partialled out (*pseudohomophones:* $r(17)=0.37$, $p>0.05$; *control nonwords:* $r(17)=0.28$, $p>0.05$). However, an association between poor segment deletion skills and a high proportion of lexicalisation errors in response to pseudohomophones in the Nonword Naming Task, proved to be independent of reading and spelling ability ($r(18)=-0.69$, $p<0.002$). In the segment deletion data from the developmental dyslexics, none of the above correlations were significant but their performance did correlate with their raw scores on the Vocabulary subtest of the WISC-R ($r(18)=0.46$, $p<0.05$).

Interestingly, the close association that was seen in Chapter 4 between deletion performance and the ability to spell the stimuli from the deletion task, was not present here. This may partially reflect differences in the nature of the experimental stimuli. The items in the present chapter may not have been sufficiently taxing to reveal what may be quite an abstract correspondence between spelling and phoneme deletion skills. It may be that the phonological segments involved in the Segment Deletion Task were more salient to both reading groups and consequently, their performances were predominantly phonologically based. In contrast, the manipulation of phonemes which are more embedded in the sound stream, may be facilitated by the use of an orthographic strategy in tasks such as the Phoneme Deletion Task.

Therefore, it was demonstrated that the dyslexic group's facility with segment deletion was commensurate with their reading level. Both the developmental dyslexics and their reading age controls were better at manipulating onset and rime segments than the units which resulted from post-vowel segmentation. Goswami (1986) has demonstrated that children with reading ages of between six and seven-and-a-half years were able to draw upon their phonological knowledge in order to make analogies which allowed them to read unfamiliar words. Analogies were preferentially based upon the rime segment. If an analogy strategy based upon an awareness of onset and rime units is indeed a critical feature of early reading development, the results of the present experiment gave no reason to suspect that the dyslexic children would be disadvantaged in the use of such a strategy, since they were equally as sensitive as their reading age controls to onset and rime units.

5.6 COLOUR-SEGMENTED LEXICAL DECISION TASK

(i) *Materials*

The stimuli used in this experiment can be seen in Appendix 9. They consisted of 20 words and 20 nonwords of the form CCVCC creating the following 2x2x2 factorial design:

1. Lexicality — comparing lexical decisions to words and nonwords
e.g. **sh***ort* vs. **cr***ing*

2. Segmentation — comparing lexical decisions to stimuli highlighted in different colours according to onset-rime or post-vowel segmentation
e.g. **ch***ild* vs. **chi***ld*

3. Blend — comparing lexical decisions to stimuli containing a consonant blend at the beginning or end
e.g. **ch***est* vs. *bru***sh**
- for the lexical stimuli, the mean frequency of the *chest* items was 84 (s.d. 102) and of the *brush* items was 83 (s.d. 94)

In the experiment as a whole, all the lexical stimuli were split into higher and lower frequency items, with mean frequencies of 150 (s.d. 95) and 17 (s.d. 12), respectively. All frequencies were calculated from the Grade 3 norms of Carroll et al (1971).

The experiment was in two halves with each stimulus forming its own control for the segmentation factor. For example, if *tr***uck** (onset-rime segmentation) appeared in the first half, *tru***ck** (post-vowel segmentation) would appear in the second half. As in the Segment Deletion Task, there was an alternative version of the test, so if *truck* featured in the first version as outlined above, then the second version would include **tr***uck* and **truc***k* to counterbalance the way the segments were highlighted. Each version of the test contained 80 items. The 40 core stimuli were randomised in each section of both versions of the test, and the administration of these alternative versions was balanced among the subjects.

(ii) *Procedure*

The stimuli were presented using the same method as was described for the Nonword Naming Task in this chapter, with external manual response keys (labelled *yes* and *no*) being substituted for the verbal response unit. An additional modification was the highlighting of stimulus segments in *cyan* and *magenta*. In the experiment as a whole, each of these colours appeared equally often highlighting the beginning and end of the stimuli. Initially, subjects were checked for colour-blindness with the aid of a test from the Ishihara (1920) series and all subjects passed the test. The subjects completed the two halves of the experiment on separate days but the procedure was the same in each half. The subjects were told that "words" would appear on the screen, some of which would be real words and others would be made-up words. Their task was to sort these out by pressing the *yes* response key when they saw a real word and the *no* response key when they saw a made-up word. All subjects started the experiment with their preferred hand on the *yes* key and their nonpreferred hand on the *no* key. Each item was preceded by a fixation point and presentation of the items was controlled by the experimenter.

Subjects initially received four practice items with corrective feedback. The experimental items were divided into four blocks of 10 items. After the first block the response keys were swapped so that the subject's preferred hand was on the *no* key. Another four practice trials familiarised the subject with the new response procedure before two blocks of experimental trials were presented.

Finally, the response keys were returned to their original positions and, after four more practice trials, the subject completed the final block of experimental trials. This procedure is used to counterbalance the advantage for the preferred hand when reaction times are gathered via manual response keys.

(iii) *Results*

One developmental dyslexic was unavailable to participate in this experiment. A reading age control with a similar reading age was dropped in order to balance the reading groups. The analysis proceeded on the remaining 19 subjects in each group, the reading age and scaled vocabulary score match between the groups remaining intact.

Once again the results were extracted from the raw data files using MINITAB.

a) MAIN ANALYSIS

Accuracy

Results were expressed in terms of percentage accuracy for each cell in the factorial design (see Table 16).[3] The data were subjected to an analysis of variance with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and three within-subjects factors: **lexicality** (words and nonwords); **segmentation** (onset-rime and post-vowel); **blend** (beginning and end). There were significant main effects of groups ($F(1,36)=8.03$, $p<0.009$) and blend ($F(1,36)=13.65$, $p<0.002$). However, the effects of lexicality ($F<1$) and segmentation ($F<1$) did not attain significance. The main effect of groups was due to developmental dyslexics being less accurate at making lexical decisions than their reading age controls. The only interaction containing the factor groups which approached significance was the interaction of groups by segmentation, $F(1,36)=3.62$, $p=0.065$. It appeared that although the developmental dyslexics tended to show an advantage for onset-rime

[3] Miss and False Alarm Rates for this experiment can be found in Appendix 12.

TABLE 16

COLOURED LEXICAL DECISION TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP*	WORDS				NONWORDS			
	ONSET-RIME		POST-VOWEL		ONSET-RIME		POST-VOWEL	
	BEGINNING BLEND	END BLEND	BEGINNING BLEND	END BLEND	BEGINNING BLEND	END BLEND	BEGINNING BLEND	END BLEND
READING AGE CONTROLS	77.37 (12.40)	83.16 (14.55)	78.95 (11.97)	82.11 (13.57)	73.16 (14.16)	80.00 (15.28)	79.47 (15.08)	86.32 (14.99)
DEVELOPMENTAL DYSLEXICS	77.37 (17.59)	76.32 (13.42)	73.68 (18.02)	71.05 (15.95)	66.84 (17.97)	75.79 (18.35)	67.89 (10.84)	78.95 (15.95)

* n=19 in both reading groups

segmentation, the reading age controls were slightly more accurate under post-vowel segmentation. The interaction lexicality by segmentation was significant ($F(1,36)=5.58$, $p<0.03$). Newman-Keuls tests were used to analyse this interaction and demonstrated that, overall, subjects were equally accurate at identifying words segmented into either onset-rime or post-vowel components. However, with nonword stimuli, subjects were significantly less accurate when onset-rime segments as opposed to post-vowel segments were highlighted. The other interaction to reach significance was lexicality by blend ($F(1,36)=6.26$, $p<0.02$). Newman-Keuls tests revealed that although lexical decisions to words were unaffected by the position of the consonant blend, lexical decisions to nonwords were significantly less accurate when the nonword began with a consonant blend (i.e. *shirp* was more difficult than *blish*). None of the other interactions achieved significance - groups by lexicality ($F<1$); groups by blend ($F<1$); groups by segmentation ($F(1,36)=3.62$, $p>0.05$); blend by segmentation ($F<1$); groups by lexicality by blend ($F(1,36)=2.78$, $p>0.05$); groups by lexicality by segmentation ($F<1$); groups by blend by segmentation ($F<1$); lexicality by blend by segmentation ($F<1$); groups by lexicality by blend by segmentation ($F<1$).

Reaction Time

Mean reaction times and standard deviations for correct responses from each group can be seen in Table 17. Tests for homogeneity of variance (Cochran's C and the Bartlett-Box F) revealed that variance was inhomogeneous between the reading groups and so a logarithmic transformation was performed on the data. This reduced the inhomogeneity of variance but only eliminated it from one of the eight cells in the experimental design. Therefore, it was decided to analyse the reaction times of each reading group separately.

TABLE 17

COLOURED LEXICAL DECISION TASK: ***Geometric Mean Reaction Time (msecs.)***
(standard deviations in brackets)

READING GROUP*	WORDS				NONWORDS			
	ONSET-RIME		POST-VOWEL		ONSET-RIME		POST-VOWEL	
	BEGINNING BLEND	END BLEND	BEGINNING BLEND	END BLEND	BEGINNING BLEND	END BLEND	BEGINNING BLEND	END BLEND
READING AGE CONTROLS	1780 (648)	1830 (452)	1741 (586)	1939 (535)	2607 (905)	2338 (957)	2630 (805)	2473 (823)
DEVELOPMENTAL DYSLEXICS	2631 (1451)	2655 (1490)	2529 (1393)	2609 (1355)	4334 (3170)	3576 (2581)	3928 (2223)	3417 (2121)

* n=19 in both reading groups

Developmental Dyslexics

An analysis of variance was carried out on the data with three within subjects factors: **lexicality** (words and nonwords); **segmentation** (onset-rime and post-vowel); **blend** (beginning and end). There were main effects of lexicality ($F(1,18)=20.10$, $p<0.0005$) and blend ($F(1,18)=4.50$, $p<0.05$) but the effect of segmentation was not significant ($F(1,18)=1.22$, $p>0.05$). The interaction lexicality by blend achieved significance ($F(1,18)=6.52$, $p<0.03$). Newman-Keuls tests indicated that while reaction times for lexical decisions to words were not affected by the position of the consonant blend, lexical decisions to nonwords were significantly slower when the consonant blend was at the beginning of the stimulus (i.e. *shirp* slower than *blish*). None of the other interactions reached significance: lexicality by segmentation ($F(1,18)=1.29$, $p>0.05$); blend by segmentation ($F<1$); lexicality by blend by segmentation ($F<1$).

Reading Age Controls

An identical analysis was performed on these data. A significant main effect of lexicality was found ($F(1,18)=62.73$, $p<0.0005$). The other main effects did not reach significance - blend ($F<1$) and segmentation ($F(1,18)=1.90$, $p>0.05$). As in the developmental dyslexic data, the interaction of lexicality by blend was significant ($F(1,18)=13.19$, $p<0.003$). Newman-Keuls tests revealed that the nature of the interaction was the same as had been found for the dyslexic children. Lexical decisions to words were unaffected by the position of the consonant blend, but lexical decisions to nonwords were significantly slower when the nonword began with this type of blend. The interaction blend by segmentation also attained significance ($F(1,18)=4.62$, $p<0.05$). Newman-Keuls tests showed that latencies to stimuli containing a consonant blend at the beginning were not affected by the type of segmentation applied. With stimuli which had a consonant blend at the end, the effect of segmentation type just failed to reach significance ($p=0.052$).

However, the trend was for subjects to respond faster under onset-rime than post-vowel segmentation. The remaining interactions were not significant: lexicality by segmentation ($F < 1$); lexicality by blend by segmentation ($F < 1$).

b) FREQUENCY EFFECTS

In this sub-analysis, responses to words were considered separately in order to investigate the effect of frequency on performance in the Colour-Segmented Lexical Decision Task.

Accuracy

Results were expressed in terms of percentage accuracy (see Table 18). An analysis of variance was performed with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and two within-subjects factors, **frequency** ("high" and "low") and **segmentation** (onset-rime and post-vowel). The only effect to reach significance was that of frequency ($F(1,36)=68.15$, $p<0.0005$) and this was due to both groups being more accurate at making lexical decisions to higher frequency words than to lower frequency words. None of the other effects were significant: groups ($F(1,36)=2.31$, $p>0.05$); segmentation ($F(1,36)=1.55$, $p>0.05$); groups by frequency ($F<1$); groups by segmentation ($F(1,36)=1.96$, $p>0.05$); frequency by segmentation ($F<1$); groups by frequency by segmentation ($F<1$).

Reaction Times

The group mean reaction times and standard deviations are contained in Table 19. Tests for homogeneity of variance (Cochran's C and the Bartlett-Box F) revealed that variance was inhomogeneous between the reading groups and so a logarithmic transformation was performed on the data. This improved the situation but failed to eliminate the inhomogeneity of variance from any of the cells in the design. Consequently, the reaction times produced by the two reading groups were analysed separately.

TABLE 18

FREQUENCY EFFECTS IN THE COLOURED LEXICAL DECISION TASK:
Mean Percentage Accuracy
(standard deviations in brackets)

READING GROUP*	HIGH FREQUENCY		LOW FREQUENCY	
	ONSET-RIME	POST-VOWEL	ONSET-RIME	POST-VOWEL
READING AGE CONTROLS	88.95 (11.50)	88.95 (14.10)	71.58 (14.25)	72.11 (15.12)
DEVELOPMENTAL DYSLEXICS	87.37 (15.58)	83.16 (17.34)	66.32 (18.92)	61.58 (18.64)

* n=19 in both reading groups

TABLE 19

FREQUENCY EFFECTS IN THE COLOURED LEXICAL DECISION TASK:
Geometric Mean Reaction Time (msecs.)
(standard deviations in brackets)

READING GROUP*	HIGH FREQUENCY		LOW FREQUENCY	
	ONSET-RIME	POST-VOWEL	ONSET-RIME	POST-VOWEL
READING AGE CONTROLS	1688 (478)	1657 (482)	1962 (573)	2064 (573)
DEVELOPMENTAL DYSLEXICS	2552 (1417)	2359 (1205)	2699 (1514)	2856 (1488)

* n=19 in both reading groups

Developmental Dyslexics

The original reaction time data for this group were subjected to an analysis of variance with two within-subjects factors, **frequency** ("high" and "low") and **segmentation** (onset-rime and post-vowel). There was a significant main effect of frequency ($F(1,18)=9.22$, $p<0.008$) but the effect of segmentation was not significant ($F<1$). The interaction frequency by segmentation attained significance ($F(1,18)=4.85$, $p<0.05$). Newman-Keuls tests showed that there was no frequency effect under onset-rime segmentation, but when post-vowel segmentation was operative, developmental dyslexics were significantly faster at making lexical decisions to higher frequency words than to lower frequency words.

Reading Age Controls

An identical analysis was performed on the original data from the reading age control group. The only effect to reach significance was the main effect of frequency ($F(1,18)=36.35$, $p<0.0005$) and was due to the reading age controls being significantly faster at making lexical decisions to higher frequency words than to lower frequency words. The other effects did not achieve significance: segmentation ($F<1$); frequency by segmentation ($F(1,18)=2.93$, $p>0.05$).

(iv) *Discussion*

As a group, the developmental dyslexics were less accurate than their reading age controls at classifying letter strings as words or nonwords. There were indications that the dyslexic group were also slower to respond but unfortunately statistical comparison of the reading groups' reaction times was not possible due to inhomogeneity of variance.

In both reading groups, accuracy in the Lexical Decision Task correlated with reading age (*reading age controls*: $r(17)=0.60$, $p<0.008$; *developmental dyslexics*: $r(17)=0.67$, $p<0.003$), spelling age (*reading age controls*:

$r(17)=0.47$, $p<0.05$; *developmental dyslexics*: $r(17)=0.76$, $p<0.0005$) and accuracy at naming control nonwords (*reading age controls*: $r(17)=0.47$, $p<0.05$; *developmental dyslexics*: $r(17)=0.65$, $p<0.004$), although this latter correlation failed to reach significance in either reading group after reading age had been partialled out (*reading age controls*: $r(16)=0.22$, $p>0.05$; *developmental dyslexics*: $r(16)=0.21$, $p>0.05$). It is possible that the types of units highlighted in the Lexical Decision Task were normally used by the children who were more successful on these measures of literacy. Those children with weaker literacy skills may have been applying phonology at the whole word level or in a serial, letter-by-letter fashion, and so were disrupted when onset-rime or post-vowel segments were highlighted.

In the reading age control group, accuracy in the Lexical Decision Task also correlated with accuracy at naming pseudohomophones ($r(17)=0.46$, $p<0.05$) and performance in the Segment Deletion Task ($r(17)=0.58$, $p<0.01$). However, these correlations did not achieve significance once reading age was partialled out ($r(16)=0.21$, $p>0.05$ and $r(16)=0.31$, $p>0.05$, respectively). The reading age controls exhibited an additional correlation between lexical decision accuracy and their spelling of words in the Spelling Task ($r(17)=0.62$, $p<0.006$), which remained significant after reading age had been partialled out ($r(16)=0.43$, $p<0.04$). In view of the absence of a correlation between nonword spelling and lexical decision accuracy, this correlation may reflect orthographic rather than phonological aspects of the Lexical Decision and Spelling Tasks.

As far as individual performances in the Lexical Decision Task were concerned, the majority of the dyslexic children scored below the mean of their reading age controls in terms of accuracy. Three dyslexic children seemed especially impaired in this task, obtaining scores which were more than two standard deviations below the mean of the reading age controls. On the other hand, four of the dyslexic children were actually above average for their reading age in the Lexical Decision Task, and one of these children scored more than one standard deviation above the mean of the reading age controls.

In the investigation of frequency effects, the dyslexic group responded with greater accuracy to the higher frequency words than to the lower frequency words, showing a similar pattern to the reading age controls in terms of accuracy. No overall difference in accuracy was found between the reading groups, in contrast to the main analysis. This finding appeared to parallel the accuracy results in the Nonword Naming Task where the performance of the dyslexic group was unexpectedly low with nonlexical items given their reading age. Children at this reading level are thought to *sound out* the stimuli in lexical decision experiments (e.g. Johnston et al, 1988) and so these results may be a consequence of decoding problems. However, this point remains highly speculative in view of the lack of an interaction between group and lexicality in the main analysis, although the tendency was for the accuracy difference between the groups to be greater in response to nonwords.

Qualitative differences between the reading groups emerged in an analysis of their speed of processing in response to words of differing frequency. The reading age controls exhibited an advantage for higher frequency words which parallelled their accuracy scores. Amongst the dyslexic children an advantage for higher frequency words was modified by an interaction with the type of segmentation required. In the onset-rime segmentation condition, the developmental dyslexics identified higher and lower frequency words with equal speed but under post-vowel segmentation they showed a speed advantage for the higher frequency words. It is possible that post-vowel segmentation of low frequency words made them more difficult to recognise.

Returning to the main analysis, the only effect of segmentation to emerge in the accuracy data was that both groups of subjects were less accurate at classifying nonwords highlighted according to their onset and rime segments, than those with post-vowel segments highlighted. This result was contrary to what might have been predicted given the influential role attached to onset and rime units in decoding by authors such as Goswami (1986, 1988) and Wise et al (1990). Post-vowel segmentation appeared to have an advantageous effect on the decoding of nonwords which would be more supportive of the evidence put forward by Fayne & Bryant (1981). On the other hand, this may tie in with the apparent difficulty in recognising low frequency words in the post-vowel segmentation condition. It may be that post-vowel segmentation looks rather strange and with less frequent words this may increase the likelihood that they are misclassified as nonwords. However, post-vowel segmentation of nonwords may actually be beneficial to performance by enhancing the impression of unfamiliarity.

The reading age controls gave the only indication of an effect of segmentation on reaction time. The trend was for these subjects to show an advantage for onset-rime over post-vowel segmentation with stimuli which had a consonant blend at the end (e.g. *truck*, *floth*). However, this effect was marginally nonsignificant. In general with nonlexical stimuli, *both* groups were faster and more accurate when nonwords ended rather than started with a consonant blend.

The type of consonant clusters used may prove to be an important factor in experiments of this type. The nature of the stimuli was such that each item contained both a consonant blend and a consonant digraph. This meant that effects ascribed to the factor *blend* may have also been influenced by the position of the consonant digraph. Consideration of this factor could provide an additional perspective on some of the results. The position of a consonant digraph could be said to have exerted an effect on accuracy in all of the groups. With nonwords, it appeared that a consonant digraph highlighted in the initial position aided decoding (e.g. *floth*). This suggested that it was relatively easy to decode a consonant digraph when it corresponded to the onset. However, there appeared to be a drawback to decoding consonant digraphs at the end of stimuli (e.g. *shont*). It was noticeable that the consonant digraphs which appeared in the end position tended to be less pronounceable than those in the initial position. Also, in the type of phonics instruction schemes which these children had been exposed to, consonant blends such as *sh*, *ch*, *th* and *wh* are frequently presented in isolation, whereas consonant digraphs like those which appeared in the end position in this experiment, occur far less frequently as isolated units e.g. *nd*, *pt*, *rt* and *ld*. The present results were indicative of these effects but, unfortunately, the stimuli chosen did not unequivocally allow the investigation of consonant digraphs and blends in isolation. For example, letter strings ending in *ing* were included as examples of stimuli ending in consonant blends along with stimuli ending in segments like *oth* and *ish*. Therefore, there was probably a familiarity confound when these blends were produced in isolation - *ng*, *th*, *sh*. It would be interesting to manipulate these segments in order to see whether highlighting the more obscure units disrupts children's recognition of words.

The above results have provided very little evidence that either of the reading groups in this experiment have formed orthographic units corresponding to onsets or rimes. This was surprising given the prominent role assigned to rimes or bodies in adult models such as the revised Dual Route Model of Patterson & Morton (1985). It could imply that none of the children in the present study had yet developed to this level of reading skill. It has been suggested that younger children make greater use of phonological information in lexical decision tasks than more skilled readers (Johnston et al, 1988). Young children are frequently observed to articulate the stimuli out loud before making a judgement, whereas adults do not. Such observations make it easier to accommodate the discrepancy between the present results and those of Treiman & Chafetz (1987). These authors studied adult subjects and found a reaction time advantage in a lexical decision task for stimuli split according to onset and rime segments (e.g. cr//isp), as opposed to a post-vowel split (e.g. cri//sp). Treiman & Chafetz found an advantage for onset-rime segmentation regardless of whether the onset corresponded to a consonant blend or digraph. It should be noted that these results were confined to the reaction time data, there were no comparable findings in their analysis of accuracy scores.

Nevertheless, the lack of an advantage for onset-rime segmentation among the children in the present study was surprising given the reports in the literature demonstrating that young children show sensitivity to onset and rime units (e.g. Treiman, 1985; Kirtley et al, 1989). Moreover, the present sample did exhibit a greater facility for deleting onset-rime segments than post-vowel segments in the Segment Deletion Task. Goswami (1986, 1988) has demonstrated that orthographic units corresponding to the rime can form the basis of analogies which are utilised to read unfamiliar words. Furthermore, she has claimed that beginning readers learn about spelling patterns on the basis of such units by grouping rhyming words together. According to this work one would expect that children with a reading age of eight years would be sensitive to orthographic onset and rime segments.

It may be that colour-highlighting of orthographic units does not place sufficient emphasis on these units. A technique such as the spatial separation of the units might be more suited to revealing differential effects in this task. Nevertheless, colour has been exploited in the teaching of reading in order to draw children's attention to letters and letter groups within words (e.g. Gattegno, 1968; Seymour & Bunce, in press). Of course, the particular colours which are chosen may be influential, as some make a more striking contrast than others.

It is conceivable, however, that task differences were responsible for the conflicting results regarding phonological and orthographic sensitivity to onset and rime units in the present study. There is a precedent for this conclusion in the work of Helfgott (1976). Helfgott examined the ability of kindergarten children to analyse and synthesise CVC words under onset-rime (e.g. C-VC) or post-vowel (e.g. CV-C) segmentation. She discovered that the children found it easier to analyse the words into their onset and rime than their post-vowel components. However, when required to blend segments to form a word, the opposite pattern prevailed. The children were more accurate at blending post-vowel than onset-rime segments. Helfgott's explanation for these effects stresses the contrast between the perception of the sounds within the word and the articulatory aspects of these sounds. In relation to segmentation, she suggested that initial consonants were more easily perceived than final consonants which would be consistent with the hierarchical nature of the syllable that was proposed by Mackay (1972). With regard to blending, Helfgott points out that the initial consonant and the following vowel are coarticulated to a greater extent than the vowel and the final consonant. Therefore, a C-VC blend would require more substantial modification of the consonant to be blended than would be necessary for a CV-C blend. These results appear to be commensurate with the present findings. It seems plausible to infer that the Segment Deletion task was primarily a test of segmentation skills. However, the segmental aspect of the Lexical Decision experiment was reduced by highlighting the units within the words and leaving blending as the main operation in the task.

These findings have implications for the theory of early reading acquisition formulated by Goswami & Bryant (1990). Their suggestion that awareness of onset and rime units is a crucial element of early reading would be tempered by the discovery of differential effects of these units in tests of segmentation and blending. In addition, if perceptual and articulatory factors are also involved in these effects then the influence of different types of phonological segmentation may vary according to the properties of the stimuli. Further work is essential to tease out the conditions under which an awareness of onset and rime units is beneficial to reading development.

5.7 VISUAL EMBEDDED FIGURES TASK

(i) *Materials* and (ii) *Procedure* were as described in Chapter 4.

(iii) *Results*

Percentage accuracy was assessed for the test as a whole (see Table 20). An analysis of variance was conducted with one between-subjects factor, **groups** (developmental dyslexics and reading age controls). There was a significant main effects of groups ($F(1,38)=16.64$, $p<0.0005$). This result replicated the finding in Chapter 4 that the reading age controls were less accurate at this task than the developmental dyslexics.

(iv) *Discussion*

The developmental dyslexic group was found to be more accurate than the reading age control group in this task. This replicated the result obtained in Chapter 4 and the mean scores for the reading groups appeared consistent between the two experiments (see Tables 8 and 20). In the earlier study, comparison with an additional chronological age control group indicated that the developmental dyslexics were performing significantly below the level of their peers in this task.

Investigation of individual performance in this task revealed that two of the dyslexic children obtained scores which were below the average of the reading age controls. One of these children was very severely impaired and scored more than one standard deviation below the average of the reading age controls, gaining a score of only 16%.

As in the previous chapter the developmental dyslexics exhibited an association between their spelling ability and their performance in the Visual Embedded Figures Task. This association was displayed by the dyslexic children both in the Schonell Spelling Test ($r(18)=0.56$, $p<0.02$), and in

TABLE 20

VISUAL EMBEDDED FIGURES TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	MEAN % ACCURACY
READING AGE CONTROLS	39 (16)
DEVELOPMENTAL DYSLEXICS	61 (19)

response to words in the additional Spelling Task ($r(18)=0.49$, $p<0.03$). However, once again performance in the Visual Embedded Figures Task did not correlate significantly with nonword spelling ability ($r(18)=0.32$, $p>0.05$).

The discovery of a relationship between visual segmentation skills and spelling ability in the dyslexic group may relate to the findings in a recent paper by Goulandris & Snowling (1991). These authors described a developmental dyslexic, J.A.S., who suffered visual memory impairments which appeared to have a particularly disruptive effect on her spelling ability. J.A.S. was bad at the Benton Visual Retention Test in which subjects are required to reproduce geometric figures from memory. The authors ascribed her difficulty with this test to a failure to attend to detail in the complex figures. This may have been due to an inability to input or store such information correctly. Goulandris & Snowling concluded that their subject's visual problems may have prevented her from establishing the well-defined, orthographic representations for words which are necessary to sustain normal spelling. It seems possible that poor visual segmentation skills such as those which have been identified in some dyslexic children in the present study could disrupt the setting up of such orthographic representations. Children who cannot disembed may have difficulty in isolating and retaining essential letter patterns within words which would facilitate future recognition and spelling.

The more lexicalisation errors that were made by the dyslexics in response to control nonwords in the Nonword Naming Task, the lower their scores on the Visual Embedded Figures Test ($r(18)=-0.49$, $p<0.03$). It could be that children with good visual segmentation skills were better able to discern that there was a mismatch between a lexicalisation and the spelling of the nonword.

It is too early to say whether the visual segmentation problems which were identified among some of the developmental dyslexics in the present study are causally related to their reading and spelling problems. If causality is to be determined, much research will need to be directed at establishing that there are common components to the Visual Embedded Figures Task and literacy development. If such connections were to be discovered, it may transpire that their basis is not in the segmental aspects of the task, but rather in visual memory or attentional skills. For the moment, however, visual segmentation skills appear to have very plausible links with the parsing of letter strings.

5.8 PHONOLOGICAL DECISIONS IN A REPETITION MEMORY TASK

(i) *Materials*

These were the stimuli used for the Nonword Naming Task in this chapter, consisting of 16 pseudohomophones, 16 matched nonwords and 8 filler nonwords (see Appendix 7).

(ii) *Procedure*

This task was only administered to subjects who had completed the Nonword Naming Task and these two tasks always took place on different days. Eight stimulus lists were prepared, each containing the original 40 stimuli in a different pseudo-randomised order (with pseudohomophones and their control nonwords separated by at least four items). The 8 lists were arranged consecutively to give a total of 320 trials in the experiment as a whole, with each list forming an experimental block. The method of presentation of stimuli was as described for the Nonword Naming experiment in this chapter, with external manual response keys (labelled *yes* and *no*) being substituted for the verbal response unit.

The children were told that the computer had made up lots of "words" and, although some of these words sounded really silly, others sounded like real words. The children had to sort out the nonwords by pressing the *yes* response key if the "made-up" word sounded like a word they knew, and the *no* key if it didn't. Each subject received six practice trials before the experiment began to familiarise them with the task. They commenced the experiment with their preferred hand on the *yes* response key and their nonpreferred hand on the *no* key. Once the subject had completed the first two experimental blocks, the response keys were switched around so that *yes* responses were now made with the nonpreferred hand. There were six novel practice items to adapt the subject to the new setup and these were followed by four experimental blocks. After the first two of these blocks, the subjects were given a few minutes rest in an attempt to ease the attentional demands of this lengthy task. When this section of the experiment had been completed, the response keys were returned to their original position and the subject was readjusted by performing six more practice items. The experiment concluded with a final two experimental blocks.

(iii) *Results*

Since the first block of the Repetition Memory Task could really be regarded as an experiment in its own right, it was decided to make an separate analysis of the results of the first block before considering the results of the Repetition Memory Task as a whole.

a) PHONOLOGICAL DECISION TASK

Accuracy

The results for Block 1 of the Repetition Memory Task were expressed in terms of percentage accuracy for each type of nonword (see Table 21).[4] An analysis of variance was carried out with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and one within-subjects factor, **type** (pseudohomophone, control and filler nonwords). There was a main effect of type ($F(2,76)=13.73$, $p<0.0005$). Newman-Keuls tests revealed

[4] Miss and False Alarm Rates for this experiment can be found in Appendix 13.

that pseudohomophones were responded to more accurately than the nonhomophonic nonwords. There was no significant difference in the accuracy of responses to the control and filler nonwords. The effects of groups ($F<1$) and groups by type ($F<1$) were not significant.

<u>Reaction Times</u>

Only reaction times to correct responses were analysed. Low accuracy prevented two subjects in each reading group from being included in the analysis since it was impossible for their reaction times to be reliably averaged. An average score was derived for all the remaining subjects from their reaction times to each type of nonword in the first block (see Table 22). Tests for homogeneity of variance (Cochran's C and the Bartlett-Box F) revealed that variance was inhomogeneous between the reading groups and so a logarithmic transformation was performed on the data. Although this transformation helped the situation somewhat, it did not eliminate the inhomogeneity in the variance between the reading groups. The largest discrepancy occurred for the control nonwords and was significant at the 0.002 level. Nevertheless, it was decided to attempt a circumspect analysis of variance with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and one within-subjects factor, **type** (pseudohomophone, control and filler nonwords). There was a main effect of groups ($F(1,34)=11.57$, $p<0.003$), indicating that the developmental dyslexics were significantly slower than their reading age controls at making phonological decisions. The effect of type was also significant ($F(2,68)=27.69$, $p<0.0005$). Newman-Keuls tests revealed that both groups were significantly faster to respond to pseudohomophones than to the nonhomophonic nonwords. Furthermore, they responded significantly more quickly to the control nonwords than to the filler nonwords. The interaction groups by type did not reach significance ($F(2,68)=1.53$, $p>0.05$).

(iv) *Discussion*

The dyslexic and reading age control groups made phonological decisions with a similar degree of accuracy. However, the dyslexic children took longer than their reading age controls to reach a decision in this task.

The developmental dyslexics performed rather uniformly in the Phonological Decision Task with a level of accuracy that was average for their reading ability, except for one of the dyslexic children who scored more than one standard deviation above the mean of the reading age controls. By comparison, the distribution of the reading age controls' scores in this task showed more dispersion.

Both the developmental dyslexics and their reading age controls were more accurate at classifying pseudohomophones than the control nonwords. An advantage for pseudohomophones was also found in terms of reaction times, but this result was less secure since both groups responded to pseudohomophones with their preferred hand in this block. However, it was the case that the dyslexic children exhibited pseudohomophone effects to the same extent as their reading age controls.

These findings are the converse of the results of a phonological decision experiment reported by Olson, Kliegl, Davidson & Foltz (1985). Olson et al found that the responses from a group of fifty learning-disabled children reading at the Grade 7 level were less accurate, but equally as fast, as their reading age controls. Unfortunately, direct comparison of that study with the present one is complicated by the differences in the reading age of the two samples, and also by the very different phonological decision tasks that were used in the two studies. Olson et al employed a forced-choice phonological decision task in which the subjects saw two nonwords (e.g. *caik* and *dake*), and had to indicate which was the pseudohomophone. In the present study, stimuli were presented for decision in isolation. Another feature of the task used by Olson et al was that the subjects received feedback on error and latency scores after each trial, perhaps promoting a strategy which favoured speed over accuracy.

Differences in the composition of the samples could also have contributed to the discrepancy between the results of the two studies. The learning-disabled children studied by Olson et al were not found to differ from their reading age controls in a lexical decision task measuring orthographic skill. In the present study, although a rather unconventional lexical decision experiment was used, the dyslexic children were found to be less accurate than their reading age controls. This may reflect orthographic problems as there were indications that some subjects in the present sample were impaired in a test of visual segmentation. However, it may be that the subjects in the present sample took a more phonological approach in the lexical decision task than the subjects studied by Olson et al. Their sample was reading at a higher level and may have made more use of a visual strategy in the phonological decision task. Furthermore, the pressure of two words being presented together for a quick decision could have further promoted the use of a visual strategy in their study. This may have proved detrimental to the performance of the learning-disabled children in terms of accuracy without affecting their speed of processing.

Among the reading age controls in the present sample, there was a strong association between accuracy in the Phonological Decision Task and reading age ($r(18)=0.56$, $p<0.02$) and spelling age ($r(18)=0.61$, $p<0.005$). The reading age controls also exhibited a strong correlation between their accuracy at classifying pseudohomophones in the Phonological Decision Experiment and their accuracy in the Spelling Task in response to both words ($r(18)=0.73$, $p<0.0005$) and nonwords ($r(18)=0.69$, $p<0.002$). This could reflect common phonological features amongst these tasks. None of the above relationships were significant in the data from the dyslexic group

TABLE 21

REPETITION MEMORY TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

NONWORD TYPE	READING GROUP*	REPETITION BLOCK							
		1	2	3	4	5	6	7	8
CONTROL e.g. *coe*	RA	56.56 (19.07)	57.81 (18.12)	51.56 (20.37)	58.13 (15.98)	55.63 (22.66)	51.56 (23.37)	54.69 (20.57)	54.06 (23.06)
	DD	58.44 (14.09)	55.31 (16.38)	51.25 (19.83)	47.81 (19.69)	48.44 (20.47)	50.31 (24.12)	48.44 (24.15)	43.44 (26.01)
PSEUDO. e.g. *loe*	RA	74.69 (17.96)	72.50 (15.50)	72.19 (19.18)	76.25 (15.92)	71.88 (18.08)	72.81 (22.51)	72.50 (17.25)	72.50 (19.49)
	DD	77.81 (13.22)	72.19 (18.75)	70.94 (19.69)	71.88 (17.27)	70.00 (23.61)	70.00 (21.90)	71.88 (20.73)	72.81 (19.58)
FILLER e.g. *blie*	RA	61.88 (19.65)	63.75 (20.24)	61.88 (24.83)	60.00 (25.20)	65.00 (26.47)	61.88 (28.81)	69.38 (26.74)	63.13 (32.06)
	DD	64.38 (15.85)	63.75 (22.54)	65.63 (25.61)	58.13 (23.04)	63.13 (18.79)	61.25 (25.94)	61.84 (23.00)	59.87 (18.90)

* RA = Reading Age Controls; DD = Developmental Dyslexics.

TABLE 22

REPETITION MEMORY TASK: ***Geometric Mean Reaction Time (msecs.)***
(standard deviations in brackets)

NONWORD TYPE	READING GROUP*	REPETITION BLOCK							
		1	2	3	4	5	6	7	8
CONTROL e.g. coe	RA	2661 (641)	2315 (703)	2208 (991)	2348 (1155)	2209 (1051)	1922 (692)	2334 (1277)	2024 (965)
	DD	4944 (3489)	3950 (2707)	3722 (3005)	3008 (2388)	2609 (1451)	2508 (1405)	2262 (1331)	1844 (716)
PSEUDO. e.g. loe	RA	2332 (597)	1851 (501)	1927 (561)	1934 (810)	1934 (926)	1608 (471)	1728 (583)	1582 (531)
	DD	3722 (2033)	2743 (1566)	2710 (1834)	2437 (1618)	2182 (995)	1943 (954)	1857 (838)	1594 (648)
FILLER e.g. blie	RA	2887 (838)	2315 (966)	2695 (1845)	2095 (1170)	2196 (1505)	1726 (697)	2079 (1480)	1881 (699)
	DD	5406 (3889)	4611 (3741)	3849 (2555)	2887 (2041)	2860 (1913)	2584 (1270)	2376 (1200)	2069 (1147)

* RA = Reading Age Controls; DD = Developmental Dyslexics; [n=18 in both reading groups]

b) Repetition Memory Task[2]

Accuracy

Results were expressed as percentage accuracy for each type of nonword in each block (see Table 21). The data were examined by applying an analysis of variance with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and two within-subjects factors, **type** (pseudohomophone, control and filler nonwords) and **block** (initial presentation and the seven repetition blocks). The main effect of type was significant ($F(2,76)=11.26$, $p<0.0005$), but the effect of groups ($F<1$) was not. The main effect of block failed to reach significance ($F(5,186)=2.25$, $p>0.05$). Newman-Keuls tests were used to investigate the effect of type. It was found that responses were significantly more accurate to the pseudohomophones than to either type of the nonhomophonic nonwords. Responses to the filler nonwords were significantly more accurate than those to the control nonwords. None of the interactions reached significance - groups by block ($F(5,186)=2.11$, $p>0.05$); groups by type ($F<1$); block by type ($F(7,269)=1.11$, $p>0.05$); groups by block by type ($F<1$).

Reaction Times

Only reaction times to correct responses were analysed. Two subjects were excluded from each reading group due to their low accuracy which made it impossible for their reaction times to be reliably averaged. An average score for each cell in the factorial design was derived for all the remaining subjects from their reaction times to each type of nonword in each block (see Table 22). Tests for homogeneity of variance (Cochran's C and the Bartlett-Box F) revealed that variance was inhomogeneous between the reading groups and so a logarithmic transformation was performed on the data. Although this transformation was

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[2] All F-ratios concerning the effects of repetition were evaluated with degrees of freedom estimated from the Greenhouse-Geisser procedure for controlling Type 1 error in repeated measures designs (see Winer, 1971).

beneficial, eight of the twenty-four cells in the factorial design still showed inhomogeneous variance. The cells involved were the scores for all types of nonword in Blocks 1 and 2, and the scores for pseudohomophones and their control nonwords in Block 3. While the analysis of variance is considered quite robust in its ability to cope with mild departures from homogeneity (Winer, 1971), the inhomogeneity in the present data appeared too severe for the analysis to be valid. The most prudent next step would be to analyse the data from each group separately. However, in an effort to avoid sacrificing valuable data concerning the relative performance of the reading groups, expert statistical advice was sought. It was suggested that pursuing an alternative analytic method involving the fitting of curves to the data and comparing the parameters of these curves, might circumvent the problem of inhomogeneous variance. The hypothesis was formed that the performance of the reading groups over the eight experimental blocks might best be characterised by a single exponential decay function with offset, the equation of which is:

$$Y = Ae^{-Bt} + C$$

where: **A+C** is the initial level of reaction times on the first presentation of the stimuli

B is the rate at which reaction times speed up during the task

C is the final level of reaction times after eight presentations of the stimuli

Such a curve would describe the facilitation of reaction time which would be expected to occur as the experiment progressed. Once curves of this nature had been fitted to each subject's mean reaction times for each of the three types of nonword over all of the eight experimental blocks, the parameters of these curves could be entered into an analysis of variance and compared. Further advice made it clear that technically the most effective method of accomplishing this would be to apply a logarithmic transformation to the data. From the hypothesis that these data are best described by an exponential function one would expect this transformation to convert the data into a linear form:

$$Y = \mathbf{P}x + \mathbf{Q}$$

where: **P** is the rate at which reaction times speed up during the task
Q is the initial level of reaction times on the first presentation of the stimuli

Once in this form, linear regression could be employed to calculate the above parameters. Although the use of this method entailed losing one of the parameters of comparison (i.e. the final level of the reaction times), there was the adjunct that the R^2 statistic associated with the linear regression technique allowed the "goodness-of-fit" of the regression to be determined. This was considered to be of great value in assessing whether the initial assumptions made about the data were appropriate.

The statistical package MINITAB was programmed to implement this latter procedure. The data for each parameter were systematically subjected to analysis of variance:

P *the rate at which reaction times speeded up in the task*

A two-way analysis of variance was conducted with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and one within-subjects factor, **type** (pseudohomophone, control and filler nonwords). There was a significant main effect of groups ($F(1,34)=14.79$, $p<0.002$), the reaction times of the developmental dyslexics showing a higher degree of facilitation in the task than those of their reading age controls. There was also a main effect of type ($F(2,68)=5.72$, $p<0.006$). Newman-Keuls tests revealed that the facilitation produced by the filler nonwords was significantly greater than that produced by either the pseudohomophones or their control nonwords. The interaction groups by type was not significant ($F(2,68)=2.61$, $p>0.05$).

Q *the initial level of reaction times in the task*

Tests for homogeneity of variance (Cochran's C and the Bartlett-Box F) revealed that variance was inhomogeneous between the reading groups. A logarithmic transformation was performed on the data. This transformation helped the situation somewhat, but did not eliminate the inhomogeneity in the variance between the reading groups. The largest discrepancy occurred for responses to the control nonwords and was significant at the 0.002 level. A circumspect analysis of variance was attempted with one between subjects factor, **groups** (developmental dyslexics and reading age controls) and one within-subjects factor, **type** (pseudohomophone, control and filler nonwords). There were significant main effects of both groups ($F(1,34)=9.15$, $p<0.006$) and type ($F(2,68)=42.92$, $p<0.0005$). The interaction of groups by type was also significant ($F(2,68)=3.96$, $p<0.03$). A Scheffe test revealed that the initial level of the groups reaction times in this task differed less in response to the pseudohomophones than to the other types of nonwords. In general, the reading age controls' initial response times were significantly faster than those of the developmental dyslexics, and the responses of both reading groups were faster to pseudohomophones than to the nonhomophonic nonwords.

R^2 *the measure of fit of the linear function to the data*

A two-way analysis of variance was conducted with one between-subjects factor **groups** (developmental dyslexics and reading age controls) and one within-subjects factor **type** (pseudohomophone, control and filler nonwords). There was a main effect of groups ($F(1,34)=13.04$, $p<0.002$), which was due to the linear function proving to provide a better description of the developmental dyslexics' data than of the reading age controls' data. The effects of type ($F<1$) and groups by type ($F<1$) were not significant.

This last analysis involving the R^2 statistic seemed to offer a critical insight into the experimental results. The average percentage of the variance explained in the linear regression was 61.52% for the developmental dyslexics but only 34.36% for the reading age controls. The linear regression was founded on the premise that a straight line would result from the logarithmic transformation of the original data because that data described an exponential decay function. It now appeared likely that this initial premise had only applied in the case of the developmental dyslexics. The two reading groups seemed to be exhibiting quite distinct patterns of facilitation; however, given the inhomogeneity in the variance between the two groups it may be more accurate to conclude that certain members of the developmental dyslexic group exhibited a deviant performance rather than the group as a whole. Indeed this seems to be indicated by the data in Figures 9a and 9b. Consequently, it does appear more appropriate to examine the reaction time data from each reading group separately.

Developmental Dyslexics

The original data from this group were subjected to an analysis of variance with two within-subjects factors, **type** (pseudohomophone, control and filler nonwords) and **block** (initial presentation and the seven repetition blocks). Significant main effects of type ($F(2,34)=14.24$, $p<0.0005$) and block ($F(1,25)=15.62$, $p<0.001$) were found. The interaction block by type also achieved significance ($F(4,60)=3.20$, $p<0.05$). Newman-Keuls tests indicated that developmental dyslexics were slower to respond to pseudohomophones in Block 1 than in Block 8. The difference between their responses in Block 1 and those in Block 6 and 7 just failed to achieve significance. In response to the control nonwords, the developmental dyslexics were slower in Block 1 than in Blocks 4,5,6,7 and 8, and slower in Blocks 2 and 3 than in Block 8. Finally, the developmental dyslexics reaction times to the filler nonwords differentiated Blocks 1 and 2 from all other blocks except their immediate neighbours. Blocks 1 and 2 contained the longest reaction times, although responses in Block 3 were also quite slow and just missed being significantly different from those in Block 8. Responses to the three types of nonwords were significantly different in

FIGURE 9a

REPETITION MEMORY TASK

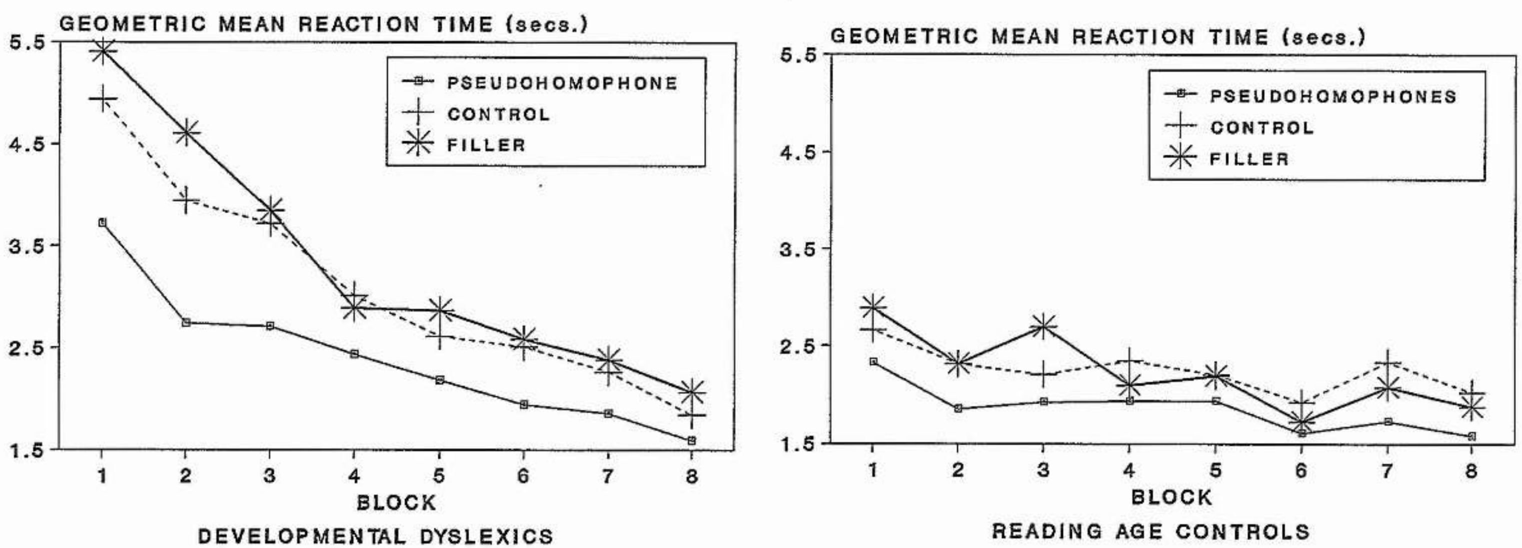
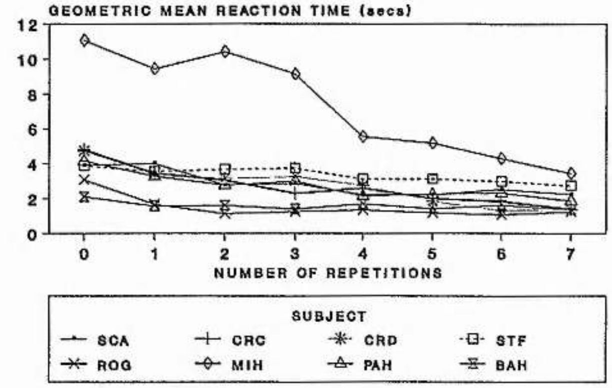


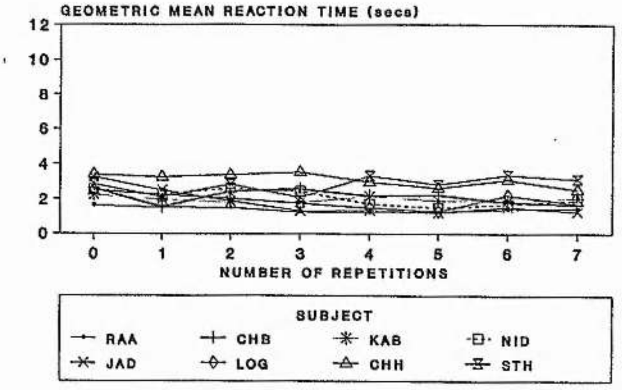
FIGURE 9b

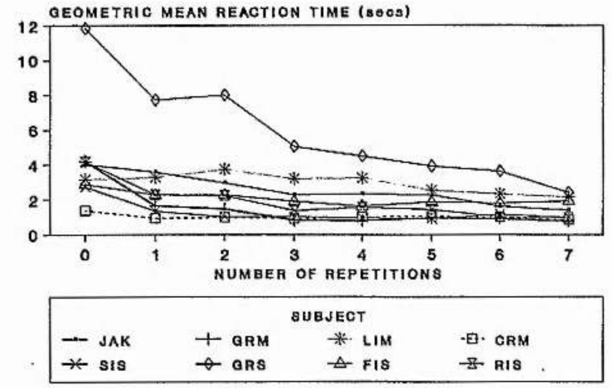
INDIVIDUAL DIFFERENCES IN THE REPETITION MEMORY TASK

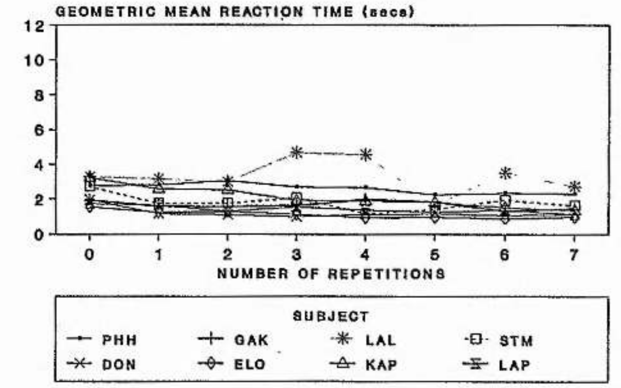
DEVELOPMENTAL DYSLEXICS

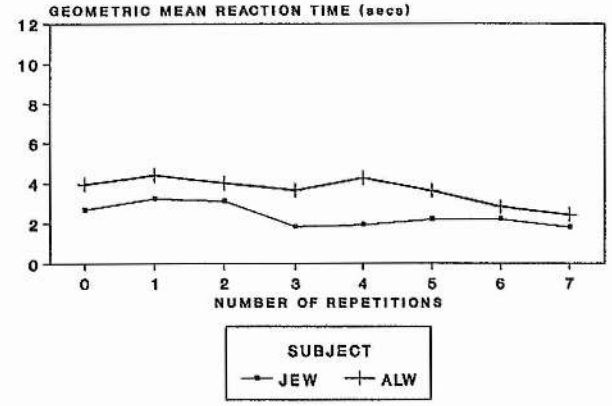
READING AGE CONTROLS

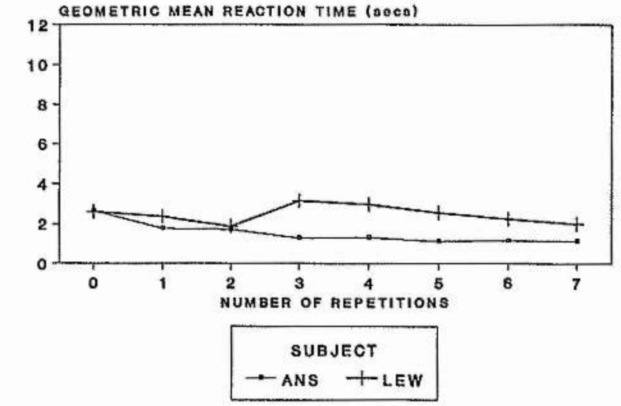












Blocks 1 and 2, with pseudohomophones producing faster reaction times than the other types of nonword (a similar result just missed significance in Block 3). In subsequent blocks responses did not differ according to nonword type.

Reading Age Controls

An identical analysis of variance was performed on the original data from the reading age control group. There were main effects of both type ($F(2,34)=9.51$, $p<0.002$) and block ($F(3,50)=5.89$, $p<0.005$). Newman-Keuls tests indicated that the effect of type was due to faster responses to pseudohomophones than to the nonhomophonic nonwords (which were responded to with equal speed). The effect of block was also investigated using Newman-Keuls tests, which showed that reaction times in the first block of the experiment were significantly slower than those in any of the subsequent blocks. Reaction times in Block 3 were also significantly slower than those in Block 6. The interaction block by type failed to reach significance ($F(3,50)=2.00$, $p>0.05$).

(iv) *Discussion*

The two reading groups were equally accurate in the Repetition Memory Task. There was a tendency for both groups to become slightly less accurate towards the end of the experiment but this effect did not attain significance. A reduction in accuracy is probably to be expected given such a lengthy and demanding task. Both groups exhibited a pseudohomophone effect in the experiment as a whole, the dyslexic children and their reading age controls being more accurate at classifying pseudohomophones than the control nonwords. Although the reaction times of the two groups could not be compared directly, both groups also produced faster responses to pseudohomophones than to the control nonwords.

The reaction times of both the developmental dyslexics and their reading age controls speeded up as a result of repetition. However, the regression analyses established that the pattern of this facilitation was quite different in the two groups. The effect of repetition on the speed of the reading age controls' responses was rather less striking than the effect seen amongst the dyslexic children. The reading age controls exhibited an immediate and relatively slight speed-up, whereas the dyslexic children showed a more dramatic improvement which continued to evolve throughout the experiment. For the reading age controls, one could only say that their reaction times in Block 1 were slower than in the rest of the blocks but for the developmental dyslexics reaction times in the first three blocks were significantly slower than those in the latter half of the experiment. The course of the reading age controls' facilitation was not as smooth as that of the dyslexic children. There was some suggestion that the reading age controls were disrupted by the change over of hands on the response keys since the general increase in their speed of responding tended to be interrupted at these points.

The reading age controls showed the same improvement in reaction time during the experiment for all three types of nonword. However, the developmental dyslexics exhibited differential patterns of facilitation for each type of nonword. Their reaction times to pseudohomophones in the first block could only be distinguished from their reaction times to these stimuli in Block 8 (the comparison between initial response times and those in Block 7 just missed significance). However, the dyslexics' initial reaction times to the control nonwords were significantly slower than their reactions to these stimuli in Blocks 4-8, similarly their responses to these nonwords in Blocks 2 and 3 were also significantly slower than those in Block 8. The filler nonwords showed the most facilitation, with reaction times in Blocks 1 and 2 being significantly different from all but their neighbouring blocks, and reaction times in Block 3 just failed to be significantly different than those in Block 8.

In the first block, the dyslexic children were significantly faster at responding to pseudohomophones than to the nonhomophonic stimuli. Although their reactions to the pseudohomophones showed a gradual improvement due to repetition, their responses to the nonhomophonic stimuli showed the greatest benefits of repetition. By the fourth block of the experiment the developmental dyslexics reaction times to the three types of stimuli could not be differentiated.

Although inhomogenous variance made it impossible to compare the groups directly, inspection of Figure 9a indicates that the dyslexic children began the experiment far more slowly than the reading age controls and then speeded up to achieve a similar level of performance by the end of the experiment. An initial difference between the groups was inferred from the speculative analysis of the reaction time data in the Phonological Decision Task, which constituted the first block of the Repetition Memory Task.

It appeared that the developmental dyslexics benefitted more from repetition of the experimental items more than did the reading age controls. Why should the dyslexic children show the greatest improvement in the time that they required to classify these nonwords as a result of repetition? The finding is consistent with the hypothesis that the decoding skills of the developmental dyslexics were initially less automatic than those of the reading age controls. Repeated exposure to the experimental items could have effected an improvement in the automaticity of the decoding process in the dyslexic children, thereby bringing their reaction times more in line with those of their reading age controls. The reading age controls may have possessed a higher degree of automaticity in the decoding process at the start of the experiment, and consequently showed a smaller, although significant, improvement due to repetition. However, this may not be the appropriate time-scale in which to talk of achieving automaticity, and it is possible that what has really taken place is a relatively short-term priming effect involving sublexical units. On the other hand, Logan (1990) has proposed that repetition priming and automaticity share common mechanisms, the storage and retrieval of representations of exposures to items, in particular.

The gradual elimination of the difference between the dyslexic's reaction times to pseudohomophonic and nonhomophonic nonwords is suggestive of a change in strategy. Perhaps in the early stages of the experiment, the dyslexic children had to decode each nonword from scratch but by the end of the experiment they were able to retrieve the phonology of at least some of the nonwords from memory. If the phonology of the nonhomophonic nonwords was learned, then a process more akin to that used in response to the pseudohomophones may have become possible for the nonhomophonic stimuli. Nevertheless, the stronger existing representations of words may have conferred an accuracy advantage on pseudohomophones throughout the experiment. This would be consistent with Logan's theory that an initial algorithm is replaced by memory retrieval as a result of repetition.

Amongst the developmental dyslexics, performance on the Repetition Memory Task did not correlate with many of the other tests. One exception was the association between slow responses in the initial blocks of the Repetition Memory Task and a high proportion of lexicalisation errors in response to pseudohomophones in the Nonword Naming Task (*Block 1*: $r(16)=0.59$, $p<0.02$; *Block 2*: $r(16)=0.50$, $p<0.04$; *Block 3*: $r(16)=0.50$, $p<0.04$). This was perhaps indicative of a laboured decoding process which often led to inaccuracies.

The reading age controls showed a strong correlation between their accuracy in the Repetition Memory Task and reading age ($r(18)=0.70$, $p<0.002$), and spelling age ($r(18)=0.79$, $p<0.0005$). Repetition Memory accuracy was also associated with performance in the Nonword Naming Task, in terms of accuracy (*pseudohomophones*: $r(18)=0.53$, $p<0.02$; *control nonwords*: $r(18)=0.59$, $p<0.007$) and reaction time (*pseudohomophones*: $r(16)=-0.56$, $p<0.02$); *control nonwords*: $r(16)=-0.63$, $p<0.006$). As in the data from the dyslexic group, higher accuracy scores amongst the reading age controls in the Repetition Memory Task were associated with fewer lexicalisation errors in response to pseudohomophones in the Nonword Naming Task ($r(18)=-0.57$, $p<0.01$), although this effect failed to reach significance once reading age was partialled out ($r(17)=-0.32$, $p>0.05$).

Substantial individual differences were present in the results of the developmental dyslexics (see Figure 9b). Two dyslexic children in particular, were extremely slow to respond in this task. However, these children did speed up with the repetition of the experimental items.

5.9 RECOGNITION MEMORY TASK

(i) *Materials*

These consisted of 48 nonwords, of which half were targets, having appeared in the Repetition Memory Task, and the remaining items acted as foils (see Appendix 10). There were three categories of targets:

1. Pseudohomophones e.g. *loe*
from the Repetition Memory Task

2. Control Nonwords e.g. *coe*
matched to the selected pseudohomophones in the Repetition Memory Task

3. Filler Nonwords e.g. *blie*
from the Repetition Memory Task

The filler nonwords were associated with two sets of closely matched foils:

4. Phonological Foils e.g. *bly*
phonologically similar but visually dissimilar to the filler nonwords

5. Visual Foils e.g. *blic*
visually similar but phonologically dissimilar to the filler nonwords

Another set of foils was included to balance the design and to prevent pseudohomophones from only appearing in the experiment as targets:

6. Pseudohomophone Foils e.g. *rong*

(ii) *Procedure*

The stimuli were pseudo-randomised, with related items being separated by at least four items. The method of presentation of stimuli was as described for the Nonword Naming Task in this chapter, with external manual response keys (labelled *yes* and *no*) being substituted for the verbal response unit.

This task was always administered immediately after the Repetition Memory Task. The children had a rest period of a few minutes, in between, while this experiment was being set up. Then they were told that they were going to see some more made-up words, some of which had appeared in the previous experiment. Their task was to press the *yes* response key if they had seen the made-up word before, and the *no* response key if they did not recognise the made-up word. The subjects commenced the experiment with their preferred hand on the *yes* response key and received four introductory practice trials with feedback in order to ensure that they understood the task. After they had completed 12 experimental trials, the response keys were swapped around so that the preferred hand was on the *no* response key. A new set of practice items were used to adapt the subjects to this new response setup. The subjects were then presented with 24 experimental trials before the response keys were returned to their original position. Four novel practice items readapted the subjects before the final 12 experimental trials were presented.

(iii) *Results*

Accuracy

Results were expressed as percentage accuracy for each condition in the experiment (see Table 23). Tests for homogeneity of variance (Cochran's C and the Bartlett-Box F) revealed that variance was inhomogeneous between the reading groups in two of the conditions. An arcsine transformation successfully

TABLE 23

RECOGNITION MEMORY TASK: ***Mean Percentage Accuracy***
(standard deviations in brackets)

READING GROUP	TARGET CONDITIONS			FOIL CONDITIONS		
	CONTROL e.g. *coe*	PSEUDO. e.g. *loe*	FILLER e.g. *blie*	PHONO. e.g. *bly*	VISUAL e.g. *blic*	PSEUDO. e.g. *rong*
READING AGE CONTROLS	88.8 (12.8)	91.9 (10.9)	82.5 (18.3)	93.8 (11.1)	81.9 (19.6)	93.8 (10.3)
DEVELOPMENTAL DYSLEXICS	78.8 (14.1)	84.4 (17.6)	70.6 (21.2)	83.8 (19.5)	68.8 (18.8)	88.8 (13.4)

homogenised the variance, allowing an analysis of variance to be conducted on the transformed data. There was one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and two within subjects factors, **type** (targets and foils)[3] and **condition** (the three conditions for each type of stimuli). There were main effects of groups ($F(1,38)=11.92$, $p<0.002$) and condition ($F(2,76)=3.76$, $p<0.03$) but the effect of type was not significant ($F(1,38)=2.25$, $p>0.05$). As the factor groups did not appear in any significant interactions it was interpreted as showing that the developmental dyslexics were less accurate than their reading age controls at the recognition memory task. The interaction of type by condition was significant ($F(2,76)=22.72$, $p<0.0005$). Newman-Keuls tests revealed that both reading groups exhibited the following pattern of performance. With regard to the target items, the pseudohomophones and their control nonwords were more accurately recognised than the filler nonwords. Examination of responses to the foil items revealed that visual foils misled the subjects the most, provoking more errors than either the phonological or the pseudohomophone foils (these latter items were responded to with equal accuracy). None of the other interactions achieved significance - groups by type ($F<1$); groups by condition ($F<1$); groups by type by condition ($F(2,76)=1.08$, $p>0.05$).

<u>Reaction Time</u>

The group mean reaction times and standard deviations are contained in Table 24. An analysis of variance was carried out with one between-subjects factor, **groups** (developmental dyslexics and reading age controls) and two within-subjects factors, **type** (targets and foils)[3] and **condition** (the three conditions for each type of stimuli). There were main effects of type ($F(1,38)=48.36$, $p<0.0005$) and condition ($F(2,76)=5.93$, $p<0.005$) but no significant effect of groups ($F(1,38)=2.18$, $p>0.05$). The following

[3] It should be noted that the targets and foils were not strictly comparable.

TABLE 24

RECOGNITION MEMORY TASK: ***Geometric Mean Reaction Time (msecs)***

(standard deviations in brackets)

READING GROUP	TARGET CONDITIONS			FOIL CONDITIONS		
	CONTROL e.g. coe	PSEUDO. e.g. loe	FILLER e.g. blie	PHONO. e.g. bly	VISUAL e.g. blic	PSEUDO. e.g. rong
READING AGE CONTROLS	1610 (591)	1506 (493)	1499 (503)	1836 (760)	2265 (955)	1760 (798)
DEVELOPMENTAL DYSLEXICS	1314 (474)	1258 (419)	1363 (345)	1610 (593)	1755 (658)	1600 (603)

interactions were significant - groups by condition ($F(2,76)=3.18$, $p<0.05$), type by condition ($F(2,76)=17.40$, $p<0.0005$) and groups by type by condition ($F(2,76)=3.65$, $p<0.04$). Newman-Keuls tests were used to investigate the latter interaction and revealed that the two reading groups recognised target items faster than they rejected foils. All target items were identified with equal speed by both groups and the developmental dyslexics responded to the various kinds of foils at the same rate. However, the reading age controls were particularly disrupted by the visual foils, as their responses to these items were significantly slower than their responses to the other kinds of foil (see Figure 10). The remaining interaction groups by type failed to reach significance ($F<1$).

(iv) Discussion

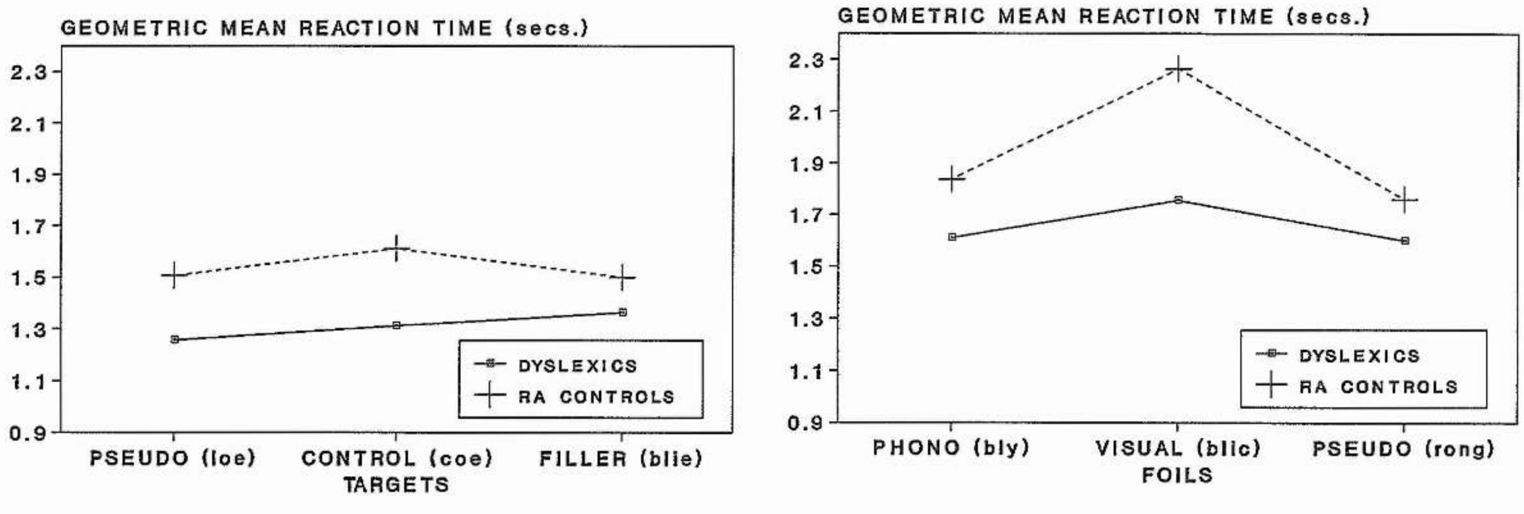
When tested for recall of the items in the Repetition Memory Task, the dyslexic group were found to be less accurate at recognising targets and rejecting foils than their reading age controls. They also tended to be slightly faster than their reading age controls although this effect did not reach significance. In any case, the pattern of errors and reaction times within the conditions were not suggestive of a speed accuracy trade-off in the dyslexic group.

Within each of the reading groups, targets and foils were classified with equal accuracy. However, both groups were significantly faster at identifying targets than they were at rejecting foils, perhaps suggesting that some kind of check was performed if an item was not recognised.

Overall accuracy in the Recognition Memory Task correlated with spelling age amongst the dyslexic group ($r(18)=0.52$, $p<0.02$). There were further correlations with reading age ($r(18)=0.54$, $p<0.02$) and both naming accuracy ($r(18)=0.54$, $p<0.02$) and naming speed ($r(18)=-0.49$, $p<0.03$) in the Nonword Naming Task, but these correlations did not attain significance after spelling age was partialled out. The reading age control group showed no significant correlations between their literacy skills and their accuracy in the Recognition Memory Task.

FIGURE 10

RECOGNITION MEMORY TASK: Interaction of Groups, Type and Condition



Examination of the individual differences amongst the dyslexic group's accuracy scores makes it clear that five of the dyslexic children suffered particularly severe impairments in the Recognition Memory Task. Four of these children scored more than 2 standard deviations below the mean of the reading age controls and the remaining child performed more than 4 standard deviations below that mean. On the other hand, 4 of the dyslexic children were above average at the Recognition Memory Task for their reading age and one of these children scored more than 1 standard deviation above the mean of the reading age controls.

Despite their lower accuracy, the pattern of errors produced by the dyslexic group was qualitatively identical to that of their reading age controls. On the target items, both groups were less accurate at recognising the filler nonwords than the pseudohomophones and their controls. This perhaps reflected the fact that the letter sequences within the filler nonwords were not repeated as often as those within each pair of matched pseudohomophones and controls. The pattern of errors made by the two groups in responding to the foil items was also similar. While both groups showed no significant difference in accuracy between their responses to the phonological and pseudohomophonic control foils, they both responded significantly less accurately to the visual foils. These latter items were designed to be visually similar to the filler nonwords in the Repetition Memory Task (e.g. *glike* was the visual foil for *glite*). Both groups appear to have been misled by the visual similarity of these foils to their targets, causing them to misidentify the visual foils as targets.

The only qualitative difference to emerge between the groups occurred in the reaction time data. The dyslexic children exhibited no latency differences in their responses to any type of target or foil. While the reading age controls also showed no difference in their speed of responding to the three types of targets, they were significantly slower at classifying the visual foils than the other two types of foil. Therefore, the reading age controls were both significantly less accurate and significantly slower at responding to the visual foils than to the other types of foils. The developmental dyslexics were only significantly less accurate at rejecting the visual foils compared to the other types of foils, although they did exhibit a tendency to be slower on these visual foils; however this was not significant.

The finding that both reading groups were most disrupted by visual foils conflicts with the outcomes of some previous investigations of recognition memory in comparable subjects, since it implies that both groups were relying upon orthographic coding.

Earlier studies of recognition memory by Mark, Shankweiler, Liberman & Fowler (1977) and Olson, Davidson, Kliegl & Davies (1984) reported that in contrast to their chronological age controls, eight year old poor readers did not make more false-positive responses to rhyming than nonrhyming foils. This was interpreted as indicating that the poor readers made less use of phonological coding in memory. However, Olson et al proposed that this conclusion applied mainly to younger poor readers since the older poor readers in their study showed more evidence of using phonological coding in memory. It seems possible that the poor readers in the above studies may well have been similar to reading age controls had this comparison been employed.

Rack (1985) investigated memory coding in dyslexic children with reading ages ranging from eight and a half to twelve and a half. He utilised auditory and visual rhyme judgement tasks each with an associated cued recall task in the same modality. The relationships between cues and targets were as follows: rhyming and orthographically-similar (*farm-harm*), rhyming and orthographically-different (*farm-calm*), orthographically-similar but nonrhyming (*farm-warm*), or unrelated (*farm-thunder*). Despite there being no overall difference in recall between the dyslexic children and their reading age controls, Rack discovered that the dyslexic children made more use of orthographic similarity between items in the recall task than their reading age controls, regardless of mode of presentation. However, with visual presentation, the reading age controls recalled more targets in response to rhyming cues than the developmental dyslexics. Rack concluded that dyslexic children make less use of phonological coding under visual presentation than their reading age controls but are able to compensate for their phonological deficiencies by means of a greater reliance upon orthographic coding.

Holligan & Johnston (1988) obtained a similar result using a rhyme judgement task in which cues and targets were initially presented visually for the subject to read in the context of a rhyme judgement task. In a test of recognition memory, dyslexic children, reading at the seven year old level, proved to be better at remembering orthographically-similar, nonrhyming words than orthographically-different, rhyming words. Responses were selected from a list of four consecutively presented items. The developmental dyslexics chose significantly more orthographically similar foils than phonological ones, while the reading age controls exhibited the converse pattern of response. Unfortunately, the dyslexic children were worse than their reading age controls at the rhyme judgement task in this study and this may have introduced some response bias into the results.

Taken together, the findings of Rack (1985) and Holligan & Johnston (1988) imply that developmental dyslexics rely upon orthographic coding for recognition memory whereas reading age controls make more use of phonological information. In the present study, both groups appeared to be relying predominantly upon orthographic coding. The phonological foils caused no more disruption than the pseudohomophone control foils. One possible explanation for the discrepancy between these results and those of the earlier studies is that the present study employed nonlexical stimuli, whereas the experiments in all of the above studies involved words. It is possible that reading age controls are better able to use phonological information in memory when the items to be recalled are words. Alternatively, the subjects in the present study had experienced repeated presentations of the target stimuli before recognition was tested. Indeed, accuracy levels were excellent, reflecting a high degree of familiarity with the stimuli. Consequently, subjects may have been biased towards a visual strategy in the ensuing Recognition Memory Task. Reliance upon this strategy may have been further encouraged by the fact that the task instructions contained no reference to the phonological aspects of the stimuli, since each stimulus was simply presented for a target-foil judgement, unlike Rack's cued recall procedure or the multiple choice offered by Holligan & Johnston. Reactions tended to be faster in both of the reading groups in this experiment than they were in the Repetition Memory Task, and the subjects did not appear to be serially decoding every item.

The differential disruption of the reading age controls in terms of their reaction times to visual foils may reflect a tendency to perform a phonological check when unsure of the response, thus slowing them down. Since the visual foils were only one phoneme different from their targets, this may not always have proved a particularly helpful strategy. It would be interesting to observe the effect of making the visual foils very phonologically distinct from their targets to see if this would improve the accuracy of the reading age controls on these items. The developmental dyslexics were not slowed down to the same extent by the visual foils which could imply that they did not make as much use of a phonological check. This would be more consistent with the reliance upon orthographic coding reported in previous studies.

The correlational analyses revealed an interesting pattern of associations between the Recognition Memory and Visual Embedded Figures Tasks. The dyslexic children who were least accurate in the Visual Embedded Figures Task were the most slowed down by the visual foils in the Recognition Memory Task ($r(18)=-0.48$, $p<0.04$). In fact, these children also tended to be slower to respond to all other types of targets and foils, with the exception of the phonological foils (*targets*: pseudohomophone [$r(18)=-0.52$, $p<0.02$], control [r(18)=-0.55, $p<0.02$], filler [r(18)=-0.55, $p<0.02$]; *foils*: pseudohomophone [r(18)=-0.47, $p<0.04$], phonological [r(18)=-0.35, $p>0.05$]). After partialling out spelling age, however, only the correlation with visual foils approached significance (r(17)=-0.37, $p<0.06$). Nevertheless, there is some suggestion that dyslexic children with poor visual segmentation skills may make more use of a phonological strategy, even if their phonological skills are also poor. Those dyslexics with good visual segmentation skills may adopt a predominantly visual approach. However, in the data from the reading age controls a different pattern prevailed. The reading age controls with the best visual segmentation skills were the most slowed down by the visual foils, independent of their spelling age (r(18)=0.48, $p<0.04$). The difference between the groups may have been that although the reading age controls may have used a predominantly visual strategy in this task, they also had the option of carrying out a phonological check if necessary.

The lower overall accuracy scores obtained by the dyslexic group in the Recognition Memory Task could not be attributed to a difference in accuracy between the groups in the original Repetition Memory Task. It may be that the attentional demands of the Repetition Memory Experiment adversely affected the developmental dyslexics, causing their qualitatively distinct patterns of processing and preventing them from setting up as accurate long-term representations as their reading age controls (Parkin & Russo, 1990).

5.10 SUMMARY DISCUSSION

With respect to nonword naming, the results of Chapter 4 were replicated. The developmental dyslexics were found to be less accurate at naming nonwords than their reading age controls. The distribution of scores for the dyslexic group in this task was generally depressed, with most children being impaired relative to the reading age controls. This difficulty with nonword naming was shown to include both the accuracy and the speed of their responses.

Tests investigating various aspects of phonological and visual processing produced a varied profile of the dyslexic group. Their phonological segmentation skill at the level of onset and rime units, as assessed by the Segment Deletion Task, was normal for their reading age. With regard to their visual segmentation skills, the dyslexic group was rather better than the reading age control group at the Visual Embedded Figures Task. The performance of the dyslexic children was at a level similar to that found in Chapter 4, when the dyslexic group was found to be impaired at this task relative to their chronological age controls. The dyslexic group were impaired for their reading age on a lexical decision task where the stimuli were divided into either onset-rime or post-vowel units.

In qualitative terms, the two reading groups were hard to distinguish. Both the developmental dyslexics and their reading age controls displayed an advantage for onset-rime over post-vowel segmentation in the Segment Deletion Task. However, there was no evidence in either reading group of an advantage for stimuli which had their onset and rime units highlighted in the Lexical Decision Task.

Various interpretations of these results are conceivable. On the one hand the findings were reminiscent of those of Helfgott (1976). She found that onset-rime division was beneficial for phonological *segmentation*, whereas post-vowel segmentation aided phonological *blending*. For segmentation, the parallel with the present findings is obvious. For blending, the connection with the Lexical Decision Task in the present study is less direct. However, it seems possible that by pre-segmenting the stimuli for the subjects, the task may make more demands upon their blending skills than their segmentation skills.

An alternative account would be to suggest that contrary to the proposals of Goswami (1986, 1988), children at this reading level do not rely predominantly upon orthographic onset and rime units in decoding. Instead, such children may utilise smaller sublexical units in decoding, especially children like those in the present sample who have been receiving phonics reading instruction. This would be commensurate with the findings of Laxon, Masterson & Coltheart (1991). These authors studied consistency and regularity effects in children's reading. The reading ages of the children in question ranged from eight to ten years. Laxon et al demonstrated that the less skilled readers, who were reading at a comparable level to the children in the present study, displayed alphabetic strategies in reading both words and nonwords. The more skilled readers, however, exhibited *consistency* effects in their reading.

However, in a study of nonword naming, Treiman, Goswami & Bruck (1990) found that even first graders were more accurate at nonwords with common rime units than at those with infrequent or non-occurring rimes. This difference arose even though all the nonwords contained the same grapheme to phoneme correspondences, and were *regular and consistent*. Laxon et al also noted that children reading around the eight year old level could occasionally make use of analogies based on larger sublexical units. For example, the children in their study sometimes made irregular responses to ambiguous words. Nevertheless, Laxon et al emphasised that the less skilled readers relied predominantly upon an alphabetic strategy because of their relative limited experience of print. It seems likely that further in depth studies of children's use of prelexical segmentation will be necessary to resolve this issue, an important factor which must be taken into account is that the way in which children have been taught to read may have a large impact on their strategy use.

In this chapter, the same stimuli were used in both the Phonological Decision and Nonword Naming Tasks. These two tasks also shared the requirement that the subjects generated an internal sound code for these nonlexical stimuli. Such features make comparison of the results of these tasks of considerable interest. It will be recalled that the dyslexic children were found to be slower and less accurate than their reading age controls in the Nonword Naming Task. In contrast, the two reading groups were equally accurate in the Phonological Decision Task, although the dyslexic children were slower to respond in this task. Therefore, it was only when they were required to name these nonwords that the dyslexic children were less accurate than their reading age controls. Despite the apparent similarities in the experimental tasks noted above, there would seem to be important differences between them which influenced the performance of the dyslexic children. Indeed, the correlational analyses revealed that although the reading age controls' accuracy in these two tasks showed a significant association ($r(18)=0.52$, $p<0.02$), this failed to reach significance once reading age was partialled out ($r(17)=0.32$, $p>0.05$). The accuracy of the developmental dyslexics in the Nonword Naming and Phonological Decision Tasks showed no significant correlation ($r(18)=0.34$, $p>0.05$).

The most obvious difference between the tasks is that the Nonword Naming Task requires articulation of the generated sound code, whereas the Phonological Decision Task does not. Articulatory skill may, therefore, be a feature which distinguishes the reading groups.

Snowling & Hulme (1989) have described a developmental phonological dyslexic, J.M., who suffered from weak output phonology. They discussed in depth how this impairment may have contributed to the child's reading problems. Poor and idiosyncratic specifications for words, letter names and letter sounds were considered to have hindered the paired associate learning that is necessary for the establishment of either an efficient sight vocabulary or of phonic reading. Similar difficulties with output phonology may well be facing some of the developmental dyslexics in the present sample and causing the differential experimental outcomes.

Snowling & Hulme (1989) had demonstrated that J.M. was impaired for his reading age at nonword naming. A phonological decision task was also administered to J.M. and a group of reading age controls. However, J.M. performed at chance in this task and although the reading age controls tended to be slightly more accurate, this difference was not significant. The task was evidently too difficult for the subjects, which was rather surprising given that the subjects were reading at the ten year old level. The stimuli used were rather unusual orthographically (e.g. *fammin*, *takken*), and this may have been the source of the difficulty. Consequently, the comparison of performances on the pseudohomophonic and nonhomophonic stimuli was inconclusive. Although J.M. was equally poor at both types of stimuli, this may just have reflected a floor effect. Furthermore, no information was given as to how the reading age controls performed on these two types of stimuli.

In the present study, both the developmental dyslexics and their reading age controls were more accurate in response to the pseudohomophones than to the control nonwords in the Phonological Decision Task. This *pseudohomophone* effect was also found in the Nonword Naming Task, where both groups named the pseudohomophones with greater accuracy and speed than they named the control nonwords.

Pseudohomophone effects in nonword naming have been taken to indicate that the products of the decoding process are being referred to stored representations of known words in compiling a pronunciation (e.g. Seymour, 1986; McCann & Besner, 1987). The pseudohomophone advantage may lie in helping the child to synthesise an internal sound code for the target letter string. Pring & Snowling (1986) have advanced the view that children at this early stage of reading development will make use of any relevant visual, auditory or contextual information in decoding. These authors suggest that children may test the products of the decoding process in deciding upon an appropriate pronunciation. If such a strategy were one that is normally applied in the course of decoding unfamiliar words, it would seem likely that there would be a lexical bias in the process, hence the advantage for pseudohomophones which sound like real words. It is also interesting to note that a high proportion of the children's errors in reading the control nonwords were lexicalisations (approximately 59% for both the dyslexic children and their reading age controls).

The influence of visual information in this process is intriguing. The stimuli in the present experiment were controlled such that the pseudohomophones and the nonhomophonic nonwords were equally visually similar to real words. This was done to ensure that any advantage for pseudohomophonic stimuli was due to their phonological similarity to real words and was not confounded with a greater visual similarity to real words (a confound identified by Patterson, 1982). The method adopted to control for this factor was devised by Taft (1982). Pairs of visually similar but phonologically dissimilar words were chosen (e.g. *gone* and *bone*) and then the words in each pair were modified in the same fashion to produce nonwords *(e.g. gon* and *bon*). An unfortunate aspect of this procedure came to light in the course of analysing the results. On some of the stimuli a pseudohomophone effect could also be produced if a visual strategy were to be used to aid the decoding of these nonwords. To illustrate this point, consider the example given above, if subjects read *gon* as gone because of its visual similarity to the word gone, they would be correct. However, applying the very same strategy to the nonword *bon* would produce a lexicalisation error. Thus, a pseudohomophone effect would be produced in the accuracy data. In actual fact, the use of such a strategy does not seem to provide a complete account of the data due to the additional reaction time advantage for pseudohomophones.

It seems more probable to suggest, in accordance with Pring & Snowling's (1986) results, that responses to pseudohomophones were facilitated because compatible auditory and visual analogies existed to finalise the decoding process. However, for the nonhomophonic stimuli, there only existed rather misleading visual analogies. Pring & Snowling (1986) argued that the system was facilitation dominant, such that if the information from different sources was inconsistent, the delay incurred would be no more than would result if only one source of information was available.

It is noticeable that the accuracy of both of the reading groups in the Phonological Decision Task was close to chance in response to the nonhomophonic stimuli. An additional phonological feature of the stimuli may have helped to produce this result. As already discussed, a visual strategy applied to the stimulus *bon* could lead to a visual analogy with the word *bone*. Unfortunately, it is possible that to children reading at this level, *bone* may also seem an acceptable product of the phonological decoding process. These two sources of information may have been combined to bias the response in favour of *bone*. Although, other stimuli such as *nair* (based on *near*) would not be subject to this effect, approximately 40% of the stimuli were of the *bon* type. In future experiments it would be important to control for this factor in order to provide a more rigorous investigation of the pseudohomophone effect.

Regardless of this, the developmental dyslexics and the reading age controls appeared to be utilising lexical information to the same extent in both the Nonword Naming and Phonological Decision Tasks. However, the source of the latency difference between the groups in the Phonological Decision Task remains to be explained. This finding implied that the developmental dyslexics were less efficient at decoding than their reading age controls. A relationship which emerged in the correlational analysis of the dyslexic children's data between reaction time in the Phonological Decision Task and raw scores in the Digit Span subtest of the WISC-R could prove to be relevant to explaining some of this inefficiency. It transpired that the poorer the dyslexics' memory spans, the slower were their responses in the Phonological Decision Task ($r(16)=-0.64$, $p<0.005$). A similar relationship was observed between memory span and response times in the Nonword Naming Task ($r(17)=-0.47$, $p<0.05$) and in addition, poor memory span correlated with low accuracy in this task ($r(18)=0.51$, $p<0.03$). These relationships were only found in the data from the developmental dyslexics. It may be that for some of the dyslexic children, severe auditory short-term memory problems combined with other difficulties to produce slow and inaccurate performances in the Phonological Decision and Nonword Naming Tasks.

Many authors have discussed the relationship between short-term memory skills and the decoding process e.g. Torgesen & Houck (1980); Snowling & Hulme (1989); Baddeley (1989).

Baddeley (1989) highlighted several aspects of word decoding which would tax auditory short-term memory:

1/ *Maintenance of already decoded sounds while the remaining elements of the letter string are being decoded*

- Baddeley pointed out that this process could be particularly demanding upon short-term memory if letter strings must be decoded letter by letter, especially with longer items. The addition of redundant vowel sounds, necessitated by the unpronounceability of certain individual consonants, could produce a phonologically similar series of units which would be difficult to retain and make order information liable to disruption.

2/ *Blending of the decoded sounds to form a single unit*

- Torgesen, Rashotte, Greenstein, Houck & Portes (1988) have demonstrated that this process can be problematic for subjects with poor digit spans *even* when the elements to be blended were provided by the experimenter. In addition, as has already been discussed here, the blended sounds must be associated with long-term representations of known words.

A further hurdle for children with poor memory spans could be a lack of automaticity in retrieving long-term information regarding phonological representations of sounds or words. This could be related to problems with output phonology, which prevented stable representations from being established (see Snowling & Hulme, 1989).

Given these sources of inefficiency in decoding, it comes as something of a surprise that the developmental dyslexics and their reading age controls were equally accurate in the Phonological Decision Task. Even although the articulatory demands have been removed, such inefficiencies might have been expected to have preserved the accuracy imbalance between the reading groups which was present in the Nonword Naming Task. A possible explanation of this concerns the nature of the Phonological Decision Task. By comparison with the Nonword Naming Task, the categorisation of the stimuli as homophonic or otherwise in the Phonological Decision Task may be a fairly gross measure of the quality of the subjects' decoding skills. The subjects may have approached decoding in the Phonological Decision Task with the expectation that the nonword would sound like a real word. This may have eased the decoding process because subjects might have been able to make decisions on the basis of a relatively unrefined approximation to the phonology of the nonword. In the Nonword Naming Task, the decoding process may have involved a greater degree of *bottom-up* processing. Errors of translation from spelling to sound which would have lowered accuracy in the Nonword Naming Task may, therefore, have stood a smaller chance of being picked up in the phonological decision paradigm.

The dyslexic children's apparent inefficiency at decoding has already been discussed with reference to short-term memory problems, however, a difficulty with longer-term representations of sounds and words could also be contributing to the developmental dyslexics lack of automaticity in decoding. These processes will now be considered.

The developmental dyslexics showed considerable benefit from the repetition of stimuli in the Repetition Memory Task. The facilitation produced by the repetitions continued to accrue for the dyslexic children during the experiment, whereas the benefit of repetition was more instantaneous amongst the reading age controls. Despite appearing to be slower than their reading age controls at the start, the dyslexic children speeded up to a similar level of performance during the experiment. However, the developmental dyslexics recognised fewer of the stimuli from this experiment in a later test of their recognition memory.

The repetition and recognition memory paradigms have been used in the adult literature to dissociate different memory systems or different aspects of memory known as explicit and implicit memory (see Graf & Schacter, 1985 for a review). The Repetition Memory Task in the present study could be said to bear upon the issue of implicit memory since the subjects have the opportunity to show the influence of prior exposure to the experimental items without being asked to consciously recollect these items. The Recognition Memory Task, on the other hand, entailed explicit memory since it required the subjects to make reference to the stimuli seen in the previous (Repetition Memory) task, and their performance was determined by their conscious recollection.

If one were to take the implicit/explicit distinction at face value within a framework such as Seidenberg and McClelland's (1989a) Model of Word Recognition, which allows activation of stored representations by nonlexical items, one could propose that in decoding the repeated nonwords, the repeated activation of the stored representations of sublexical units led to facilitation of this process. This could be something akin to encountering a previously unfamiliar word in a passage of text in which the word features strongly. By such an account, although the decoding skills of the developmental dyslexics may have been less automatic at the start of the Repetition Memory Task, the repetition of the stimuli and consequent repeated activation of the stored representations involved in the decoding process produces facilitation. If the stimuli were repeated sufficiently often it seems likely that the dyslexic readers could be brought to the same level of automaticity as the reading age controls. However, the longevity of this effect may be worth investigating in view of the low, background level of automaticity exhibited by the dyslexic readers when the experiment began.

The deficit shown by the developmental dyslexics in the Recognition Memory Task, which tested explicit recall, indicated that another aspect of memory may need to be explored. The superior recollection of the experimental stimuli by the reading age controls may reflect a difference between the reading groups which could have had a bearing on the results of the Repetition Memory Task. As the reading age controls appeared to be better at explicit recall than the dyslexic children, it is possible that the reading age controls could have already had their recognition of the items facilitated before the Repetition Memory Task was carried out. This is because the items were first presented the Nonword Naming Task. In the design of the experimental programme, it was thought that testing nonword naming at least one day before repetition memory would be sufficient to prevent the children's initial exposure to the experimental stimuli from influencing the outcome of the Repetition Memory Task. However, the differential patterns of facilitation displayed by the two reading groups in the Repetition Memory Task were consistent with the reading age controls having an advantage in processing efficiency due to superior recall of the previous encounter with the experimental stimuli. The dyslexic children may not be as good as their reading age controls at retaining information relevant to decoding specific items over longer time-intervals. In future investigations it would be important to ensure that both groups were unfamiliar with the items to be decoded in order that their patterns of facilitation could be compared with greater assurance.

It would also be interesting to test explicit recall in both groups after only one encounter with the experimental items. It seems possible that the deficit in explicit recall shown by the developmental dyslexics in the Recognition Memory Task would have been even more profound had they not been repeatedly exposed to the experimental stimuli in the earlier experiment.

The contamination of the results of the Repetition Memory Task by explicit memory may not be restricted to the influence of the first encounter with the experimental stimuli. The reading age controls may be at an advantage throughout the experiment. This would mean that interpretation of the results solely in terms of implicit memory may be fallacious. A manipulation which ought to circumvent this difficulty would be to interfere with the conditions which are normally required to promote explicit memory. The extent to which this alters the performance of the reading groups in a Repetition Memory Task would give an indication of whether the differences observed in the present experiment were due to the superior explicit recall of the reading age controls. Such an experiment would provide a less contaminated comparison of implicit memory in the two reading groups.

One factor which is known to disrupt explicit memory is *divided attention* (Parkin & Russo, 1990). The simultaneous performance of an additional task during the study phase places demands upon attentional capacity during learning and reduces the amount of information which will be consciously recalled. The knowledge that such conditions are disruptive to conscious recall of information leads one to consider that divided attention might be relevant to the explanation of the dyslexic children's performance, despite the fact that that this was not deliberately manipulated. If the developmental dyslexics suffer a lack of automaticity in decoding words, such as was exhibited in the Nonword Naming Task, a state of divided attention may be approximated in these readers. The strain that such a state would impose upon their attentional capacities might inhibit their long-term recall of information pertaining to the letter string which they are processing. This question merits further investigation because of its implications for remediation. By concentrating upon remediating some of the components of the decoding process in isolation, it may be possible to relieve some of the attentional demands on the dyslexic child and produce conditions which are more conducive to learning. This suggestion is similar to the recommendations of Laberge & Samuels (1974), who stress the importance of ensuring that the basic processes of a task are automatic before an attempt is made to progress to the more advanced levels of processing in the acquisition of a complex skill.

CHAPTER 6

GENERAL DISCUSSION

6.1 IMPLICATIONS FOR MODELS OF DEVELOPMENTAL DYSLEXIA

(i) *Phonological Processes*

It is widely held that the problems suffered by the vast majority of developmental dyslexics are primarily phonological in nature, e.g. Vellutino (1979); Frith (1985); Stanovich (1988). Frith (1985) claimed that *classic* developmental dyslexia constituted arrest at the logographic phase in her stage model of reading development. Phonological dysfunction, she believed, was the reason for their failure to advance to the alphabetic phase. Empirical support for this view is manifold, e.g. Bradley & Bryant (1978); Snowling (1980, 1981); Snowling et al (1986); Bruck & Treiman (1990). Furthermore, training and longitudinal studies of normal readers have yielded convincing evidence that a child's early sensitivity to phonology has an influence on later reading ability e.g. Liberman et al (1977); Lundberg et al (1980); Mann (1984); Maclean, Bryant & Bradley (1987); Lundberg et al (1988).

Assessment of the phonological skills of the developmental dyslexics in the present study did reveal impairments. The presence of these impairments varied, however, according to the phonological test employed and the individual under examination. For example, the sample of developmental dyslexics in Chapter 4 was impaired relative to their reading age control group on the Phoneme Deletion Task. Nevertheless, the dyslexic group performed at a similar level to their reading age controls on the Rhyme Judgement Task and were better than these reading age controls on the Auditory Organisation Task. For the sample in Chapter 5, there was no difference between the dyslexic and reading age control groups on the Segment Deletion Task, with both groups exhibiting a similar advantage for onset-rime over post-vowel segmentation.

Thus the phonological difficulties exhibited by these dyslexic children could not be described as a general inability to reflect upon the phonological properties of spoken language. Rather, the data were consistent with the dyslexic children experiencing a very specific problem with the most analytical level of phonological segmentation tested, namely the manipulation of phonemes.

Exploration of the nature of this difficulty is required. Phoneme deletion is acknowledged to be one of the most demanding tests of phonological awareness (e.g. Golinkoff, 1978; Yopp, 1988). However, this is not only because it involves an extremely detailed phonological analysis of spoken words. Yopp (1988) observed that phoneme deletion tasks were also demanding of auditory short-term memory which was found to be an area of weakness in the samples of dyslexic children under consideration in this thesis. Furthermore, performance on phoneme deletion tasks has been shown to be influenced by orthographic knowledge (e.g. Stuart, 1990). Indeed, the consistency between the orthography and phonology of a letter string was found to exert an effect on performance in the phoneme deletion test carried out in this thesis (see Chapter 4), and phoneme deletion skill was closely linked to the ability to spell the stimuli used in this experiment. Morais et al (1979) have demonstrated that learning to read is associated with a great improvement in phoneme deletion skills. Given the literature cited above, which suggests a causal role for phonological awareness in reading development, it appears that there is likely to be a reciprocal relationship between phonemic awareness and reading acquisition (e.g. Morais et al, 1987). Consequently, it may only be possible to interpret data from phonological awareness tasks in purely phonological terms when the subjects are essentially prereaders. The study by Goulandris & Snowling (1991) contains a possible illustration of this problem.

(ii) *Individual Differences*

So far, the experimental results have been discussed without mention of individual differences. When the distribution of scores was examined in each of the phonological tasks, it was always possible to identify dyslexic children who were very obviously impaired on that task. However, it also emerged that there were always some developmental dyslexics whose performance was *above* average for their reading age. The heterogeneity of variance apparent in many of these tests was also indicative of a range of performance not present amongst the controls. It was concluded earlier, on the basis of group performance, that developmental dyslexics suffered an impairment specific to *phonemic* awareness. Given the individual variation apparent in the experimental results, it has to be asked to what extent this overall conclusion is either an accurate or a useful description of the difficulties experienced by these dyslexic children?

This conclusion was in line with the guidelines that Bryant & Goswami (1987) set out for the interpretation of group studies comparing developmental dyslexics with reading age and chronological age controls. Bryant & Goswami contended that when the performance of the developmental dyslexic group was equal to, or better than the reading age control group, and worse than the chronological age control group, it was impossible to interpret the results. They claimed that the dyslexic groups' superior mental age relative to their reading age controls and inferior reading skills relative to their chronological age controls meant that such findings were ambiguous.

While excellently worked out at the group level, their arguments failed to consider the question of heterogeneity within the sample (Hulme & Snowling, 1990, make a similar point). Substantial variation was evident in the phonological problems exhibited by the developmental dyslexics in this thesis. While many of the children in the dyslexic sample in Chapter 4 were found to have phonemic segmentation problems, comparatively few of these children had rhyme judgement problems. The relative infrequency of insensitivity to rhyme in this particular sample of dyslexic children meant that there was no significant difference between the dyslexic and reading age control groups in the Rhyme Judgement Task (see Chapter 4). For Bryant & Goswami, this would constitute an uninterpretable result. They have pointed out that the superior mental age of the dyslexic group may have assisted their performance in the rhyme judgement test and concealed a genuine insensitivity to rhyme. Obviously, this is an important observation which must be borne in mind when comparing developmental dyslexics with younger reading age controls. Nevertheless, the results of the present study seem to indicate that Bryant & Goswami have chosen to apply their arguments at too gross a level, and consequently may have let a great deal of very illuminating data go to waste. The treatment of group results at this macro level provides only a summary of performance and should be regarded as a fairly rough indicator of areas of difficulty. Cognitive impairments which are less frequent, but nevertheless potentially of importance in explaining the difficulties of some developmental dyslexics, are apt to be overlooked using this approach. This is a particular problem with small samples, in which the incidence of children with certain less frequent impairments is likely to be low.

(iii) *Visual Processes*

The question of visual impairments in developmental dyslexia would appear to have suffered just such a fate. Boder (1973) reported that the incidence of dyslexic children with visual problems was lower than that of dyslexic children suffering phonological problems. Moreover, when dyslexic children are from dyslexia clinics or units, as in the present study, it may be that the sample is liable to subtle selection biases. One cannot help but think that the recent emphasis on phonological problems as being the typical *symptom* of developmental dyslexia may well have had an influence on which children are referred for remedial help to dyslexic clinics. In accordance with what would be expected from the arguments outlined above, group studies have often failed to find evidence that developmental dyslexics are impaired in visual tasks relative to their reading age controls. However, researchers adopting a cognitive neuropsychological approach to the study of developmental dyslexia have reported cases of dyslexic children whose problems were not thought to be primarily phonological in nature. Instead, these children have shown evidence of some visual impairment, and have been labelled as suffering from developmental surface, visual or morphemic dyslexia e.g. Coltheart et al (1983); Seymour (1986). In general, however, interest has focussed on the pattern of these subjects' reading performance which reflects their spared phonological capacities, rather than on establishing the nature of their impairments.

The analysis of developmental dyslexia provided by Seymour (1986) was an exception to this trend. Seymour offered the following descriptions of developmental dyslexia which appeared to result from visual impairment:

> *Visual Processor Dyslexia*
> typified by slow reaction times when making same-different judgements about pairs of letter arrays and slow serial processing when reading vertically distorted words.
>
> *Morphemic Dyslexia*
> characterised by slow serial processing in reading both lexical and nonlexical stimuli with problems perceiving sequences of letters.

The difficulty in visual processor dyslexia was interpreted as an inefficiency affecting the analytic mode of the visual processor. Morphemic dyslexia was held to result from a disruption to the holistic functioning of the visual processor which often resulted in a reliance upon the analytic processing mode.

The tasks that Seymour (1986) utilised were very much *reading-related* and as such have been criticised by Wilding (1989). Seymour's motivation for using such tasks derived from a belief that the visual processor might be functionally distinct from other visual analysers. Wilding (1989) put forward a more epigenetic view, which may be more appropriate for the early stages of reading development. He argued that since the cognitive processes involved in reading were likely to have been evolved for other purposes, it should be possible to identify underlying impairments in dyslexia using tasks extrinsic to reading. In Chapter 3, it can be seen that extrinsic tasks have already been used to great effect in revealing phonological problems among developmental dyslexics and in implicating early phonological awareness as an important predictor of later reading achievement. In the present study, phonological awareness tasks did prove to be sensitive to varying levels and types of phonological impairment within the dyslexic group. However, visual processing in developmental dyslexia was also investigated in this thesis by means of an extrinsic task. On the basis of previous work (e.g. Johnston et al, 1990), the Visual Embedded Figures Task was selected as a test of visual segmentation skills. Such skills were thought to be relevant to the reading process since graphemic segmentation of a letter string is held to be one aspect of acquiring and applying knowledge about the correspondence between spelling and sound in written language (e.g. Ellis, 1985). The developmental dyslexics outperformed their reading age controls in the Visual Embedded Figures Test but the sample of dyslexic children in Chapter 4 for whom there was a chronological age comparison, were found to be impaired for their chronological age at this task. Thus, the developmental dyslexics exhibited a similar level of performance relative to their controls on both the Visual Embedded Figures and Auditory Organisation Tasks. The difficulty of interpreting such a result at the group level has already been discussed. One of the most plausible accounts is that learning to read improves visual segmentation skills. However, there was some suggestion in a study by Kolinsky et al (1987) that the educationally derived benefit for such skills is a general effect of schooling rather than a specific effect of literacy training.

An additional interpretation arises when one examines individual differences in the Visual Embedded Figures Test. The samples of developmental dyslexics in both Chapter 4 and Chapter 5 contained dyslexic children who were severely impaired at this test even for their reading age. The possibility emerges that this visual test has exposed impairments which affect only a minority of the dyslexic group, but which may prove a major stumbling block to these children's reading aquisition. Once again, statistical methods applied at the group level have failed to register severe impairments in task performance because these impairments were suffered by only a few children in the group. It would be a disservice to these children to forego investigation of the nature of their visual difficulties because of the group results. In general, consideration of the contribution of visual skills to the reading process might lead to a fuller understanding of the reading acquisition and might provide more accurate explanations of the problems faced by some developmental dyslexics.

The recent case study by Goulandris & Snowling (1991) marks a breakthrough in this respect. The assessment that these authors made of the developmental dyslexic, J.A.S., included measures of her visual processing as an extension to the traditional cognitive neuropsychological approach to the study of reading disorders. Consequently, they were able to demonstrate that their subject suffered profound deficits in visual memory and visual analysis, which appeared to account for the pattern of subtle reading problems and poor spelling that their subject exhibited.

In view of the above results, it would appear judicious to reevaluate the question of visual impairments in developmental dyslexia. This time around the issue should be approached with slightly modified expectations. The indications are that it may be inappropriate to assess visual problems at the group level due to the relative infrequency of these problems. Instead, it might be more productive to attempt to identify single cases or subgroups of individuals who suffer from visual impairments. The challenge will be to establish whether visual processes are critically involved in normal reading development and whether visual weaknesses can account for some cases of reading disorders. For this to be possible, longitudinal and training studies will need to be conducted which investigate visual skills in a manner similar to the growing literature on phonological awareness. If visual skills were to prove to be predictive in these type of studies, then one could be more confident that the relationship between visual processes and reading achievement was causal rather than merely associative.

(iv) *Memory Processes*

A further point of interest for future research is the interaction between processing in the various sensory modalities and memory. Snowling & Hulme (1989) have drawn attention to the involvement of *paired-associate learning* in the early stages of reading acquisition e.g. look-say or letter-sound associations. In their study of a developmental phonological dyslexic, these authors argued that deficiencies in output phonology had been detrimental to this child's acquisition of either a sight vocabulary or a phonic approach to reading. Specifically, the child's degraded phonological representations of words and sounds were likely to have inhibited the learning of associations between spoken and written forms of words and letters. By inference, one could also imagine a situation in which a visual impairment such as the inability to perceive letters or letter groups within written words could disrupt the associative processes involved in reading acquisition.

A complementary issue is the relationship between short-term memory capacity and the ability to carry out the component processes of reading. As a group, the developmental dyslexics in the present study were equivalent to their reading age controls on a measure of phonological short-term memory. The repercussions that impaired phonological short-term memory capacity would have for reading development have already been discussed in Chapter 3. The blending of phonological segments was highlighted as a particular area of difficulty for children with such problems e.g. Baddeley (1989); Torgesen et al (1989). Once again a visual parallel could presumably be made. An impaired visual short-term memory might inhibit the use of visual information because of an inability to learn common letter sequences. For example, Goulandris & Snowling (1991) reported that J.A.S. showed great difficulty in retaining item order information. These authors argued that this was likely to impede the development of a visual input lexicon, which would lead to both reading and spelling difficulties.

So far, only impairments to the individual *slave*[1] systems of Working Memory have been discussed. If instead, the capacity of the central executive system was found to be limited in some developmental dyslexics, then more general impairments might arise. Baddeley (1989) has set out a role for the central executive as a processing system which could select strategies and integrate information from different sources. He speculated that the central executive may have a supervisory, attentional role such as that described by Norman & Shallice (1980). It seems possible that an impairment to this system might disrupt the learning of complex processes which require several operations to be performed, such as phonological decoding.

Conversely, when the component operations are themselves the problem, such that they have not yet become *automatic* and still demand considerable attention for implementation, the central executive may be strained even if apparently functioning normally itself. This may delay the acquisition of more advanced skills in a manner which may relate to the concept of automaticity outlined by LaBerge & Samuels (1974).

(v) *Overview*

In Chapter 4 of the present study, an assessment was made of the status of the cognitive abilities of developmental dyslexics in the phonological, visual and tactile modalities. The selection of cognitive abilities to be investigated was

[1] see Baddeley (1989) for a description of the component processes in Working Memory.

based on current hypotheses concerning the component operations involved in the reading process. Analysis of the results at the group level revealed only a limited phonological impairment relative to reading age in the dyslexic group. Substantial heterogeneity was observed, however, within the dyslexic group in the performance of many of the experimental tasks. It was argued that in the past group studies may have obscured less widespread but nevertheless, disabling cognitive impairments in developmental dyslexia.

Ellis (1985) proposed that developmental dyslexia may not comprise a number of discrete and homogeneous subtypes. Rather, there may be several cognitive skills which form the dimensions of reading ability. Ellis proposed that each of these dimensions would be a continuum where a normal distribution of results would be expected. Heterogeneity in both the dyslexic and the normal population would be classifiable in this multidimensional space. The present study has yielded evidence that specific phonological, visual and memory skills may be differentially impaired among developmental dyslexics. It is suggested that these cognitive abilities are candidates for forming the dimensions of reading ability and that the pattern of abilities along these continuous dimensions determines the course of reading acquisition. Future research will be necessary to establish whether these relationships are truly causal and to elaborate upon the nature of the fundamental skills in these areas. This discussion will conclude with a reevaluation of developmental models of reading from this new perspective.

6.2 IMPLICATIONS FOR MODELS OF READING DEVELOPMENT

The review of cognitive neuropsychological models of skilled reading in Chapter 1 was intended to illustrate the techniques and assumptions which have been influential in conducting and interpreting recent research into developmental dyslexia. The experimental rigour of this approach has been utilised to great effect in delineating patterns of reading performance and reading related skills. However, this has been very much a "top-down" approach to the study of developmental reading disorders. The preformist stance of Marshall (1984) represents an extreme example of this, where a model of skilled word recognition was held to provide an appropriate framework for the exploration of the developing system. Bryant & Impey (1986) admirably illustrated the dangers of neglecting developmental issues when they demonstrated that, with the exception of nonword naming performance, the reading patterns held to identify the developmental equivalents of acquired phonological and surface dyslexics were found among children who read normally for their age.

In developmental reading models, such as those by Marsh et al (1981) and Frith (1985), the process of learning to read was recognised as transitional. Unfortunately, to date, developmental reading models have been more descriptive of externally observable strategies than of the cognitive mechanisms which underpin these strategies. Furthermore, it has become evident that the sequence of stages in Frith's model are proving to be too invariant to capture either the impact of differing methods of reading instruction on the nature of reading acquisition (e.g. Seymour & Evans, in press), or the individual differences which exist among normal readers (e.g. Baron & Treiman, 1980; Bryant & Impey, 1986; Seymour & Elder, 1986). Furthermore, Campbell (1985) has called the traditional sequence of reading strategies into question, and more recent studies appear to have demonstrated concurrent strategy use.

Goswami (1986) has shown that five year olds are able to employ analogies in their decoding of novel stimuli, although this had been thought to be a relatively late developing skill (e.g. Marsh et al, 1981; Frith, 1985;). Seymour & Evans (in press) have also reported that logographic and alphabetic reading strategies can be present simultaneously amongst early readers. Johnston, Anderson, Perrett & Holligan (in prep.) have also described subjects who appear to have a variety of strategies available at a point when only alphabetic reading would be expected according to Frith (1985) and Morton (1989).

The potential of pursuing the issue of reading acquisition from the "bottom-up" is now beginning to be realised. Despite longstanding allusions to the importance of constitutional factors in determining the course of reading development (e.g. Snowling, 1983, 1987; Frith, 1985), it is only now that these are being investigated. So far, the main emphasis has been on phonological awareness, and there is indeed an impressive literature which suggests that early phonological awareness is causally related to reading development e.g.Liberman et al (1977); Lundberg et al (1980); Mann (1984); Maclean, Bryant & Bradley (1987); Lundberg et al (1988). Although attempts have been made to outline the manner in which phonological awareness may contribute to reading acquisition (e.g. Stuart & Coltheart, 1988; Goswami, 1986, in press; Goswami & Bryant, 1990), the sequence of children's developing awareness of sound remains poorly understood and the influence of reading instruction needs to be addressed (see Seymour & Evans, in press). As was mentioned earlier, phonological processing has been identified as a major area of difficulty for developmental dyslexics. In the present study, variation was revealed in the levels of phonological analysis that caused difficulty for such children. On the whole, there was support for a developmental sequence from a holistic to a more analytic appreciation of sound, which could be disrupted at any point, but this pattern was not invariant - at least one dyslexic child showed preserved phoneme deletion skills in spite of impaired rhyming skills. Thus, future assessments of phonological processing amongst dyslexic children should not be content with identifying a single phonological impairment but should aim to provide a comprehensive analysis of the phonological strengths and weaknesses of their subjects. In particular, this area would benefit from more longitudinal investigations similar to the study of J.M. (Snowling et al, 1986; Snowling & Hulme, 1989), if we are to be able to specify the consequences that early phonological difficulties will have for reading acquisition.

Nevertheless, in the present study, dyslexic children were identified who possessed phonological skills which were appropriate for their reading age. Furthermore, children with poor phoneme deletion skills were found in the reading age control group. These findings weaken arguments that the status of such skills alone determines reading achievement, and it seems likely that models such as those of Stuart & Coltheart (1988) and Seymour (1990) will have to incorporate additional cognitive skills which have a similar role to phonological awareness skills. There were indications in the present study that cognitive impairments to visual and memory skills were also associated with developmental dyslexia. A pressing question is whether such skills are *causally* related to reading achievement. For this reason longitudinal and training studies investigating aspects of visual processing and memory are urgently required.

At the moment, the involvement of visual memory in reading development seems an exciting area which needs to be explored given the case studies of J.A.S. (Goulandris & Snowling, 1991) and R.E. (Campbell & Butterworth, 1985). While J.A.S. appeared to be hampered in her reading, and more especially spelling development, by her severely impaired visual memory, R.E. was apparently able to utilise her good visual memory to achieve an adult level of reading despite very poor phonological skills. Accounts of reading development which adhere closely to Frith's (1985) stage model make no provision for the influence of visual memory in normal reading acquisition. The use of visual memory is seen as an abnormal strategy invoked to compensate for phonological difficulties. This view is looking increasingly inadequate for it seems implausible to suggest that such a potentially useful skill as visual memory should not be an integral part of normal reading development.

There is a need for theorists to reflect upon the cognitive skills which are available to children as they start to learn to read, for these may disclose the determinants of early reading ability. As Pring & Snowling (1986) have argued, it seems likely that children will call upon many sources of information in reading. The nature of the reading instruction that they receive may bias them towards a predominant mode of processing, but for children developing normally, information from various perceptual and cognitive sources will be available and seems likely to be utilised interactively during reading acquisition. For this reason, characterising each stage of reading development in terms of only one strategy probably belies the complexity of what is really taking place.

The Dual Foundation Model devised by Seymour (1990) seems the best attempt to address such issues (see Figure 11). According to this model, logographic and alphabetic strategies are said to form a *dual foundation* for orthographic development[2]. Seymour & Bunce (in press) have suggested that phonological awareness is interactively related to alphabetic development. One could conceive that there may be a corresponding visual process which allows reflection on the visual aspects of letter strings at various levels of analysis. This may be the locus of the *holistic* and *analytic* modes of visual processing which Seymour (1986) concluded were impaired in cases of developmental morphemic

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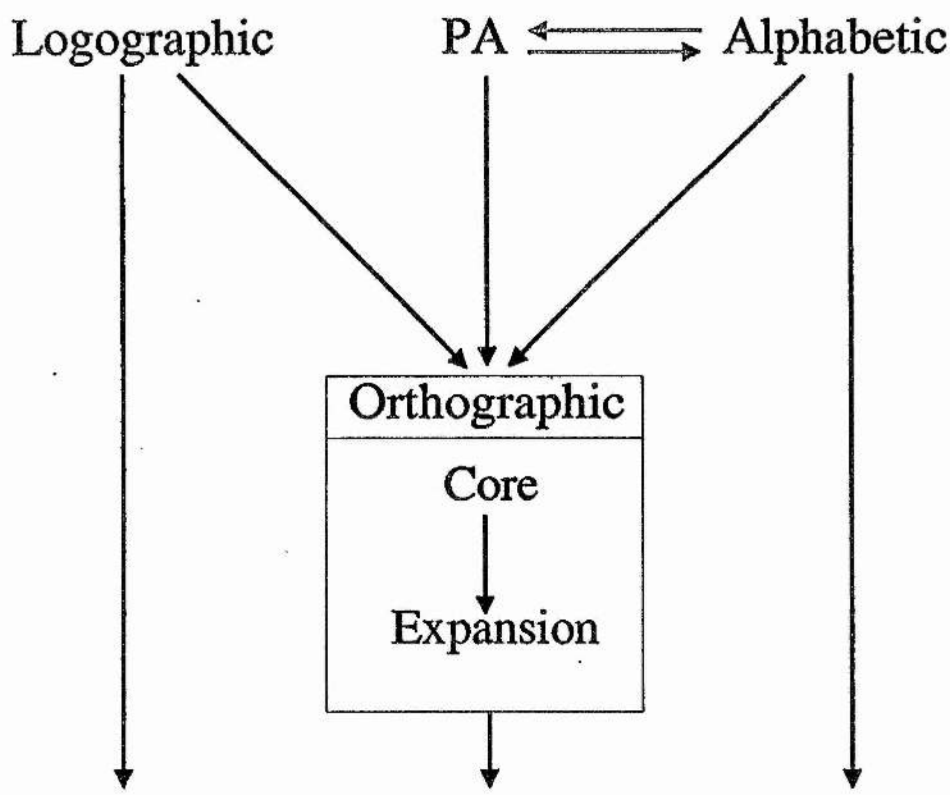
[2] The idea that the logographic strategy constitutes part of the basis for the more sophisticated analyses attributed to the orthographic strategy is initially a little hard to reconcile. This may be a fault of terminology rather than theory. One associates logographic reading with the descriptions contained in studies such as Masonheimer, Drum & Ehri (1984) and Seymour & Elder (1986). However, this may simply be a rudimentary form of the logographic foundation in Seymour's model, just as the painstaking serial application of letter-sound correspondences would probably be viewed as an early manifestation of the alphabetic foundation. It seems possible that visual representations of words are gradually refined from a preliminary form in which salient graphic features are registered, towards a more complete representation of all the letters and their groupings.

FIGURE 11

THE DUAL FOUNDATION MODEL OF READING DEVELOPMENT
(From Seymour & Bunce, in press)



or visual processor dyslexia. Furthermore, the skills measured by the Visual Embedded Figures Task could relate to such a feature of reading development.

Seymour (1990) proposed that developmental dyslexia could arise as a result of a phonological impairment which disrupted alphabetic development or from an impairment to logographic development. According to his model, either type of impairment would lead to difficulty in establishing an orthographic framework. His model implies that after impairment of one of these processes, the remaining process, either alphabetic or logographic, may continue to develop and to support reading if skill is sufficient. In this sense, either type of development would in effect be a *compensatory* strategy, since although the fundamental processes involved might be the same ones as would normally be involved in reading, their development would lack the guidance which input from the impaired process normally provides. Consequently, development would be deficient, even if in relatively subtle ways, and a complete orthographic framework would not be established. When considering the prognosis for developmental dyslexics it may, therefore, be essential to assess the balance of their skills and weaknesses. For example, it appears that if phonological impairment is accompanied by good visual processing e.g. R.E., Campbell & Butterworth (1985), or if visual impairment coincides with preserved phonological processing e.g. J.A.S., Goulandris & Snowling (1991), then attainment of an adequate, but probably not outstanding, level of adult reading may be possible.

Assessment of the relative balance of skills may contribute to our understanding of the approach that both good and poor readers favour when learning to read. Johnston, Anderson & Duncan (1991) have demonstrated that two groups of dyslexic children, who were impaired to a similar extent in their phonological processing, differed in their approach to reading according to whether their visual skills were weak or strong. The group with good visual skills appeared to adopt a visual approach to reading, whereas the group with poor visual skills seemed to rely upon their equally poor phonological skills in reading. Rather perversely, given their dual impairment, this latter group outperformed the others in a nonword naming task, presumably because their phonological approach was the more effective strategy when it came to reading nonwords. Therefore, nonword naming ability may not always be a reliable index of phonological impairment since reliance upon a visual approach can also be detrimental to performance in this task.

Thus, a wide-ranging appraisal of the cognitive abilities of developmental dyslexics may be required if one is to fathom the nature of their reading performance. The identification of a phonological impairment would not enable one to predict the approach that a dyslexic child will adopt in attempting to read until more is known about the status of their other cognitive abilities. Furthermore, methods of reading instruction and remediation will be an important influence on the strategies used in reading and reading related tasks. Assessment of a wide selection of cognitive skills in a dyslexic child would allow a more informed decision to be made concerning the most suitable form of remediation. Obviously, the two groups of developmental dyslexics in the study by Johnston et al (1991) would not derive equal benefit from attempts to establish a sight vocabulary, despite their similar levels of phonological impairment.

The level of complexity that is now required in order to incorporate what is known about normal and impaired reading development in a single model is great. It may be that the paradigm most suited to this task at present is connectionism. The model put forward by Seidenberg & McClelland (1989a) is encouraging but will need to accommodate more of the developmental literature if it is to prove viable.

As Seidenberg & McClelland pointed out themselves, their implemented model was a much simplified version of the full processing system involved in single word processing. Although this may have been sufficient for their purposes, it has been argued here that a model of reading development would benefit greatly from consideration of the initial state of cognitive systems such as those developed for speech perception and visual pattern recognition. For example, Goswami (1986) theorised that a sensitivity to onset and rime units within spoken words could be utilised by beginning readers to group together words which rhyme, which could lead to the realisation that such words often have common spellings. This path will not be available to a child who has not yet attained this degree of phonological awareness and this should be reflected in any model of early reading development. In fact, Johnston et al (in prep.) have speculated that developing perceptual skills may determine the timing of the adoption of certain reading strategies in normal reading acquisition. Thus, the attainment of the ability to reflect upon the smaller sounds in speech or to see the parts within a gestalt may enable more analytic strategies to be utilised in reading. Furthermore, incorporating an interactive relationship between the speech perception system and reading development would accommodate the effects of orthography on phonological awareness reported by Ehri & Wilce (1980), Stuart (1990), and in this thesis.

Seidenberg & McClelland's model will need to be extended to accommodate reports that a reliance upon a sight vocabulary can be part of early reading development if instruction is predominantly *look-say*, or as a consequence of phonological impairment e.g. Seymour & Elder (1986); Seymour & Evans (in press); Campbell & Butterworth (1985); Funnell & Davison (1989). The advantage for irregular over regular words among some of the dyslexics in the present study suggests that this may be a feature of their reading.

Children who receive reading instruction in letter-sound correspondences, and who are able to utilise this information, possess an additional set of associations to aid their word recognition. Hinton (1991) recently emphasised the advantages of providing connectionist models with all available information in order to improve the power of simulations. Therefore, it would seem advisable to encode such relevant aspects of instruction in the network during the training phase in these simulations.

At present, the orthographic and phonological content of words are represented in Seidenberg & McClelland's model as sets of letter or phoneme triples. This system was introduced for simplicity, but the authors later admitted that this system may have led to the high incidence of single feature errors in their simulations (see Seidenberg & McClelland, 1990). It might be better to run the model with no such preconceptions and to observe what system the model comes up with for encoding the correspondence between letters and sounds. Authors such as Wylie & Durrell (1970) have pointed out that in English words the consonantal coda generally has more bearing upon the pronunciation of the vowel than the onset. One might expect, therefore, that the model would eventually derive this feature from the training vocabulary, and exhibit a sensitivity to *bodies* or *rime* units when the training phase was complete. Whatever the outcome, observation of the characteristics of such a training phase should prove fascinating, especially the comparison of the methods that the system devises for encoding spelling-to-sound correspondences with the existing hypotheses in the developmental literature. As discussed above, it is likely that the accuracy of such simulations would be improved by an interactive link with phonological awareness, and possibly some complementary visual process such as visual segmentation.

A particularly attractive aspect of connectionist models of word recognition is that their system of *weights* which encode knowledge about the correspondence between orthography and phonology illustrates very clearly the involvement of memory in the reading process. Hinton & Plaut (1987) have proposed that the distinction between long-term and short-term learning may be represented in connectionist models by the type of weights involved. Baddeley, Papagno & Vallar (1988) and Gathercole & Baddeley (1989) discuss this point in relation to phonological memory. They suggest that short-term retention is based on fast weights which are easily altered but decay rapidly, and that long-term memory is based on more stable slow weights which gradually accrue information over successive trials. Gathercole & Baddeley speculated that the construction of slow weights might be disrupted by a difficulty which prevented the setting up of fast weights or by a more general impairment which inhibits the formation of either type of weight. These issues seem worth pursuing in relation to connectionist models of reading development and may produce an account of memory problems such as those observed amongst the dyslexic children in the present study and reveal how these might contribute to their reading problems.

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APPENDIX 1

STIMULI FOR THE NONWORD NAMING TASK IN CHAPTER 4

ORDINARY NONWORDS	*PSEUDOHOMOPHONES*
coe	loe
loase	hoase
nair	bair
gosp	wosp
doove	moove
sayd	layd
bon	gon
druv	luv
loast	poast
hoz	woz
soam	hoam
brud	flud
cotch	wotch
spreed	teech
brode	gole
brise	bild
doan	bloan
blum	blud
mosh	wosh
haive	saive
goan	oan
lurd	wurd
proe	groe
moath	boath

APPENDIX 2

STIMULI FOR THE AUDITORY RHYME JUDGEMENT TASK IN CHAPTER 4

RHYMING		*NONRHYMING*	
SIMILAR ORTHOGRAPHY	*DIFFERENT ORTHOGRAPHY*	*SIMILAR ORTHOGRAPHY*	*DIFFERENT ORTHOGRAPHY*
gate-late	paid-fade	move-love	beat-harp
burn-turn	tale-pail*	deaf-leaf	tame-paid
bake-cake	rule-fool	warn-barn	cave-mail
horn-born	bear-hare*	want-pant	pair-lake
long-song	case-face	wear-dear*	club-fled
sick-pick	coat-note	warm-harm	soap-code
wing-ring	pies-size	pear-year*	pins-side
land-band	wait-mate	gone-lone*	cast-fact
gift-lift	pain-lane*	post-cost	pair-fake
plan-flan	base-race	most-lost	rude-foal
gown-down	clue-flew	does-goes	hope-goat
hand-sand	hole-goal	work-fork	poor-sort
sold-bold	pour-sore*	pint-mint	cost-none
rice-mice	soak-coke	wolf-golf	wail-mats
farm-harm	bowl-coal	done-gone	bare-rake

* responses to this item were not included in the analyses

APPENDIX 3

STIMULI FOR THE AUDITORY ORGANISATION TASK IN CHAPTER 4

MEMORY PRETEST

jam	big	kiss	ball
leap	gun	car	hot
flat	toss	band	hill
nut	leg	sun	wet

EXPERIMENTAL ITEMS

INITIAL CONDITION

bud	bun	bus	rug
tip	pig	pip	pit
hid	hit	lip	him
peg	bed	pen	pet
log	loss	lot	cod
pad	man	mat	mad
ham	tap	had	hat
roof	room	food	root

MIDDLE CONDITION

dot	cot	pot	bat
nod	red	fed	bed
fun	gun	pan	run
lit	cat	bit	fit
name	game	same	home
bin	men	hen	ten
feed	reed	wood	seed
fish	mash	dish	wish

FINAL CONDITION

fat	sat	pat	bad
job	hop	top	pop
pin	win	sit	fin
weed	peel	need	deed
hard	yard	card	farm
moon	loot	hoot	boot
hand	bank	sand	land
wig	fig	rib	dig

APPENDIX 4

STIMULI FOR THE PHONEME DELETION TASK IN CHAPTER 4[1]

WORDS	*NONWORDS*
hard	fard
learn	ferm
scale	spale
blood	klud
stood	spoot
mind	gind
flat	smab
small	snol
floor	froash
wild	jild
work	durk
brown	trown
grass	prass
desk	besk
turn	purm
step	skep
cost	nost
class	blass
next[2]	lext
salt	nolp
must	nust
breath	preath
sleep	smeep
most	koasp

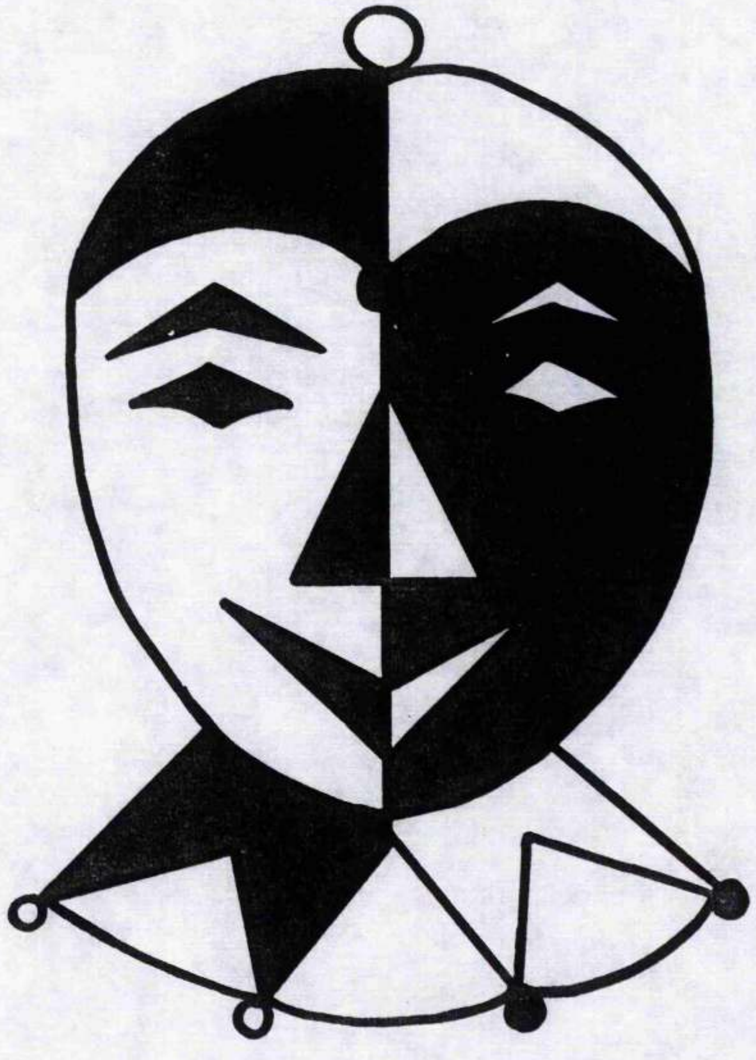
[1] Note that *r* is a consonant in Scottish English.
[2] This item contains an extra phoneme relative to the other stimuli.

APPENDIX 5.1

STIMULI FOR THE VISUAL EMBEDDED FIGURES TASKS IN CHAPTERS 4 & 5:
EXAMPLE OF SERIES 1

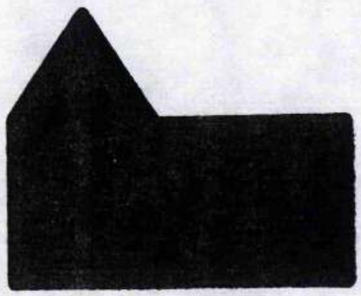
tent shape

figure



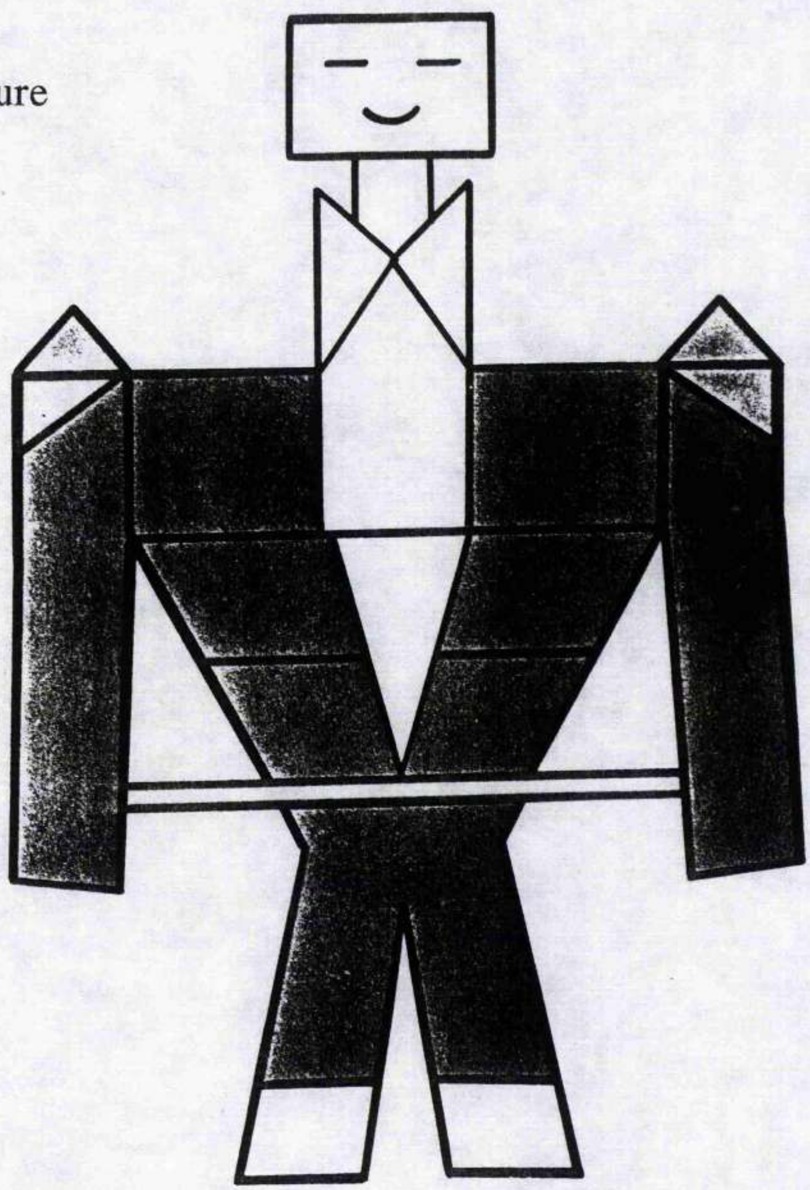
APPENDIX 5.2

STIMULI FOR THE VISUAL EMBEDDED FIGURES TASKS IN CHAPTERS 4 & 5:
EXAMPLE OF SERIES 2



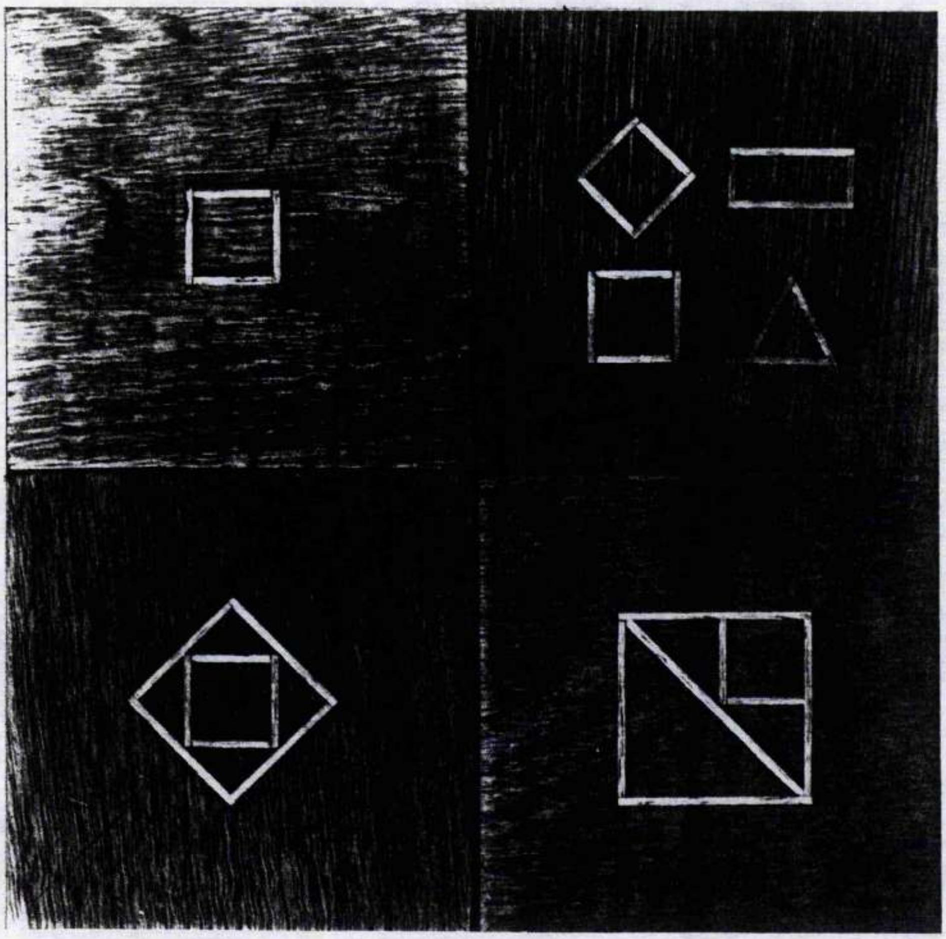
house shape

figure



APPENDIX 6.1

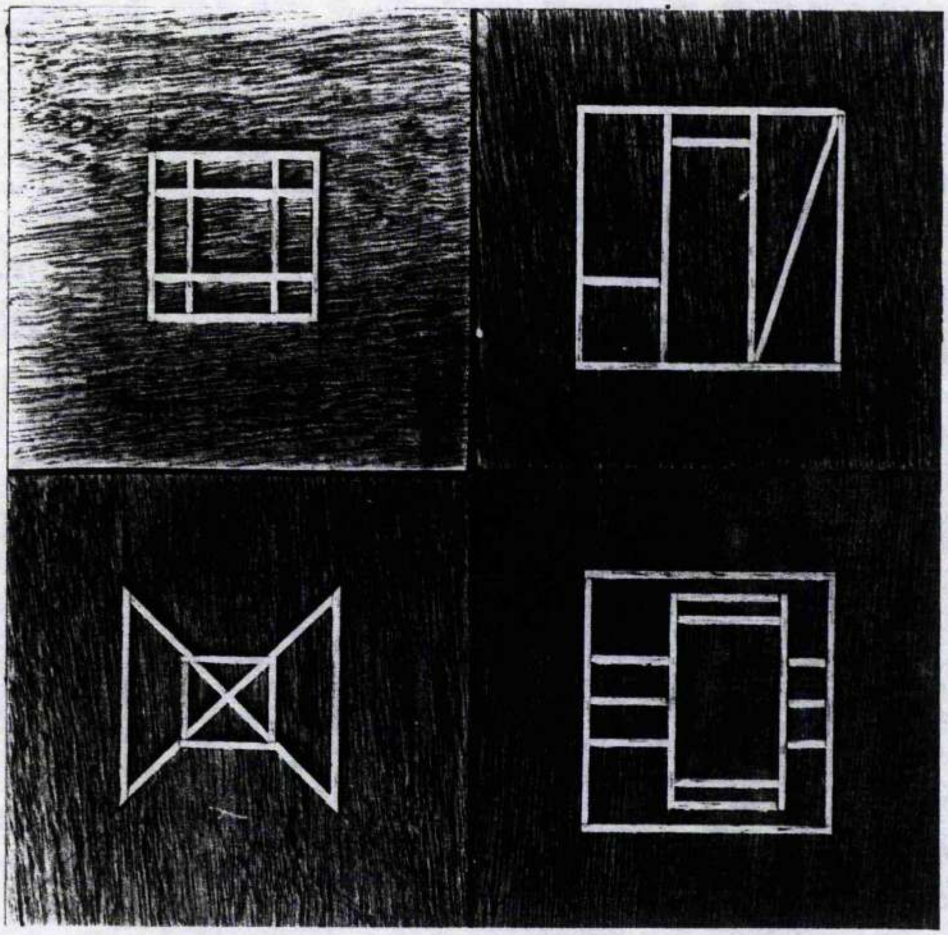
STIMULI FOR THE TACTILE EMBEDDED FIGURES TASK IN CHAPTER 4:
TARGET SHAPE[1] AND PRACTICE ITEMS



[1] The target shape is the figure on the upper left and measured 3x3 cms.

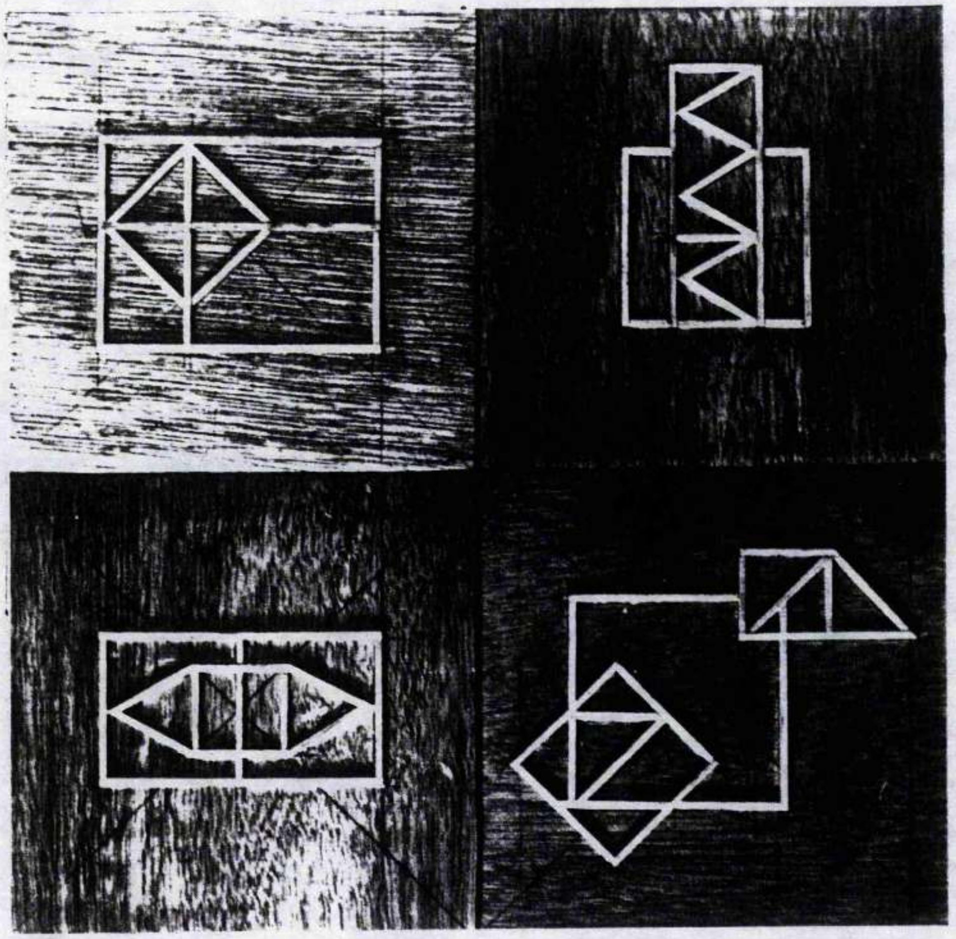
APPENDIX 6.2

STIMULI FOR THE TACTILE EMBEDDED FIGURES TASK IN CHAPTER 4:
EXPERIMENTAL ITEMS 1-4



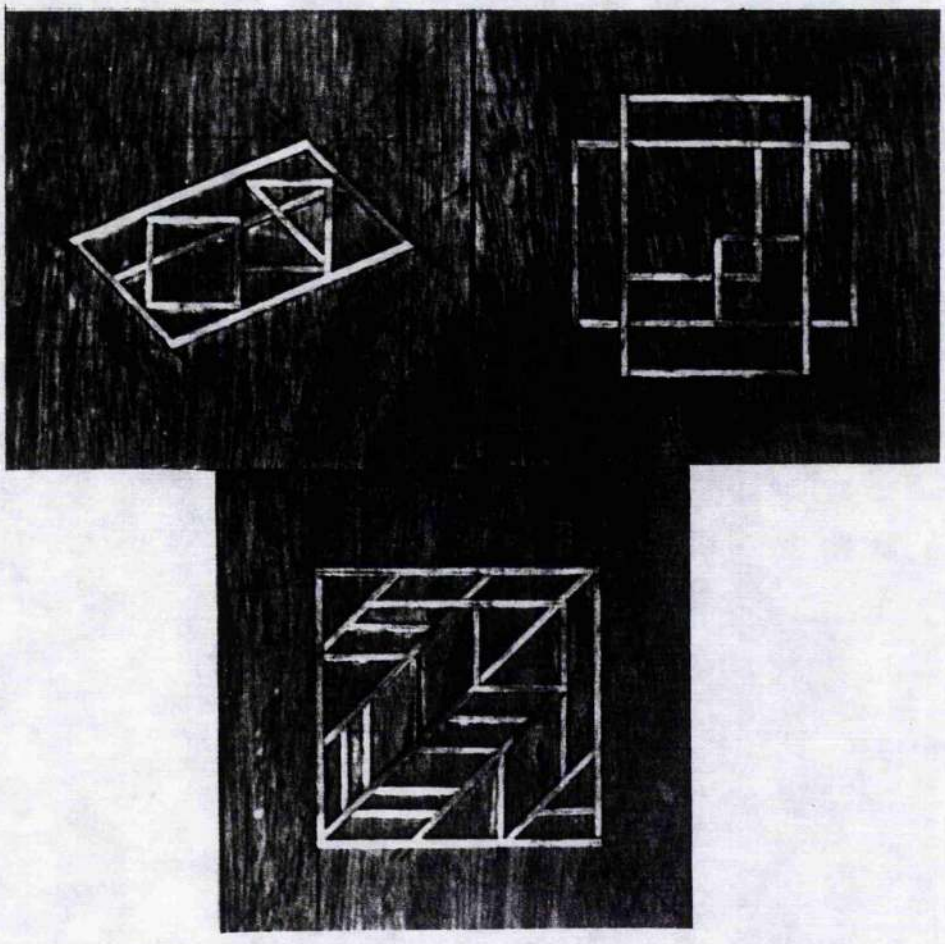
APPENDIX 6.3

STIMULI FOR THE TACTILE EMBEDDED FIGURES TASK IN CHAPTER 4:
EXPERIMENTAL ITEMS 5-8



APPENDIX 6.4

STIMULI FOR THE TACTILE EMBEDDED FIGURES TASK IN CHAPTER 4:
EXPERIMENTAL ITEMS 9-11



APPENDIX 7

STIMULI FOR THE NONWORD NAMING TASK IN CHAPTER 5

ORDINARY NONWORDS	*PSEUDOHOMOPHONES*	*FILLER NONWORDS*
coe	loe	glite
loase	hoase	blie
nair	bair	crade
gosp	wosp	liske
doove	moove	moop
sayd	layd	neab
bon	gon	stoil
hoz	woz	drack
soam	hoam	
brud	flud	
cotch	wotch	
blum	blud	
mosh	wosh	
haive	saive	
lurd	wurd	
moath	boath	

APPENDIX 8

STIMULI FOR THE SEGMENT DELETION TASK IN CHAPTER 5[1]

WORDS	*NONWORDS*
front	prunt
spent	stent
storm	florm
slept	bript
tramp	gromp
scarf	sterf
sport	slort
crept	grupt
stamp	clemp
print	crint
blast	clust
frost	drost
trust	snert
plump	drump
dwarf	storf
crisp	frisp
crest	frest
blond	brund
blunt	flent
stunt	scalt
drift	preft
grasp	drasp

[1] Note that *r* is a consonant in Scottish English.

<u>APPENDIX 9</u>

STIMULI FOR THE COLOURED LEXICAL DECISION TASK IN CHAPTER 5

WORDS	*NONWORDS*
short	shont
third	thift
child	chisp
sharp	shirp
shirt	whirk
chest	chern
ghost	thost
thump	shump
wrist	wrept
sword	ghort
black	blish
truck	bruck
fresh	floth
clock	frick
swing	spung
brush	crosh
drank	glenk
truth	scath
stalk	sleck
sting	cring

APPENDIX 10

STIMULI FOR THE RECOGNITION MEMORY TASK IN CHAPTER 5

TARGETS*

CONTROLS	*PSEUDOHOMOPHONES*	*FILLERS*
coe	loe	glite
nair	bair	blie
doove	moove	crade
bon	gon	liske
soam	hoam	moop
cotch	wotch	neab
haive	saive	stoil
lurd	wurd	drack

FOILS

*PHONOLOGICAL***	*VISUAL***	*PSEUDOHOMOPHONE*
glight	glike	rong
bly	blic	brane
kraid	crode	luv
lisc	lishe	tule
mupe	noop	dile
kneeb	reab	sutch
stoyl	sloit	bloan
drac	drask	rist

* all targets appeared in the Repetition Memory Task in Chapter 5

** these foils are matched to the filler targets

APPENDIX 11

SEGMENT DELETION TASK: ***Analysis investigating the effect of the different stimulus lists***

Percentage accuracy was calculated for each subject in every cell of the experiment. An analysis of variance was carried out with two between-subjects factors, **groups** (developmental dyslexics and reading age controls) and **lists** (version A and version B), and three within-subjects factors: **lexicality** (words and nonwords); **segmentation** (onset-rime and post-vowel); **position** (beginning and end). The effect of lists failed to reach significance ($F<1$) and the remaining results were similar to those obtained in the earlier analysis which had contained only groups as a between-subjects factor. There were main effects of lexicality ($F(1,36)=8.90$, $p<0.006$), segmentation ($F(1,36)=106.48$, $p<0.0005$) and position ($F(1,36)=8.99$, $p<0.006$), but not of groups ($F(1,36)=1.28$, $p>0.05$). As before, the only interaction to achieve significance was that of segmentation by position ($F(1,36)=70.56$, $p<0.0005$). Newman-Keuls tests revealed that the nature of this interaction was unchanged by the addition of lists as a between-subjects factor. The remaining interactions were all nonsignificant: groups by lists ($F<1$); groups by segmentation ($F(1,36)=2.06$, $p>0.05$); lists by segmentation ($F<1$); groups by lists by segmentation ($F(1,36)=1.92$, $p>0.05$); groups by lexicality ($F<1$); lists by lexicality ($F(1,36)=1.01$, $p>0.05$); groups by lists by lexicality ($F<1$); groups by position ($F<1$); lists by position ($F<1$); groups by lists by position ($F(1,36)=1.06$, $p>0.05$); segmentation by lexicality ($F(1,36)=2.68$, $p>0.05$); groups by segmentation by lexicality ($F<1$); lists by segmentation by lexicality ($F<1$); groups by lists by segmentation by lexicality ($F<1$); groups by segmentation by position ($F<1$); lists by segmentation by position ($F<1$); groups by lists by segmentation by position ($F<1$); lexicality by position ($F<1$); groups by lexicality by position ($F(1,36)=2.83$, $p>0.05$); lists by lexicality by position ($F(1,36)=3.58$, $p>0.05$); groups by lists by lexicality by position ($F<1$); segmentation by lexicality by position ($F(1,36)=1.32$, $p>0.05$); groups by segmentation by lexicality by position ($F<1$); lists by segmentation by lexicality by position ($F<1$); groups by lists by segmentation by lexicality by position ($F<1$).

APPENDIX 12

COLOURED LEXICAL DECISION TASK: ***Mean Miss and False Alarm Rates***

READING GROUP*	MISS RATE				FALSE ALARM RATE			
	ONSET-RIME		POST-VOWEL		ONSET-RIME		POST-VOWEL	
	BEGINNING BLEND	END BLEND	BEGINNING BLEND	END BLEND	BEGINNING BLEND	END BLEND	BEGINNING BLEND	END BLEND
READING AGE CONTROLS	.226	.168	.211	.179	.268	.200	.205	.137
DEVELOPMENTAL DYSLEXICS	.226	.237	.263	.290	.332	.242	.321	.211

* n=19 in both reading groups

APPENDIX 13

PHONOLOGICAL DECISION TASK: ***Mean Miss and False Alarm Rates***

READING GROUP	MISS RATE	FALSE ALARM RATE
READING AGE CONTROLS	.253	.386
DEVELOPMENTAL DYSLEXICS	.222	.408