A NEUROCOGNITIVE INVESTIGATION OF
PHONOLOGICAL PROCESSING IN DYSLEXIA

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ABSTRACT

This thesis firstly reviews the nature of the phonological deficit in developmental dyslexia. An established hypothesis is that the phonological representations are inadequately specified in dyslexia. Another perspective, considered in this thesis, is that inefficiency in resolving phonological competition compromises the functional availability of phonological information. The neural basis of the phonological deficit is also examined, particularly in relation to the left posterior inferior temporal lobe (BA37) and the left angular gyrus.

Six experiments – four behavioural and two neuroimaging – were carried out, with adult developmental dyslexics, and controls matched for age and performance IQ. In Experiment 1, word-reading and picture-naming speed and accuracy were investigated in a single trial format. In Experiment 2, phonological neighbourhood density was manipulated in a continuous naming format. Dyslexic participants were differentially impaired by those factors that increased the level of phonological competition – the presence of orthography, the rate of presentation, and phonological neighbourhood density. These results supported the phonological competition hypothesis. Experiment 3 investigated the neural basis of these impairments during reading and naming. Dyslexic participants showed reduced activation in left BA37 during both tasks. This indicated a general impairment in phonological retrieval, independent of orthographic decoding. Experiment 4 aimed to establish whether similar regions would show abnormal activation during auditory word repetition. In fact, dyslexic participants showed reduced activation in the right hemisphere, particularly the anterior superior temporal lobe (BA22). This was attributed to an attentional bias in the dyslexic group towards phonological aspects of the auditory input. Experiment 5 demonstrated an effect of length in a phonological awareness task. Experiment 6 established that the phonological deficit can have a general impact, influencing performance in tasks that are ostensibly non-verbal.

In the light of these findings, the nature of the phonological deficit in dyslexia is re-evaluated and suggestions for further research are discussed.
# TABLE OF CONTENTS

## INTRODUCTION

1.1. **The Definition of Dyslexia** .................................................................................................................................................. 12
1.2. **Aims of the Thesis** ........................................................................................................................................................................... 15
1.3. **Overview** .................................................................................................................................................................................. 17

## PHONOLOGICAL PROCESSING

**Part I: Characterising the Phonological Deficit at the Cognitive Level**

2.1. **Introduction** ........................................................................................................................................................................... 19
2.2. **The Phonological Deficit in Dyslexia: A Representational Impairment?** ................................................................. 20
2.3. **The Phonological Deficit in Dyslexia: A Competition Account** ........................................................................................ 25
    - Phonological access ........................................................................................................................................................................ 25
    - Phonological competition .................................................................................................................................................................. 27
    - (i) Reading ............................................................................................................................................................................... 27
    - (ii) Picture naming ................................................................................................................................................................ 30
    - (iii) Tasks of phonological awareness .................................................................................................................................. 39
2.4. **The Role of Inhibition in the Competition Account** ........................................................................................................... 41
2.5. **Conclusions** ............................................................................................................................................................................. 43

**Part II: Characterising the Phonological Deficit at the Behavioural Level**

2.7. **Tasks of Phonological Repetition** ................................................................................................................................. 45
2.8. **Confrontation Naming** ............................................................................................................................................................ 46
2.9. **Picture Naming: Rapid Automatic Naming (RAN)** ........................................................................................................ 52
2.10. **Picture Naming: Formats Compared** ............................................................................................................................ 53
2.11. **The Spoonerism Task** ............................................................................................................................................................. 56
2.12. **Conclusions** ............................................................................................................................................................................ 57
DISORDERED PHONOLOGICAL PROCESSING
EVIDENCE FROM FUNCTIONAL NEUROIMAGING

3.1. INTRODUCTION .................................................................................................................... 60
3.2. EARLY STUDIES.................................................................................................................. 60
3.3. EVIDENCE IMPLICATING THE LEFT ANGULAR GYRUS (BA39)........................................ 63
3.4. EVIDENCE IMPLICATING THE LEFT POSTERIOR INFERIOR TEMPORAL LOBE (BA37) .... 74
3.5. EVIDENCE IMPLICATING THE LEFT HEMISPHERE FRONTAL REGIONS............................ 76
3.6. EVIDENCE FOR RIGHT HEMISPHERE DYSFUNCTION..................................................... 77
3.7. OUTSTANDING QUESTIONS .............................................................................................. 78

AN INVESTIGATION OF PHONOLOGICAL RETRIEVAL EFFICIENCY
EXPERIMENT 1: THE EFFECT OF WORD LENGTH AND FREQUENCY ON
PICTURE NAMING AND WORD READING

METHOD ............................................................................................................................................ 84
Participants..................................................................................................................................... 84
Visual and Semantic decision tasks
Materials ........................................................................................................................................... 85
Procedure ....................................................................................................................................... 85
Picture naming and word reading tasks
Materials........................................................................................................................................... 86
Procedure ....................................................................................................................................... 88
RESULTS........................................................................................................................................ 89
Semantic and Visual decision tasks............................................................................................ 89
Reading and Naming: Combined analysis.................................................................................. 90
Reading ........................................................................................................................................... 90
Picture Naming............................................................................................................................. 91
Error analysis............................................................................................................................... 94
DISCUSSION .................................................................................................................................. 95
# Experiment 2: The Effect of Phonological Neighbourhood during a Task of Rapid Automatic Naming

## Introduction

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>100</td>
</tr>
<tr>
<td>Participants</td>
<td>100</td>
</tr>
<tr>
<td>Procedure</td>
<td>100</td>
</tr>
<tr>
<td>Results</td>
<td>101</td>
</tr>
<tr>
<td>Discussion</td>
<td>102</td>
</tr>
</tbody>
</table>

## Method

1. **Participants**
2. **Materials**
3. **Procedure**

## Results

## Discussion

# A PET Investigation of Phonological Retrieval

## Experiment 3: A PET Study of Picture Naming and Word Reading

## Introduction

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>111</td>
</tr>
<tr>
<td>Participants</td>
<td>111</td>
</tr>
<tr>
<td>Background measures</td>
<td>111</td>
</tr>
<tr>
<td>Stimuli</td>
<td>113</td>
</tr>
<tr>
<td>Activation tasks</td>
<td>113</td>
</tr>
<tr>
<td>PET scanning procedure</td>
<td>114</td>
</tr>
<tr>
<td>Data analysis</td>
<td>114</td>
</tr>
<tr>
<td>Behavioural data</td>
<td>114</td>
</tr>
<tr>
<td>PET data</td>
<td>114</td>
</tr>
<tr>
<td>Results</td>
<td>115</td>
</tr>
<tr>
<td>Background measures</td>
<td>115</td>
</tr>
<tr>
<td>Behavioural measures during PET</td>
<td>116</td>
</tr>
<tr>
<td>PET results: Naming</td>
<td>117</td>
</tr>
<tr>
<td>PET results: Reading</td>
<td>118</td>
</tr>
<tr>
<td>Regions showing interactions of task with group</td>
<td>119</td>
</tr>
<tr>
<td>Discussion</td>
<td>119</td>
</tr>
</tbody>
</table>
A PET STUDY OF PHONOLOGICAL REPETITION

EXPERIMENT 4: ABNORMAL FUNCTIONAL ACTIVATION DURING A SIMPLE WORD REPETITION TASK

INTRODUCTION .................................................................................................................................................. 124
METHOD................................................................................................................................................................... 126
   Participants ................................................................................................................................... 126
   Background measures ............................................................................................................................ 127
   Activation tasks ................................................................................................................................. 127
   PET scanning procedure .............................................................................................................. 128
DATA ANALYSIS............................................................................................................................................................................... 128
   Behavioural data .......................................................................................................................... 128
   PET data ........................................................................................................................................ 129
RESULTS................................................................................................................................................................................. 129
   Background Measures ................................................................................................................. 129
   Behavioural measures during PET ............................................................................................. 131
   PET results .................................................................................................................................. 132
DISCUSSION .................................................................................................................................................. 134

EXPLORING THE PHONOLOGICAL AWARENESS DEFICIT

EXPERIMENT 5: A DISCRETE TRIAL SPOONERISM TASK

INTRODUCTION ........................................................................................................................................... 140
   Predictions ................................................................................................................................. 145
METHOD............................................................................................................................................................. 146
   Participants ................................................................................................................................... 146
   Stimuli and Apparatus ................................................................................................................. 146
   Procedure ...................................................................................................................................... 149
RESULTS ................................................................................................................................................. 150
DISCUSSION ........................................................................................................................................... 153
THE IMPORTANCE OF BEING VERBAL

AN INVESTIGATION OF PHONOLOGICAL PROCESSING IN A NON-LANGUAGE TASK

INTRODUCTION............................................................................................................................................. 156

EXPERIMENT 6A: TARGET SWITCHING WITH NAMEABLE STIMULI

METHOD......................................................................................................................................................... 160
Participants ................................................................................................................................160
Design .........................................................................................................................................160
Stimuli and Apparatus .............................................................................................................. 162
Procedure ...................................................................................................................................163
RESULTS....................................................................................................................................................... 165
DISCUSSION ................................................................................................................................................ 167

EXPERIMENT 6B: TARGET SWITCHING WITH ABSTRACT STIMULI

METHOD...........................................................................................................................................................................................168
RESULTS...........................................................................................................................................................................................169
DISCUSSION ....................................................................................................................................................................................170
GENERAL DISCUSSION............................................................................................................................................................ 171

OVERVIEW AND FUTURE DIRECTIONS

9.1 INTRODUCTION ......................................................................................................................................... 175
9.2 AN OVERVIEW OF THE EVIDENCE............................................................................................................. 175
9.3 RETHINKING THE PHONOLOGICAL DEFICIT IN DYSLEXIA........................................................................ 179
9.4 LIMITATIONS.............................................................................................................................................. 182
9.5 FUTURE DIRECTIONS.................................................................................................................................... 184
Developing the process account.............................................................................................................. 184
Generalised effects of the phonological deficit....................................................................................... 186
Future imaging investigations................................................................................................................ 187
9.6 CONCLUDING REMARKS .......................................................................................................................... 189

BIBLIOGRAPHY ........................................................................................................................................... 190

APPENDIX.......................................................................................................................................................... 214
LIST OF TABLES

**TABLE 4.1.** Behavioural profile of participants, Experiments 1 and 2

**TABLE 4.2.** Stimuli used in the word reading and picture naming tasks

**TABLE 4.3.** Characteristics of the stimuli used in Experiment 1

**TABLE 4.4.** Task performance of the dyslexic and control groups in Experiment 1:

- Reading, naming, semantic and visual decision

**TABLE 4.5.** Mean percentage of coded errors on the Picture Naming task

**TABLE 4.6.** RAN task performance across control and dyslexic groups: speed to name

- 50 items from dense vs. sparse phonological neighbourhoods

**TABLE 5.1.** Behavioural profile of participants, Experiment 3

**TABLE 5.2.** Behavioural measures during PET scanning: accuracy and latency of response in the word reading and picture naming conditions

**TABLE 5.3.** Brain areas activated during reading and naming in the dyslexic and control groups. Groups differences also indicated

**TABLE 6.1.** Participant characteristics, Experiment 4: reading abilities

**TABLE 6.2.** Participant characteristics, Experiment 4: phonological abilities

**TABLE 6.3.** Areas of greater activation in the control relative to the dyslexic

- Group for words and pseudowords combined, relative to rest

**TABLE 6.4.** Studies showing activation and deactivation of the right anterior superior temporal gyrus

**TABLE 7.1.** Behavioural profile of participants, including subtest scores, Experiment 5

**TABLE 7.2.** Long and short spoonerism pairs with associated correct responses

**TABLE 7.3.** Mean percentage error in the control and dyslexic groups for short and long spoonerism pairs

**TABLE 7.4.** Mean response times (msec) for the control and dyslexic for short and long spoonerism pairs

**TABLE 8.1.** Behavioural profile of participants, Experiment 6

**TABLE 8.2.** Task switching performance with nameable objects, Experiment 6A:

- Accuracy, latency of response and number of false positives in the dyslexic and control groups

**TABLE 8.3.** Task switching performance with nonsense shapes, Experiment 6B:

- Accuracy, latency of response and number of false positives produced by the dyslexic and control groups

---

9
LIST OF FIGURES

FIGURE 1.1. A CAUSAL MODELLING DIAGRAM APPLIED TO DYSLEXIA ................................................. 13
FIGURE 2.1. SCHEMATIC INFORMATION PROCESSING MODEL OF LANGUAGE PROCESSING .................. 21
FIGURE 2.2. SCHEMATIC OF PHONOLOGICAL COMPETITION DURING READING ............................. 28
FIGURE 2.3. LEXICAL HYPOTHESIS MODEL OF WORD READING AND PICTURE NAMING, AS POSTULATED BY GLASER & GLASER (1989) ................................................................. 31
FIGURE 2.4. CONTRASTING THE PATHWAY FROM THE PERCEPT IN THE TASK OF READING ALOUD WITH THE PATHWAY OF THE PICTURE NAMING TASK.............................................. 32
FIGURE 2.5. CONTRASTING THE PATHWAY IN THE PICTURE CATEGORISATION TASK WITH THE PATHWAY IN THE WORD CATEGORISING TASK ....................................................... 33
FIGURE 2.6. A SIMPLIFIED DEPICTION OF A DISCRETE TWO-STAGE MODEL OF LEXICAL RETRIEVAL. 34
FIGURE 2.7. A SIMPLIFIED DEPICTION OF AN INTERACTIVE ACTIVATION MODEL OF LEXICAL RETRIEVAL ................................................................................................................ 35
FIGURE 2.8. PHONOLOGICAL COMPETITION IN NAMING A PICTURE THAT IS POORLY SPECIFIED AT THE SEMANTIC LEVEL ..................................................................................................... 37
FIGURE 2.9. PHONOLOGICAL COMPETITION IN NAMING A PICTURE THAT IS WELL SPECIFIED AT THE SEMANTIC LEVEL ..................................................................................................... 37
FIGURE 4.1. WORD READING LATENCIES (MSEC) FOR DYSLEXIC AND CONTROL PARTICIPANTS AS A FUNCTION OF WORD LENGTH AND WORD FREQUENCY ........................................ 93
FIGURE 4.2. PICTURE NAMING LATENCIES (MSEC) FOR DYSLEXIC AND CONTROL PARTICIPANTS AS A FUNCTION OF WORD LENGTH AND WORD FREQUENCY ........................................ 93
FIGURE 4.3. CONTRASTING A WORD FROM A DENSE PHONOLOGICAL NEIGHBOURHOOD WITH A WORD FROM A SPARSE PHONOLOGICAL NEIGHBOURHOOD ................................................ 98
FIGURE 4.4. GRAPH DEPICTING THE RAN TASK TIME IN SECONDS FOR THE CONTROL AND DYSLEXIC GROUPS AS A FUNCTION PHONOLOGICAL NEIGHBOURHOOD DENSITY .............. 101
FIGURE 5.1. COGNITIVE MODEL OF THE PROCESSING COMPONENTS INVOLVED IN READING AND PICTURE NAMING ........................................................................................................ 107
FIGURE 5.2. EXAMPLES OF STIMULI USED IN EXPERIMENT 3: I. WORDS; II. FALSEFONT; III. PICTURES; IV NONSENSE SHAPES ........................................................................................................... 111
FIGURE 5.3. REGION OF GREATER ACTIVATION IN THE CONTROL GROUP IN THE POSTERIOR TEMPORAL LOBE (BA37) DURING NAMING AND READING ............................................. 118
FIGURE 6.1. COMMON ACTIVATION FOR DYSLEXIC AND CONTROL GROUPS: WORDS & PSEUDOS – REST .......................................................................................................................... 132
FIGURE 6.2. CONSISTENT ACTIVATION ACROSS DYSLEXIC AND CONTROL SUBJECTS: WORDS – REST. INDIVIDUAL CONJUNCTURE ANALYSIS ........................................................................ 133
FIGURE 6.3. GREATER ACTIVATION FOR CONTROL RELATIVE TO DYSLEXIC GROUP: WORDS & PSEUDOWORDS-REST. RANDOM EFFECTS MODEL ............................................................................................................. 133
**Figure 6.4.** The area of the right anterior superior temporal lobe (52, -8, 8) identified by an individual conjunction analysis as consistently more active in the control group relative to each dyslexic subject ..................................................... 134

**Figure 7.1.** Mean percentage error for the control and dyslexic groups in the spoonerism task for both the short and long word conditions ............... 150

**Figure 7.2.** Latency of response (msec) for the control and dyslexic groups in the spoonerism task for both the short and long word conditions .......... 151

**Figure 7.3.** Latency of response (msec) for the control and dyslexic groups in the spoonerism task with the shorter set of two-syllable words and the longer set of two syllable words ................................................................. 151

**Figure 8.1.** Schematic drawing of the shift-attention task, with Harp and Shoe as the target pictures, and nonsense shape distracters.......................... 162

**Figure 8.2.** Nameable target stimuli (real objects) varying along both visual and phonological dimensions used in Experiment 6A ........................................ 163

**Figure 8.3.** Nonsense shape distracter stimuli used in experiments 6A & 6B .......... 163

**Figure 8.4.** Latency of response (msec) across dyslexic and control groups showing the effect of phonological similarity ........................................ 166

**Figure 8.5.** Mean number of false positive responses across dyslexic and control groups target switching with nameable objects .......................... 167

**Figure 8.6.** Abstract shape stimuli used in experiment 6B ................................ 169

**Figure 8.7.** Mean number of false positive responses across dyslexic and control groups target switching with abstract shapes ........................... 170
INTRODUCTION

1.1. The Definition of Dyslexia

Traditionally developmental dyslexia has been defined as a specific impairment in learning to read despite average, or above average, intelligence, educational opportunity, conventional instruction and the absence of sensory impairment (Critchley, 1970). Although this behavioural definition has enjoyed widespread usage it is extremely limited: it is a definition by exclusion that fails to provide a positive characterisation of dyslexia. That is, it fails to specify the neuro-physiological and cognitive mechanisms that underlie the symptomatic reading problems in dyslexics. This definition, nevertheless, succeeds in capturing the inherently perplexing nature of the disorder: why should some children experience such extraordinary difficulty in learning to read when, in other respects, their development is perfectly normal?

Doctors, educationalists and researchers have been addressing this controversial question for over a century, since the first case study of a 14-year old dyslexic child was described by Pringle-Morgan (Pringle-Morgan, 1896). The burgeoning literature on dyslexia over recent years has failed to neutralise this controversy; in fact, if anything, the debate regarding the nature of dyslexia is more impassioned than ever. Some consensus has emerged, however, regarding the limitation inherent in a purely behavioural definition (Siegel, 1992). Such a definition is based on the concept of a discrepancy between observed reading ability and what would be expected on the basis of IQ. There are several problems with this approach. For example, we do not as yet fully understand the causal basis of the correlation between IQ and reading which is in fact only moderate to low even in the normal population (Stanovich, 1986). In addition, the implication of this definition is that remediation, which improves the individual's reading skill, can cure dyslexia. Unfortunately, however, a vast amount of evidence indicates that the impairments experienced by dyslexics in childhood persist into adulthood despite compensation (e.g. Bruck, 1992; Elbro, Nielsen and Petersen,
1994). Like the definition proposed by Critchely, (1970) the discrepancy definition fails to tell us what dyslexia actually is.

One recent approach to these limitations has been to consider dyslexia within the framework of a causal model (Morton and Frith, 1995). Within such a model, causal links between the biological, cognitive and behavioural levels are made explicit, along with their interactions with a variety of environmental factors (Frith, 1997; see Figure 1.1). Within this framework a clear distinction is made between the behavioural and the cognitive level. As shown in Figure 1.1 a single deficit at the cognitive level may give rise to a set of behavioural impairments. Critically, however, the manifestation of these impairments does not necessarily imply the existence of that cognitive deficit. In other words a poor score on a given test is not conflated with an inferred underlying ability – it merely acts as a pointer. Its power to inform is entirely contingent on our understanding of the cognitive components entailed in a given task, and of the other factors whether cognitive (e.g. attentional) or environmental (e.g. remedial teaching) that may influence performance. Furthermore, the behavioural pattern of impairment in the dyslexic individual will vary with age, as development and cognition interact.

Cognitive dysfunction is in turn underpinned by dysfunction at the biological level. From the beginning of the last century evidence for a familial recurrence of dyslexia has been documented in case reports, an observation not formally investigated until Hallgren (1950) carried out the first genetic epidemiological study of dyslexia.
Modern twin studies have provided evidence that such familiality is in fact substantially genetic (see DeFries, Alarcon, and Olson, 1997 for a review) with linkage studies now identifying those regions whose genes influence both normal reading and dyslexia (Gilger, Borecki, DeFries and Pennington, 1994). At the neuroanatomical level, there is evidence of abnormalities in both the structure (Galaburda, Menard, and Rosen, 1994) and activity (e.g. Rumsey, Andreason, Zametkin, Aquino, King, Hamburger, Pikus, Rapoport, and Cohen, 1992; Brunswick, McCrory, Price, Frith, and Frith, 1999; see Chapter 3) of brain regions associated with language function. The causal pathway from biology, through cognition to behaviour is influenced at all stages by environmental factors. These range from prenatal influences, to later influences in diet and quality of teaching. Only recently has the influence of the orthography been recognised as a key environmental factor in the manifestation of dyslexia (Landerl, Wimmer and Frith, 1997; Paulesu, Demonet, Fazio, McCrory, Chanoine, Brunswick, Cappa, Cossu, Habib, Frith, and Frith, 2001).

The challenge of the cognitive-developmental approach is to characterise the biological and cognitive basis of the disorder within a single explanatory framework, that takes into account such environmental influences, in order to explain the range of behavioural impairments associated with dyslexia.

In the experiments presented in this thesis, a theoretically neutral definition was adopted for the purposes of recruitment. All dyslexic participants were university students and as such were invariably well motivated, bright and unlikely to be characterised by sensory, motor or emotional impairments. In addition they had all received a recognised diagnosis from an appropriately qualified psychologist or educational psychologist. Given that these assessments were carried out over a large geographical area (participants originated from all parts of the UK) and over many years (some participants had been diagnosed in early childhood while others only in late adolescence) it is likely that a diverse set of empirical and theoretical criteria were employed. A discrepant performance between intelligence and achievement most likely represented a cornerstone of many of these assessments. The limitations of the discrepancy definition, however, were balanced with three advantages of recruiting in this way. Firstly, the difficulties associated with a discrepancy definition are somewhat less relevant to a university population where high performance abilities provide a reliable contrast with literacy skill. Secondly, it was felt important to assess a
representative sample of ‘dyslexic’ individuals who are recognised in the broader population by current practitioners. Thirdly, this approach provided the opportunity to establish whether these individuals, regardless of their different experiences of assessment, were characterised by a common cognitive profile. In particular, whether they all shared a common difficulty in phonological processing. The phonological deficit contends that dyslexic individuals are characterised by a core deficit in processing the speech — or phonological — structure of words (Stanovich, 1986; Snowling, 2000). Such a deficit affects not only the acquisition and development of reading, but performance on a range of tasks that extend beyond literacy, including verbal short term memory (Nelson and Warrington, 1980), picture naming (Denckla and Rudel, 1976a; Katz 1986) and verbal repetition (Snowling, 1981). Each of these findings has been replicated; Snowling (2000) has recently reviewed this work. The core role of the phonological deficit in dyslexia is not disputed even by those researchers who postulate more general problems in dyslexia at the perceptual level in auditory (Tallal, 1980) or visual (Stein and Walsh, 1997) processing, or at a more general level in automatisation (Nicolson and Fawcett, 1990). What characterises each of these accounts is the suggestion that the phonological processing deficit is itself only a secondary or tertiary consequence of another more general impairment. The failure to specify in any detail how such an impairment might ultimately lead to poor literacy has led to the criticism that these accounts, while drawing attention to problems that affect some individuals with dyslexia, fail to provide any reasoned account of the phonological processing impairment per se (Hogben, 1997).

1.2. Aims of the thesis

The aims of this thesis were to further characterise the nature of the phonological deficit in dyslexic adults at the (i) behavioural (ii) cognitive and (iii) neurofunctional levels. The first aim was to assess more accurately the behavioural performance of dyslexic individuals. In order to achieve this aim speed of response was routinely employed as a dependent variable. In Experiment 1, for example, both the accuracy and speed of word reading and picture naming are assessed. While developmental studies of picture naming report reliable picture naming deficits in dyslexic children, studies of adult dyslexics have reported intact performance under standard conditions (Snowling, van Wantendong and Stafford, 1988; Felton, Naylor and Wood, 1990).
Given that adult dyslexics are known to be slower in word reading even when reading accurately (Brunswick, McCrory, Price, Frith and Frith, 1999) it is possible that a similar pattern characterises picture naming performance. Similarly, in Experiment 7, speed of response on a spoonerism task (a standard task of phonological awareness) was measured. Normally the time to perform the entire task is taken as a dependent variable (e.g. Brunswick et al., 1999); here, however, performance latency was measured for each individual trial.

The second aim of the thesis was to critically evaluate our understanding of the phonological deficit at the cognitive level. This aim was motivated by the somewhat surprising dearth of theoretical specification as to how the phonological impairment should be characterised at the cognitive level. Katz (1986) outlined two possible forms that such specification might take: either the phonological representations themselves were impaired in some way, or alternatively, the processes that act upon those representations were in some way compromised. Even today Katz treads a neutral line between these two possibilities referring to the phonological deficit as “underlying phonological deficiencies” (Katz, 1996). Those researchers who have chosen to place a differential emphasis on these possibilities have come down in favour of an account that postulates an impairment in phonological representation. Snowling and Hulme (1994), for example, hypothesize that dyslexic children have ‘poorly specified’ phonological representations that preclude the efficient mapping of orthography and the sound of spoken words. In addition, they argue that such poor quality representations impede normal performance on the range of other tasks associated with dyslexia, such as verbal memory and tasks of phonological awareness. This representational account of the phonological deficit now represents an uncontroversial framework within which to consider the phonological processing deficits of dyslexic children and adults (Liberman, 1998; Snowling, 2000; Swan and Goswami, 1997b).

Yet, as outlined in Chapter 2, this position is not only under-specified but fails to account for a number of observations commonly reported in the literature. An alternative perspective of the phonological deficit is developed in this thesis which views phonological representations within a process-based framework. This account, termed the phonological competition hypothesis, proposes that the phonological deficit relates specifically to an impairment in resolving phonological competition—that is, the simultaneous activation of more than one phonological form. It is suggested
that those factors that increase the level of such competition differentially impair the dyslexic individual. Such competition may serve to impair word retrieval (Experiments 1, 2 and 3) as well as impair phonological manipulation (Experiment 5). In addition, the possibility that such an impairment may affect verbal mediation of ‘non-verbal’ tasks, is explored in Chapter 6.

The third aim of this thesis is to characterise at the neural level these putative cognitive impairments. In view of the relatively recent advent of functional neuroimaging, we are still only at an early stage in understanding the complex interaction of those brain areas that underpin normal language function. Price (2000) provides us with a comprehensive review for the normal population. In the field of dyslexia a number of studies have reliably implicated the left posterior temporal-parietal region (see Chapter 3). Dyslexic participants show reduced activation within this region during tasks which entail phonological retrieval (such as reading) or phonological processing more generally (e.g. rhyme judgement). One limitation in the majority of such studies to date is that they have focused primarily on tasks that employ orthographic stimuli. Yet the neurofunctional differences in brain activation of dyslexic individuals have been taken as empirical support of a general deficit in phonological processing. In this thesis two paradigms are developed to address this limitation, one requiring participants to name pictures, and the other requiring participants to repeat words aloud. The first, reported in Experiment 3, explores the phonological retrieval deficit in the absence of orthographic input to establish whether a common neural locus underpins dyslexics’ known retrieval impairments in reading and naming. The second, reported in Experiment 4, investigates whether similar findings would be obtained in a task of auditory word repetition, which does not entail visual processing. Both these studies allow the investigation of phonological processing efficiency in the absence of orthographic processing demands.

1.3. Overview

In summary, two core objectives underpin the work in this thesis: The first is to narrow down what is meant by the phonological deficit in dyslexia; and the second is to further establish the neural basis of this putative cognitive deficit.
Currently the phonological deficit is widely characterised as an inadequacy of phonological representation. According to this account, dyslexics fail to restructure phonological representations from a global to a segmental organisation and this leads to an impairment in mapping between orthography to phonology. A given lexical item, for example, that is not fully segmented will be poorly accessed during naming or during a task of phonological awareness (e.g. Swan and Goswami, 1997b). An alternative perspective is developed in this thesis: the phonological competition hypothesis. According to this position, phonological representation and access are viewed within a more dynamic context. The phonological representations themselves are taken as fully specified at the informational level; it is the functional access to the lexical or sublexical elements which is compromised. It is hypothesised that this functional access is impaired because dyslexic individuals have a difficulty in resolving phonological competition. That is, they have difficulty in selecting one phonological code from a set of simultaneously activated phonological codes. Importantly, the level of competition can vary for the same lexical item – for example, if the rate of access is increased.

With regard to the neural basis of the phonological deficit the experiments in this thesis aimed to overcome two limitations that have often characterised functional imaging studies in dyslexia: (i) a failure to match behavioural performance across the dyslexic and control groups; (ii) the use of orthographic stimuli to index phonological processing. The use of non-orthographic tasks that can be performed normally by dyslexic participants reduces the possibility that behavioural confounds in performance might underlie observed differences in neural activation. In addition, by going beyond tasks of reading, the investigation of phonological processing is extended to encompass the broader language system. These investigations are carried out in the context of an existing literature based on the normal population. This literature provides the framework to evaluate and interpret the commonalities and differences in neural activation observed in the dyslexic participants.
2 PHONOLOGICAL PROCESSING

Part I: Characterising the phonological deficit at the cognitive level

2.1. Introduction

'Phonological processing' is a term of considerable remit. It covers the interests of developmental psychologists in assessing early speech processing and literacy acquisition, the interests of cognitive psychologists in modelling adult language processing, and the interests of phonologists who consider phonotactic regularities, suprasegmental structure, stress and rhythm. This breadth of compass has provided the context in which a consensus has arisen regarding a core deficit in phonological processing in dyslexia (Stanovich, 1986; Snowling, 2000). While explanatory models from these domains have been useful in establishing the general presence of a phonological impairment in dyslexia, they have contributed somewhat sparingly to a specific cognitive characterisation of what the phonological deficit in dyslexia actually represents. At its most general level phonological processing refers to the sound structure of spoken words. In dyslexia, the considerable empirical support for a phonological deficit is most commonly accounted for within a general explanatory framework that refers to the quality of phonological representation. It is postulated that over development dyslexic individuals fail to attain fully specified phonological representations. Not only are these poor quality representations more difficult to retrieve, they are mapped with limited success onto orthographic representations during reading acquisition. This chapter will first focus on the nature of this account, termed here the phonological representation hypothesis. This will be followed by a description of an alternative characterisation of the phonological deficit in dyslexia: the phonological competition hypothesis. According to this perspective, representations are not viewed as fixed entities. Rather, the dynamic processes of retrieval are seen as integral to the representation of any given phonological form. Specifically, it is suggested that the phonological processes, necessary to resolve phonological competition during retrieval, are impaired in dyslexia. Arguably, this
perspective fits more naturally into current models of language processing and provides a more parsimonious account of the nature of the phonological deficit in dyslexia.

After this theoretical discussion, the second half of the chapter reviews the empirical evidence for a phonological processing impairment in dyslexia. In particular, evidence for impairments in picture naming, phonological repetition and phonological awareness are reviewed. These paradigms are investigated in later experimental chapters.

2.2. The phonological deficit in dyslexia: a representational impairment?

A broad consensus has emerged within the field of dyslexia that the verbal deficit in dyslexia arises at the phonological level. This is illustrated in Figure 2.1, which presents a standard schematic information processing model of language processing. Here the primary locus of impairment falls at the phonological level (as indicated by the shaded area). If orthographic or semantic processes are affected then these are taken to be secondary to the disordered processing within the phonological system (Snowling, 2000). The robust behavioural evidence for a phonological deficit in dyslexia (reviewed later in this chapter) has been accompanied by several suggestions as to how this deficit might best be characterised at the cognitive level. Katz (1986), an early proponent of a phonological deficiencies hypothesis, outlined two broad positions. According to the first, the difficulty shown by dyslexics in phonological processing arises from an impairment in phonological representation while according to the second, such difficulty was attributable to an impairment in the processes which acted on those representations. Researchers have largely favoured the former position – that is a representational framework within which to characterise the phonological deficit. For example, Snowling and Hulme (1989), Hulme and Snowling (1992), McDougall, Hulme, Monk and Ellis (1994) and Swan and Goswami (1997a and 1997b) among others have suggested that it is the accuracy of the underlying phonological representations of words that are compromised. The manner in which the representations are poorly specified is variously defined; yet these definitions themselves are characterised by a lack of specification. According to one more detailed account, the poor specification reflects a failure of the phonological representation...
representations to properly undergo the normal developmental progression from an holistic state to one of segmental organisation. Fowler (1991), for example, explores this possibility in relation to tasks of phonological awareness. She argues that the development of phonological awareness in normal children (that is the ability to access and manipulate sublexical phonological segments) reflects a fundamental change in the specification and segmental organisation of the phonological lexicon. Similarly Walley (1993) suggests that during development lexical items are gradually restructured, and specified within a segmental organisation that progresses from the level of the syllable, to level of onsets and rimes, and finally to the level of the phoneme. Within this context Fowler (1991) was one of the first to suggest that the phonological difficulties of dyslexic individuals may arise because they fail to effect

Figure 2.1 Schematic information processing model of language processing. The shaded area indicates the domain of phonological processing and representation, postulated to be impaired in dyslexia.

21
such a reorganisation and as a consequence develop phonological representations that are comparatively poorly specified.

Swan and Goswami (1997b) investigated the suggestion that phonological analysis skills in dyslexic readers depend on the underlying representations of the words. Phonological segmentation ability at several sublexical levels was assessed. Words were first classified as having either accurate or inaccurate phonological representations on the basis of picture naming performance: if a picture name could be retrieved then it was predicted that its corresponding phonological representation was adequately specified. This prediction was partly supported: names that were correctly retrieved could be successfully segmented at the syllable, onset and rime levels, but a phonemic level of analysis was still impaired. It was concluded that while an individual with dyslexia may develop more fully specified lexical entries, weaknesses in phonemic representation persist. In particular longer lower frequency words are least likely to be fully specified. This view was supported in a separate study by the same authors (Swan and Goswami, 1997a), and in an earlier study of picture naming by Katz (1986).

Tasks of phonological awareness have been a popular and effective means to assess the phonological skills of normal and impaired readers. Treiman and Zukowski (1991) comment that such tasks allow the investigation of “...the effects of linguistic level on the availability of sublexical units to overt analysis” (p. 68; italics added). They present highly convincing evidence for a developmental improvement in conscious access to increasingly finer-grained phonological units. Yet such an improvement is properly considered by the authors within a theoretically neutral framework. No undue emphasis is given either to the underlying integrity of the phonological forms nor to the processes of phonological access. In contrast, within the domain of dyslexia research, the temptation has been to equate the salient difficulty in word segmentation ability with a concomitant lack of segmentation in the underlying phonological representations themselves. It is arguable that such a position simply conflates behavioural and cognitive levels of analysis. While poor phonological awareness performance in the dyslexic may arise from poorly specified or segmented phonological representations this is by no means a necessary inference: the representations may be pristine in their degree of information specification – the
problem may lie in the functional access or manipulation of that information. For example in a strong form of their position, Swan and Goswami argue that “...the phonological skills of dyslexic children depend on the accuracy of the underlying phonological representations of words and on the segmental organization of those representations...” (Swan and Goswami, 1997b; p.21, their italics). Similarly Snowling concludes that the observed impairments in dyslexia “can be united under the hypothesis that dyslexic readers have deficits at the level of underlying phonological representations. Put simply, the way in which the dyslexic person encodes phonology is different from that of the normal reader” (Snowling, 2000, p.60). In both cases, the possibility that dyslexic children may have perfectly well-specified phonological forms but poor functional access to those forms is, by implication, discounted.

There is little doubt that across development and with the influence of literacy (e.g. Morais, 1987) children gain more fluent access to individual word segments. The question which faces us as psychologists is how that change might best be accounted for at the cognitive level. The attraction of a representational account arises from its intuitive appeal, from its resonance with behavioural tasks of phonological awareness, and from its concurrence with theories of normal linguistic development. According to an alternative characterisation, however, the phonological representations of dyslexic individuals are fully specified. It is not that the phonological representations are degraded, but rather it is the functional engagement of the phonological code that is compromised. In this context representations are not viewed as static entities but dynamic states of informational representation. This definition is explored in the next section.

A number of established findings sit very uncomfortably with the representational account. Three such findings, specifically related to naming will be considered here. According to a representational account, during development, phonological representations will tend to become increasingly specified and differentiated (Swan and Goswami, 1997a). Those words which are short and of high frequency are most likely to become accurately specified at the phonological level given their high degree of exposure. In contrast longer lower frequency words are least likely to achieve normal specification. For example, Swan and Goswami (1997a) have shown that in a
task of confrontational naming, dyslexic children made more errors in naming pictures with long infrequent words than short high frequency words. One would predict, therefore, that by adulthood normal naming performance would be attained on tasks where the items to be named are both short and of high frequency. Digits represent such a set of highly familiar over-learned items. Yet on tasks of rapid naming, where a series of single digits have to be named, adult dyslexics are strikingly impaired (e.g. Felton et al., 1990); this is the case even for dyslexic students at university level matched with their peers both for verbal and performance IQ (Brunswick et al., 1999). According to the representational account such items should, over years of regular use, have become fully specified and easily accessed.

A second prediction that follows from a representational account is that a poorly specified phonological item should be inefficiently accessed or manipulated irrespective of the task. For example, if the phonological form of the word ‘apple’ is inadequately specified, then retrieving this item in a task of reading or naming should be impaired. This is likely since a common representation -- which is degraded -- is accessed in both instances. Yet it has been reported that dyslexic adults manifest normal confrontation picture naming ability, for example, in the context of continuing difficulties in reading (e.g. Hanley, 1997; Felton et al., 1990). While it may be the case that reading and naming index the underlying quality of representation to differing degrees, a representational account does explain why this might be so. Nor does it provide an explanation to account for this interaction of the phonological deficit and retrieval context. One possibility is that the naming of individual pictures is impaired, but more sensitive measurements (e.g. latency of response rather than accuracy) and more challenging stimuli (e.g. long, lower frequency names) are necessary to reveal the inadequacy of the underlying representations.

A third shortcoming of a representational account, is that it does not explain the apparent context sensitivity of naming impairments in dyslexic adults. It has been previously noted that this group are unimpaired in naming pictures during tasks of confrontation naming. In contrast, they show robust impairments on tasks of rapid serial naming of pictures (Felton et al., 1990; Hanley, 1997). Similarly, when naming individual pictures at a rapid pace they produce significantly more errors (Wolff, Michel, and Ovrut, 1990). Again, a proponent of the representational position might
argue that a more sensitive measure, such as latency of response and the use of more complex stimuli, would index the underlying inadequacy of the phonological representations – even at a slow pace of presentation. The question arises whether during tasks of phonological awareness, the availability of phonological information is influenced by the rate of presentation. According to a representational account of the phonological deficit, it is not clear how context would impact on phonological access.

2.3. The phonological deficit in dyslexia: a competition account

In the following section an alternative characterisation of the phonological deficit in dyslexia is described in which phonological representations are not seen as fixed entities, but rather as dynamic states of informational representation. In the first section, general processes of phonological access and specification are introduced. This discussion provides the backdrop for the second section in which the phonological competition hypothesis is described, in relation to (i) reading, (ii) naming and (iii) tasks of phonological awareness.

Phonological access

Production models have generally shared the non-controversial assumption that speech can be broadly characterised by successive stages of non-phonological and phonological representation. A speaker begins with an idea or intention - the initial stage of conceptualisation that involves the non-verbal specification of the concepts to be expressed. These preverbal concepts are then mapped onto a lexical level during formulation that is generally regarded as requiring two components. The first step maps the conceptual representation of a word onto a lexical representation – the lemma - that captures its semantic and syntactic features. The second step, phonological encoding, entails the specification of the phonological form – the lexeme – and its insertion into a prosodic structure in preparation for articulation (Dell 1986; Levelt, 1989).

Evidence for two stages of formulation come from studies of the tip-of-the-tongue (TOT) phenomenon where subjects appear to be able to access semantic and syntactic properties of a given word but are unable to retrieve the word itself. At the same time they are better than chance when reporting some phonological features of the word,
such as the initial letter or number of syllables, thereby indicating that while the correct lemma has been selected, the corresponding lexeme has not been fully activated (Brown and McNeil, 1966; Brown, 1991). Evidence from studies of aphasia have also supported separable stages of formulation. Aphasic patients have been reported who, while able to demonstrate knowledge of the meaning of a word, are unable to produce it in response to a picture or definition. This can be in spite of a preserved ability to repeat, comprehend or read the word in question. There is an extensive literature pertaining to the treatment (Howard, 1994) and the cognitive basis (McCarthy and Warrington, 1990) of aphasia, a review of which is beyond the scope of this thesis.

While a general consensus exists regarding these various components of language production, there remains significant controversy in relation to how these processes are instantiated. In particular, it remains a matter of debate whether the two stages of formulation occur in a discrete or in an interactive fashion. Proponents of a discrete two stage model (Levelt, 1992; Levelt, Schriefers, Vorberg, Meyer, Pechmann, and Havinga, 1991) argue that the lemma is accessed and selected prior to specification of the lexeme and that this process is strictly hierarchical, with information flowing in one direction only. In contrast, other theories of word access have proposed that these stages overlap in time (Dell, 1986; Stemberger, 1985). Here the retrieval processes entail interactive activation between processing stages which can progress in parallel. Furthermore, the connections between levels are bidirectional, allowing a continual flow of information between levels. So, for example, a given lemma might be activated giving rise to activation of its associated phonological codes at the lexeme level. According to the interactive account, the activation of these codes can feed back to the lemma level, potentially activating a different lemma with similar phonological structure. Such backward flow of information is not permitted in a discrete stage model.

Most theorists concur however that once a lexeme or wordform is selected its associated phonological segments are activated first as a disassembled collection and then assembled into the phonological code that controls production (e.g. Dell, 1986; Garret, 1982; Levelt, 1989). Phonological encoding may be characterised by two stages: first, initial retrieval of the phonological code and second, later assembly of its
segments into a whole word form. Levelt, Roelofs and Meyer (1999) contrast the notion of frames and fillers. The frames are metrical units such as word or syllable frames. The fillers are phonemes or clusters of phonemes that are inserted into these frames during phonological encoding. There are good linguistic reasons for such a distinction between structure and content. The functional basis for this disassembly is that it permits efficient control of the motor programming of articulation. For example, phonological segments are often resyllabified in speech plans (Levelt et al., 1999). In addition speech error evidence supports such a distinction. When errors do occur they generally respect positional rules so that, for example, vowels are exchanged (e.g. bud beggs, for bed bugs) or two codas are exchanged (e.g. god to seen, for gone to seed).

The nature of the phonological code is a matter of considerable debate. Traditionally it has been suggested that stored word forms are decomposed into phoneme sized units (e.g. Coltheart, Curtis, Atkins, and Haller, 1993; Levelt et al., 1999). While this will be the unit adopted here for purposes of discussion, it is recognised that other units have been proposed. For example, one major contemporary hypothesis postulates a sub-phonemic level of coding such that phonemic features are extracted from speech input, and features compose the accessed lexical representations (e.g. Lahiri and Marslen-Wilson, 1991; Marslen-Wilson and Warren, 1994).

**Phonological competition**

The phonological competition hypothesis in dyslexia proposes that there is a subtle deficiency in resolving the competition between phonological segments prior to their assignment to the word frame. The deficiency is subtle since it becomes behaviourally manifest only when there are unusually high levels of phonological competition. It is suggested that during speech production at a normal rate the level of phonological competition is comparatively low. However, in the following sections it is suggested that the degree of competition will vary depending on the task (greater during reading than naming) the orthography (greater in opaque than transparent orthographies), and the rate of production (greater at faster relative to slower rates).

(i) **Reading**

The process by which competition might arise at the phonological level during reading is differentially instantiated in different models. Here it is the general principle that
some phonological segments (shown here as phonemes), not present in the target word, may receive a degree of activation and compete for selection. The model that has been chosen to illustrate the phenomenon is shown in Figure 2.2. (O'Seaghdha and Marin, 2000). Here for the sake of simplicity the distinction between wordforms and lemmas has been collapsed. In the example shown the target ‘pin’ activates the phonemes /l/ and /n/ which in turn feedback to the word level tin. The /t/ of tin may then compete with the /p/ of pin for the first consonant slot. Which of these phonemes are selected depends on the relative degree of activation of each.

This illustrates the phenomenon of more than one phonological segment competing for a given slot in a word frame. This competition is likely to be weak since it is mediated via the lexical level. However, if the word ‘tin’ had been presented recently such feedback may lead to ‘t’ being inappropriately selected. An alternative account of how the phonological code is assembled has been put forward by Berent and Perfetti (1995) in their two cycles model of ‘phonology assembly’. They hypothesise that the sound of written vowels and consonants are derived by processes that differ in speed and automaticity. Consonants are derived first by automatic computations and vowels are added subsequently to the evolving representation via strategically controlled
computations. However, in parallel distributed models the vowel consonant distinction is at best implicit, referring to processing differences within a common network (e.g. Plaut, McClelland, Seidenberg, and Patterson, 1996). Although the processing of vowels and consonants occurs concurrently, the resolution of vowel phonology may take longer than the resolution of consonant phonology.

English has a particularly opaque orthography in view of the historical influence of many other languages. One consequence of this inconsistency is that it is likely to generate a higher degree of phonological competition since competition will arise by the direct activation of two phonemes associated with a single grapheme. Within an interactive framework, both English and Italian will have the kind of competition shown in Figure 2.2 where the phonological constituents of one word feedback to other similar lexical items, which in turn become phonologically encoded. However, in English there is an additional kind of activation, that is specific to an inconsistent orthography. Here a grapheme – particularly if it is a vowel – directly activates more than one corresponding phoneme. For example, the grapheme ‘a’ is associated not only with the phoneme /a/ as in ‘car’ but also with the phoneme /A/ as in ‘cat’. Depending on the model of phonological activation this would give rise to phonological competition in different ways. The grapheme ‘a’ for example might activate both vowels directly. Equally, within a spreading activation model (after Dell, 1986; Sevald and Dell, 1994) in which there is a left to right activation of the presented string, a letter string such as ‘car’ would activate the words ‘car’ and ‘cat’. The initial phoneme is shared. However the two competing vowels are activated by the one grapheme. Only when the final grapheme of ‘car’ is processed can this competition be resolved. In addition, semantic input may influence the resolution of this competition. If dyslexic readers have difficulty in resolving this competition then they will be slower and also less accurate in assigning these phonological segments to the word frame. This kind of competition is reduced in a transparent orthography in which a given grapheme is associated with a single phoneme.

It has been established that in those languages with a high degree of transparency (such as Italian) dyslexic individuals present with comparatively mild literacy deficits – in contrast to English dyslexics (Paulesu et al., 2001). Arguably this difference is attributable to the high degree of consistency between the graphemes and phonemes in
Italian. If the dyslexic individual has a specific impairment in efficiently resolving the competition between two directly activated phonemes competing for the same positional slot then a language such as Italian (in which such competition rarely occurs) is likely to be more 'dyslexia-friendly'. Indeed if the critical difficulty in dyslexia is in processing phonological competition then one would predict cases of double dissociation, where an individual would be impaired in an opaque orthography (where the level of competition is high) but not a transparent orthography (where the level of competition is low). Wydell and Butterworth (1999) recently described such a case. Here a 16 year-old English/Japanese bilingual boy reported to be severely dyslexic in English is of normal aptitude in Japanese. The authors explain this dissociation on the basis of the greater degree of granularity required to read a language such as English in contrast to Kana which is syllable-based. They also draw attention to the high degree of transparency of the Kana script. It is arguable that it is this transparency which is critical and that greater transparency can be achieved with larger ‘granules’, at least in Japanese. Reading Japanese, like reading Italian, generates only moderate phonological competition during reading, whereas in English, multiple competing phonological codes, especially vowels, are activated directly when reading even the simplest of words. It has been suggested that this ambiguity may account for the slower reading speed of skilled English readers relative to their Italian counterparts (Paulesu et al., 2000). This contrast between opaque and transparent orthographies demonstrates, somewhat surprisingly, that reading may or may not be problematic for the dyslexic individual. According to the competition hypothesis, it is not the global process of reading that is impaired, but only those computational processes dedicated to resolving phonological competition.

(ii) Picture naming

The act of putting a name to a picture is one of our earliest acquired language skills. The apparent simplicity of this task contrasts with the increasingly complex cognitive processes that must be postulated to account for the range of behavioural phenomena reported in the experimental and neuro-psychological literature. Models of picture naming have generally incorporated perceptual, semantic and phonological processing stages. Differences emerge however in how these stages are characterised and inter-related. Several models of lexical retrieval during picture naming will be considered before phonological competition is discussed.
Cognitive models of picture naming have attempted to reconcile behavioural data which suggest differential processing characteristics for words and pictures from Morton's logogen model (1969; 1980) to that of Glaser and Glaser (1989). It has been long established for example that word reading is faster than picture naming (Cattell, 1885). This suggests that orthography maps more directly onto the phonological representations of words than do the visual features of pictures. However word classification has been found to be slower than picture classification (Segui and Fraisse, 1968), suggesting that the visual features of pictures map more efficiently onto their semantic features. More recent studies have employed Stroop-like interference tasks to explore these differences. For example, while naming a picture is disrupted by the presence of an incongruent word, reading a word is not disrupted by the presence of an incongruent picture (Glaser and Düngelgoff, 1984). In addition Stroop-like word-word interference does not exhibit semantic properties. In contrast, during categorisation, word processing is disrupted by an incongruent picture, but picture categorising is not disrupted by the presence of an incongruent word (Glaser and Düngelgoff, 1984). Together these results have been taken to indicate an asymmetry of access for pictures and words, with pictures showing privileged access to semantics and words showing privileged access to phonology.

**Figure 2.3.** Lexical hypothesis model of word reading and picture naming, as postulated by Glaser and Glaser (1989).
These findings form the basis of Glaser and Glaser’s (1989) model of object and word processing (subsequently named the ‘lexical hypothesis’, Glaser, 1992). This model, which is presented in Figure 2.3, is a relatively simple architecture with a large concrete and abstract, semantic and non-verbal system on the one side and an equally large verbal and linguistic system on the other. Several points should be noted here. Firstly there is a significant amount of autonomous word processing that can occur independently of semantics, since the word module provides no semantic processing, not even of abstract meanings or relations. Secondly, whereas the perceptual features of objects are functionally integrated with the meaning of their concepts, the graphemic features of words are independent of, but connected to, their associated lexical features.

This model can accommodate the various behavioural findings discussed above. For example, the fact that word naming proceeds faster than picture naming arises because retrieving the name of a picture necessarily requires mediation via the semantic level, whereas reading a word entails direct access to its lexical form (Figure 2.4).

Conversely, whereas picture categorisation proceeds via the semantic level, followed by activation of the appropriate category label, word categorisation requires lexical processing, semantic processing, followed by re-access to the lexicon (Figure 2.5).

**Figure 2.4.** Contrasting the pathways from the percept in the task of reading aloud and picture naming (after Glaser and Glaser, 1989).
As with models of speech production, there exists a significant level of debate in the literature regarding the nature of the relationship between the semantic and phonological levels. While the perceptual, semantic and phonological representations of a given object are believed to activate sequentially, it remains unclear whether this activation operates in discrete stages, or in parallel. Levelt, Schriefers, Vorberg, Meyer, Pechmann, and Havinga (1991) argued for the so-called discrete two-stage (DTS) model, which stipulates that: (i) *Lexical access is serial*. That is, it proceeds in two stages that follow a fixed temporal order. Initially there is lexical-semantic activity followed by lexical-phonological activity. There is no feedback between levels; and (ii) *Lexical access is discrete*. During lexical selection (lexical-semantic processing) there is only semantic activity, whereas during phonological encoding there is only phonological activity. Moreover, only the lexically selected item becomes phonologically encoded. In terms of lexical selection, competition at the phonological level only arises within a phonological cohort surrounding the phonological form of the selected lexical item (see Figure 2.4). In contrast to the DTS model, nondiscrete models such as the Cascade Model (e.g. Humphreys, Riddoch and Quinlan, 1988) and the Interactive (IA) Model (e.g. Dell, 1986; Martin, Dell, Saffran and Schwartz, 1994) assume that phonological competitors may become activated, in addition to the activation of the target phonological form. These models stipulate that the different representational levels progress in parallel, even if processing at the previous level has not been completed.
Figure 2.6. A simplified depiction of a discrete two-stage model of lexical retrieval. Bold circles indicate the target representation at the semantic and phonological levels. Arrows indicate information transfer across levels. Connections between lexical-semantic representations define a semantic cohort, and connections between lexical-phonological representations define a phonological cohort.

For example in the IA word production model put forward by Martin et al., (1994), connections between the semantic, lexical and phonological layers are bidirectional rather than feedforward. This results both in (i) the stages of lexical retrieval overlapping in time and (ii) multiple representations becoming phonologically encoded, rather than the one with the highest activation (as proposed by the DTS model). For example, a picture will elicit activation in a targeted set of semantic features, which activates a target lexical node as well as related lexical nodes. Both the target and the primed lexical nodes in turn spread activation to corresponding segmental phonological nodes – but once these phonological nodes are primed they send feedback to their source node, and prime other lexical nodes to which they are related. Thus, lexical competitors may be semantically or phonologically related to the target item (see Figure 2.7). For example activation feeds forward to semantically related lexical nodes (cat->dog), and to their corresponding phonological forms. Activation feeds back from phonological segments to lexical nodes that are phonologically related (cat->mat), activating in turn their phonological forms. Note that there are lexical nodes that are both semantically and phonologically related (cat->rat) that receive priming activation via both a. and b. All these lexical items become phonologically activated to some extent. One prediction of the model states that semantically related competitors will be more activated than phonologically related competitors (Laine et al., 1996). This arises since the former are primed first by direct
feedforward activation which is stronger than the feedback activation that primes the phonological competitors.

The view that the retrieval of semantic and phonological representations of words in picture naming is nondiscrete is given support by its capacity to model the pattern of naming errors in anomic patients (Laine and Martin, 1996) and observations of mediated semantic-phonological priming in normal readers (O’Seaghdha and Marin, 1997). Since all activated lexical semantic representations become phonologically activated to some extent, structurally similar objects will result in the activation of their corresponding phonological representations. This contrasts with the DTS account which maintains that the effect of structural similarity is confined to the initial lexical-semantic stage.

**Figure 2.7.** A simplified depiction of an interactive activation model of lexical retrieval, based on Laine and Martin, 1996 and Dell and O’Seaghdha, 1991. Connections between nodes across levels of representation originate as feedforward activation but are eventually bidirectional. a. and b. reflect semantic and phonological priming respectively. Note phonological segments are for illustrative purposes only and do not reflect actual representation in the model itself.

Both models therefore propose some degree of phonological competition between the target phonological form and phonological competitors. They differ however in the manner by which such competition arises.

In English it has been established that the salient difficulty experienced by dyslexic children is in reading and spelling. Studies of adult dyslexics have consistently shown persisting impairments on reading accuracy (e.g. Felton et al., 1990) and reading
speed, even for high frequency regular words (e.g. Brunswick et al., 1999). However children with dyslexia also show mild but reliable impairments in picture naming (e.g. Swan and Goswami, 1997a). A child with dyslexia makes more semantic and phonological errors on a simple confrontation naming task than his peers (Katz, 1996). Why? As shown in Figure 2.7 ‘competitors’ may become activated via semantic or phonological mediation. If an individual is impaired in his ability to resolve phonological competition then both phonological and semantic errors would arise even though the impairment is specifically at the phonological level. Katz (1996) in a study of object naming with children, reported that naming errors bore a significant semantic and phonetic similarity to the target names for both skilled and less-skilled readers, with less skilled readers making significantly more errors overall. This finding is consistent with the view that both kinds of reader face comparable sources of phonological competition, but that this competition is inefficiently addressed by the dyslexic children. Katz remains entirely neutral with regard to the nature of this phonological difficulty, stating that “…the use of inadequate phonological representations or inadequate processing of phonological representations may lead to naming problems in less skilled readers” (Katz, 1996; p. 201). He is also quite clear that this difficulty arises specifically at the phonological level, citing previous studies which indicate normal semantic ability in dyslexic children (e.g. Murphy, Pollatsek, and Well, 1998; Vellutino, 1995).

In contrast to reading, the degree of phonological competition elicited during picture naming is not contingent on the level of orthographic consistency. This is because a given lemma and its associated set of phonological constituents are activated via a semantic not an orthographic representation. A highly specified semantic representation would be most likely to selectively activate its associated lemma. However, if a semantic representation is poorly specified then several semantically
Figure 2.8. Phonological competition in naming a picture that is poorly specified at the semantic level. Here a poorly specified semantic representation of CAT leads to the activation of two semantically related lemmas that share a number of semantic attributes ('cat' and 'dog') that in turn become phonologically encoded and compete for selection.

Figure 2.9. Phonological competition in naming a picture that is well specified at the semantic level. Here a highly specified semantic representation of CAT leads to the selective activation of a single lemma which is in turn strongly activated at the phonological level. Semantically related lemmas are encoded only weakly at the phonological level, greatly reducing any phonological competition.

associated lemmas may become activated. In children, where the semantic representations of given objects are weakly specified, then the difference between the
activation of the target and that of semantic competitors will be less (see Figure 2.8). This would result in increased competition at the phonological level within a spreading activation network making an error in target selection more likely. By adulthood the degree of phonological competition elicited when naming an object is likely to have markedly reduced given that more detailed semantic representations will have become established (see Figure 2.9). These will permit more selective activation of the target lexical form increasing the differential between the activation level of the target item and its competitors.

Picture naming in adulthood is therefore likely to generate only a weak degree of phonological competition in view of the increased specification of the semantic representations. This is consistent with the observation that dyslexic adults no longer show deficits in picture naming (e.g. Felton et al., 1990). However in those instances where the relative competition from other phonological items is increased, one would predict an increase in naming difficulty - even for an adult dyslexic. This may occur if one increased the rate at which naming proceeds. In a task of rapid automatic naming (RAN) for example, a participant must name a randomly repeated set of five pictures and the rate at which this naming proceeds is significantly faster than the slow pace employed in a confrontation format. An impairment on this task not only predicts later reading ability (Wolf and Obregon, 1992) but has been shown - unlike confrontation naming - to persist into adulthood (e.g. Felton et al., 1990). Similarly, when presented with pictures to be named in a slow paced discrete trial format, dyslexic adults' naming accuracy is normal; however as the rate of presentation increases so too does the rate of error (Wolff et al., 1990). The representation hypothesis fails to explain this pattern in naming performance. This in turn has led a variety of researchers to appeal to a general deficiency in processing speed that extends beyond a specifically linguistic deficit (Wolff et al., 1990; Wolf and Bowers 1999). Yet from a phonological viewpoint what differs most strikingly across a confrontation naming format and a rapid continuous format is the rate at which lexical retrieval proceeds. According to the competition hypothesis, increasing the rate of presentation places increased stress on the process of lexical retrieval by effectively augmenting the degree of competition during selection. The proposal is that by naming one item immediately after the production of a previous item, activity of the latter will not have had time to decay. This serves to increase noise, and reduce the differential between the activation levels
of the target item and its competitors. If this increased competition is inefficiently resolved, then the number of errors and the time taken during selection are likely to be increased.

Phonological neighbourhood density is another factor that may influence the level of phonological competition during naming. While the precise definition of what constitutes a phonological neighbour may vary, the essence of the term refers to the degree of phonological similarity of one word form to another. A word such as 'mat' for example will have many phonological neighbours (words that are similar sounding, e.g. hat, rat, man). In contrast words from sparse neighbourhoods will have few words that are of similar phonological form. If it is the case that activation of one word form leads to spreading activation to phonologically similar word forms (possible within both discrete and interactive models) then such a word must be retrieved in the context of a higher level of associated phonological competition. According to the competition account of the phonological deficit, dyslexics may be slower to name such items relative to other pictured items matched along other linguistic dimensions. This is investigated in Chapter 4, Experiment 2.

(iii) Tasks of phonological awareness
Unlike reading and picture naming there are no extant cognitive models that detail the processes engaged during tasks of phonological awareness. These tasks invariably require participants to consciously manipulate or identify sublexical word segments in a manner that invokes not only a considerable degree of metacognitive processing (Morton and Frith, 1995) but the involvement of working memory (Landerl and Wimmer, 2000). However, testing a population of dyslexic adults who have attained a tertiary level of education, minimises the possibility that failure on tasks of phonological awareness could be attributed to these additional cognitive demands. A cognitive evaluation of the task is complicated further by the evidence of a reciprocal relationship between the acquisition of literacy skills and the development of phonological awareness (Perfetti, Beck, Bell and Hughes, 1987).

The logic of a phonological representation account is that if an individual has a high quality phonological representation of a word, then that representation will have been clearly restructured at different linguistic levels, rhymes, syllables and phonemes,
allowing access to all segments of that word. A process account takes a dynamic view of segmentation. Here a given lemma, once activated, leads to the activation of its associated set of phonological constituents. If we are required to isolate the final phoneme of the word ‘cat’, for example, then we are required to select only one phonological constituent from this set of activated phonological segments. This requires that for selection to be optimally efficient there must be effective activation of the required segment as well as effective inhibition of the simultaneously activated segments. As with reading these segments will be inserted into a word frame. As discussed previously, the constraints built in at the level of word shape frame preclude a random allocation of the phonological segments. Two predictions arise from this position.

Firstly, one would predict an effect of length in tasks of phonological awareness. Short words should elicit less difficulty than long words since the latter will entail a larger set of phonological elements from which selection must occur. This should be over and above working memory requirements favouring shorter over longer words. So, even if dyslexics were as accurate as their peers in performing a task of phonological manipulation, they would be slower, since it will take them longer to resolve the phonological competition during the processes of selection. A representational account would not predict this slowness if a phonemic level of specification has been achieved (demonstrated by successful completion of the task).

According to the representation account, the critical factor that should determine performance, is how well a given phonological form is specified. It is theoretically possible that a monosyllabic word could be less well represented than a multi-syllabic word – with the shorter word posing more segmentation difficulty. Yet given that performance on the phonological awareness task is used as an index of representational accuracy (e.g. Swan and Goswami, 1997b) it is unclear how representational accuracy might be measured independently of task performance. In many ways this circularity highlights the difficulty inherent in the representational position. Unlike the competition account, a representational account would not predict differences between words that differed by a single phoneme (assuming they were matched in overall frequency) since there is no reason to suppose that representational
accuracy would vary intimately in this way with phonological length. The effect of length in a task of phonological awareness is investigated in Experiment 5.

A second prediction, also investigated in Experiment 5, is that the same phonological representation may be manipulated with varying success in different contexts. That is, the degree of phonological competition may vary as a function of factors other than those inherent in the stimuli. As with picture naming, a sufficiently fast rate may lead to an increase in the overall level of competition. In effect, a weakness in resolving phonological competition extends the refractory period for the dyslexic, limiting the rate of retrieval. This illustrates the notion that a phonological representation is a dynamic entity. Such contextual effects are not predicted by the representational account that implies phonemic elements (for example) are available once a given word has become ‘fully specified’ and ‘segmented’.

2.4. The Role of Inhibition in the Competition Account.

The past two decades have seen the increasing influence of connectionist models capable of instantiating models of language function. While a proper review of this field is beyond the scope of this thesis, selective consideration is given to the mechanisms that are postulated to manage competition effects in such networks. Within any connectionist network, units interact within and between layers to encode input that is transformed as a function of the connection weights that determine the spread of activation between units. When learning occurs, the strength of these weights may increase or decrease over time. A phonological representation in such models differs radically from traditional ‘box-and-arrows’ models in that representation and access are integrated: a given ‘representation’ is not viewed as a fixed and discrete entity. This competition account fits naturally within this perspective.

There are several advantages of testing complex cognitive models by computer simulation. Firstly, such simulation requires specificity from the cognitive scientist with regard to the assumptions in a given model. Secondly, it may predict hidden effects which can then be tested empirically. And thirdly, competing models can be compared under conditions where each makes differential predictions. A number of
limitations have, nevertheless, characterised the use of such connectionist simulations. Generally models have focused on a single specific task. Models of reading for example have not concurrently simulated the processes engaged during picture naming. This limits the degree to which models are constrained by the inherent complexity of configuring several cognitive skills within the same system. Similarly, within the connectionist reading literature, the existence of a semantic component at a theoretical level is often postulated (e.g. Plaut, McClelland, Seidenberg and Patterson, 1996) but rarely instantiated computationally (see Harm and Seidenberg, 2001 for an exception). In addition, nearly all models of reading have been designed to process an extremely limited word corpus. For example, nearly all to date have employed only monosyllabic words, neglecting the specific constraints that arise when reading polysyllabic words, such as stress and vowel reduction (see Rastle and Coltheart, 2000 for one recent exception).

Connectionist models provide a natural framework within which phonological competition might be conceptualised. Any given network must (i) address the danger of too many nodes in a network being overactive simultaneously (the 'heat death' problem') and (ii) efficiently output a correct unit in face of competition from other nodes (the 'selection problem'). Processes of inhibition may be critical in addressing these problems. Inhibition, both between levels and laterally within a given level, has been incorporated from the early days of connectionist modelling (McClelland and Rumelhart 1981), yet its role in language production is as yet unresolved. In the connectionist literature, some models (e.g. Stemberger, 1985), make use of it while others (e.g. Dell, 1986) do not. However, the role of inhibition as a general modulator of lexical activation is now largely accepted (e.g. Berg and Schade, 1992; McClelland and Rumelhart, 1981; O'Seaghdha and Marin, 2000). Berg and Schade (1992) convincingly argue not only for the existence, but for the necessity of an inhibitory component in word production models, presenting evidence from both the psycholinguistic literature and from a series of computer simulations. They argue that inhibition constitutes the natural counterpart to excitatory processes and is "instrumental in striking the requisite balance between activational and deactivational forces in the activation network" (Berg and Shade, 1992; p.431). They distinguish between 'self inhibition' (where a node inhibits itself immediately after selection) and 'other inhibition' (where an activated node sends inhibition through the network) and
explain how each is necessary to address the problems both of ‘heat death’ and selection. These will be considered in turn.

The problem of ‘heat death’ refers to the undesirable situation in which the network amasses too much activation – a critical problem, because no information can be coded in such a uniformly activated network. The advantage of lateral inhibition, is that it both combats any excessive activation and simultaneously enlarges the difference between the activation values of a target and its competitors. In contrast, a decay mechanism serves to blur the differences between the activation values of the nodes. This difference is of particular importance to the selection process. It is understood that for a unit to be selected for output it must possess an activation value that exceeds that of the other nodes in the network. However noise (construed as randomly fluctuating activation levels) may inadvertently provide an advantage to other nodes at the expense of the target node. Given the infrequency of errors in normal language production, it is likely that only a combination of various sources of noise will have tangible effects. That is, it will reduce the difference between the target node’s activation value and of the activation values of the non-target nodes. Since lateral inhibition can be shown to enlarge the differences between competing nodes, it is better suited to grapple with the selection problem than simple decay.

In a simulation of word output, Schade and Berg (1992) investigated the impact of network size on such competition effects. They demonstrated that small networks may function effectively relying simply on a fixed rate of decay; this is largely attributable to the fact that small networks have few members, and consequently an intended element has few competitors. However in larger networks the degree of competition is much higher, and the production of a given item may be jeopardised by the pressure from large numbers of concurrently activated units. They contend therefore that the larger the network the more necessary lateral inhibition becomes.

2.5. Conclusions

This overview of the phonological deficit in dyslexia has introduced two perspectives of the phonological deficit in dyslexia that will be considered in this thesis. The established view, the phonological representations account, attributes the phonological
impairment to poor specificity or segmentation of the phonological representations themselves. In contrast, the phonological competition hypothesis places the emphasis on the *functional access* of phonological information. Specifically, it is suggested that dyslexics are characterised by inefficient resolution of phonological competition when a given representation is encoded. It is not suggested that the processes which mediate such resolution are absent (clinically dyslexics are not characterised by unusually frequent spontaneous speech errors), rather dyslexic individuals are subtly impaired developmentally in fine tuning these processes to resolve high levels of phonological competition. In this way, phonological representations at both a lexical and a sublexical level are viewed as dynamic rather than as fixed entities whose functional availability may vary depending on other factors. In the following section, the behavioural evidence for a phonological deficit in dyslexia during tasks of repetition, naming and phonological awareness will be reviewed. These tasks form the basis of the experiments presented in this thesis.
Part II: Characterising the phonological deficit at the behavioural level

2.7. Tasks of phonological repetition

It has long been established that dyslexics are prone to mispronounce long words, (such as ‘statistical’ or ‘parallelogram’, Miles, 1974). A large number of studies have shown this to be a general characteristic of the dyslexic population. While it is the case that repetition studies employing short monosyllabic words have sometimes failed to find group differences (Lieberman, Meskill, Hilton, and Schupack, 1985) longer words result in poorer performance in less skilled readers (Brady, Poggie and Rapala, 1989; Catts, 1986, 1989). Similarly, difficulty has been increased by the use of pseudowords rather than real words. These represent more or less novel phonological sequences that cannot be repeated solely on the basis of existing lexical entries. Several studies have now shown significantly impaired pseudoword repetition in poor readers when they are compared to younger children matched for reading age (Stone and Brady, 1995). What is the basis of this repetition difficulty? While it is probable that it arises from an underlying impairment in phonological processing it is conceivable that differences in i. speech perception, or ii. vocabulary knowledge, might equally explain the impairment. Both these possibilities have been carefully investigated.

Snowling (1981) for example, examined the possibility that the dyslexic’s difficulty was due to a problem of perception rather than production. She designed an auditory discrimination task in which a child had to decide whether two pseudowords were the same or different (e.g. fizidor-fizitor). Differences were in terms of a single phonetic feature, making the task particularly challenging. No differences in performance were found on this task between a group of dyslexic children and a group of younger reading age matched controls. It was proposed then that impairments in auditory discrimination could not account for the differences observed in repetition performance. In a later investigation, Brady, Shankweiler and Mann (1983) reported increased difficulty in poor readers while repeating words in noise. This was taken as evidence of a perception impairment, which could in turn underlie their repetition deficits. However no reading age matched control group was included leaving open
the possibility that the normal readers could invoke their enhanced orthographic knowledge to successfully perform the task. This shortcoming was addressed in a study by Snowling et al., (1986) in which reading age was controlled. A comparable effect of noise masking was reported for dyslexic, reading-age and chronological-age matched controls – indicating no differential effect of noise masking between the groups.

A second possibility is that a depleted vocabulary, a common characteristic of dyslexic children, may underlie their poor repetition – even for pseudowords. Existing lexical entries may partially match sequences of the pseudowords and influence both encoding and articulation processes. For example, significant correlations are reported between pseudoword repetition and vocabulary (Gathercole and Baddeley, 1989, 1990). Yet several studies have now shown significantly impaired pseudoword repetition in poor readers when they are compared to younger children matched for reading age (Stone and Brady, 1995; Taylor, Lean and Schwartz, 1989), and this has been shown even when vocabulary knowledge has been controlled (Stone and Brady, 1995). The use of longer, polysyllabic pseudowords, have also revealed repetition impairments in dyslexic adults (Apthorp, 1995). Again, differences in repetition performance remained even when vocabulary knowledge was statistically controlled. Therefore impaired vocabulary knowledge or impaired auditory perception are not sufficient to account for the dyslexics’ difficulty in repetition. Instead such difficulty appears associated with a core deficit in phonological processing.

2.8. Confrontation Naming

Geschwind (1965) was the first to propose that the requirements of reading and naming were shared, and that a good way to predict a child’s reading ability would be to assess his naming ability. This proposal was based on the assumption that naming tasks share many of the component processes necessary for reading, a view still strongly held (e.g. Wolf, 1991). Picture naming ability has largely been assessed with a confrontation naming paradigm. Confrontation naming simply refers to the procedure in which participants are shown the picture of an object and asked for its name. However a much smaller number of studies have presented pictures on a monitor, and measured latency and/or accuracy of response. The more extensive
literature on confrontation naming will be considered first, before a review of the few studies which have reported picture naming latencies in single trial formats.

The first study to evaluate the relationship between early picture naming ability and reading skill was carried out by Jansky and de Hirsch (1972). They assessed a group of children from kindergarten age until Grade 2, with a series of tasks that included tests of picture naming and reading. They reported a strong correlation between picture naming ability and reading level ($r=.53$) and proposed that picture naming performance in kindergarten represented a powerful predictor of later reading skill. Subsequent predictive studies served to support this claim. Wolf and Goodglass (1986) employed the Boston Naming Test (BNT; Kaplan, Goodglass and Weintraub, 1983), a frequency based confrontational naming test. While picture naming performance was predictive of the three different forms of reading measured (oral single word reading; oral discourse reading; reading comprehension), it was only weakly related to word recognition ($r=.29, p<.01$), but more strongly related to discourse reading ($r=.48, p<.001$) and reading comprehension ($r=.53, p<.001$). It was suggested that these higher correlations with text reading indicated that the BNT tapped semantic processes more strongly in contrast to the lower level operations of grapheme-phoneme conversion and lexical retrieval necessary for single word reading.

In the latter part of this longitudinal study Wolf and Obregon (1992) report the findings for grade 3 and 4. The results replicated the differential pattern found in the earlier years: namely strong relationships between BNT performance and reading comprehension (emphasizing high level processes) but only modest relationships with word recognition (which emphasizes lower level processes).

The predictive studies of Scarborough (1990) and Badian, McAnulty, Duffy and Als (1990) report similar findings. Scarborough (1990) assessed children at an even earlier age, both at 2 years 6 months and at 3 years 6 months. When IQ was partialled out performance on the BNT failed to predict reading disability when measured in children at the first age level (2 1/2 years). However BNT scores at age 3 1/2 were found to be significantly lower for the reading impaired group. Likewise Badian et al., (1990) report that performance on the BNT at kindergarten was one of six variables that best predicted reading several years later in Grade 4.
Together these studies demonstrate that the processes tapped by confrontation naming are related to those subsequently employed in acquiring literacy skills, even when IQ has been controlled. In addition Wolf and colleagues (Wolf and Goodglass, 1986; Wolf and Obregon, 1992) suggested that naming particularly taps skills related to higher level language processes given the weaker correlation with single word reading. This pattern has not been independently replicated and is in fact only a matter of degree: BNT performance did predict single word reading ability, only less strongly. The smaller correlation found may have arisen as a function of the restricted class of words used in the single word reading task (monosyllabic high frequency words) in contrast to range of words types (polysyllabic mixed frequency words) used in the text reading tasks. So, while pre-school confrontation naming performance can robustly predict later reading performance, it remains unclear whether it can predict different performance on different types of reading task.

Denckla and Rudel (1976b) were the first to address the possibility that poor picture naming performance in the dyslexic group could be attributable to poor vocabulary levels. They assessed confrontation picture naming performance in a group of dyslexic and non-dyslexic learning disabled children aged between 8 and 10 years. The control group for both consisted of 120 chronological aged matched children of a similar age. An adapted version of the Oldfield-Wingfield Picture Naming test (Oldfield and Wingfield, 1965), which consists of black on white line drawings of object names which varied in frequency values, was employed as the experimental measure. The dyslexic group were found to perform significantly less accurately than both the non-dyslexic learning disabled group (who performed in the normal range) and the chronological age matched controls. In contrast, on a measure of receptive vocabulary, the Peabody Picture Vocabulary Test (PPVT), the dyslexic readers performed normally. Denckla and Rudel suggest that impaired picture naming performance is unlikely to result from impoverished vocabulary deficits, but rather from a weakness in the process of linguistic retrieval.

In their longitudinal study, Wolf and colleagues (Wolf and Goodglass, 1986; Wolf and Obregon, 1992) were able to assess picture naming performance at several ages. Participants were assessed in Grades 1 to 4 providing a range in age from 6 to 9 years. For children of all Grades no impairment was found on a measure of receptive
vocabulary between dyslexic and average readers. However their performance on the confrontation naming task (the BNT) was significantly impaired at each age. The receptive vocabulary test they employed represented an improvement on that used by Denckla et al., (1976b) since it evaluated the very words that a given subject failed to name during the confrontation naming task. The missed word was represented at the end in a multiple-choice format with three foils: a perceptual foil, a semantic foil and a phonological foil. If the child could match the (auditorially presented) word with the correct target, then a deficit in retrieval rather than in vocabulary might be inferred.

While there were no significant group differences there was a trend for many impaired readers to select the correct target in a multiple-choice array after an error had earlier been made. These results, with those of Denckla and Rudel (1976b), together suggest retrieval rather than vocabulary deficits play an important role in the naming impairment shown by the dyslexic group. Wolf and colleagues (1992) are careful however to point out that this does not exclude a role for vocabulary in picture naming; rather lack of gross-level vocabulary deficits fail to account for the pattern of picture naming errors shown by the dyslexic participants.

Snowling, van Wagtendonk and Stafford (1988) also investigated whether poor vocabulary knowledge was sufficient to account for deficits in picture naming. They tested a group of dyslexic children between the ages of 8 and 11 matched for chronological age and performance on a word definition task, and a group of control children. Participants were assessed during a task of picture vocabulary and picture naming. In the former they had to point to one in a set of four pictures that best matched a word spoken by the examiner, while in the latter they had to name a set of pictures aloud. Performance in the picture vocabulary task did not differentiate the groups, whereas the picture naming task did. Like Wolf et al., (1992), Snowling and colleagues suggest that the difficulty lay in retrieving the names of objects.

That picture naming deficits are shown by dyslexic readers, but not by poor readers in general is a question which has been addressed only relatively recently. If dyslexics are failing to read at the expected level for the same reasons as “garden variety poor readers” who show depressed IQ, then one would not expect a qualitatively different pattern of performance on a task of picture naming. However if they do differ, then such a finding would lend support to the claim that dyslexics represent a distinct group of impaired readers (Ellis, 1985). As Stanovich (1998) points out, the inference would
be that these two groups differ in cognitive subprocesses and are arriving at the same reading level by alternate routes. Wolf et al., (1992) assessed their dyslexic group at Grades 3 and 4 with a group of garden variety poor readers on their picture naming tasks; while both groups were impaired they did not differ significantly for either the picture naming task or the follow up task of receptive vocabulary. However, relative to the garden variety poor readers they reported that dyslexic readers were significantly more likely to choose the correct target in the latter task, suggesting that their poor performance on the picture naming task arose not because they didn’t know the word (which appeared to be the case for the garden variety poor readers) but because they could not retrieve it. Again the authors present this as “modest evidence pointing toward specific-retrieval deficits in dyslexic children” (Wolf et al., 1992, p. 239).

Swan and Goswami (1997a) also reported a picture naming deficit in a group of dyslexic and garden variety poor readers. While both groups made more errors than chronological age matched controls, the children in the dyslexic group tended to make more errors with polysyllabic and / or low frequency words, suggesting a possible phonological basis for their deficit. Furthermore the authors report that the dyslexic children recognised significantly more unnamed target words than any of the other groups, indicating that they had both phonological and semantic representations of these items. Their difficulty was instead evidence of a particular problem in the retrieval of phonological codes. In contrast the main source of error in the garden variety poor readers was an absence of vocabulary knowledge for the items presented. Studies which have administered simple tasks of confrontation naming to adult dyslexics have reported normal naming performance (e.g. Hanley, 1997; Felton, Naylor and Wood, 1990) in the context of continued impairments on tasks of reading. So while confrontation naming studies of dyslexic children have converged to suggest that dyslexic readers are characterized by a picture naming impairment, this appears not to be the case by adulthood. These studies however measured only accuracy, and not latency of response. Furthermore, unlike carefully controlled studies such as that of Swan et al., (1997a), lexical factors such as word length and frequency, have not been manipulated. Words which are longer and of lower frequency may be more sensitive in eliciting behavioural differences in performance, since they are likely to be less well specified at the phonological level.
Those developmental studies which have measured latency of response during single trials of picture naming have been rare, and have reported variable results. In an early study, Perfetti, Finger, and Hogaboam, (1978) assessed naming latency in a group of 32 children, half of whom were unskilled readers (i.e. not necessarily dyslexic). All participants performed tasks of colour, digit and picture naming as well as word reading. They report differences only for words, with slower responses particularly for longer words. They conclude that the poor readers have difficulty specifically in alphabetic coding, rather than in word retrieval generally. Such a conclusion may not apply to dyslexic readers given the extensive evidence that has accumulated in favour of a naming deficit in dyslexic children. If the study included such children it may have failed to detect slower naming performance in view of the relatively high frequency of the words used. Alternatively, as no accuracy measurements were taken, the possibility remains that overall picture naming performance was impaired but not measurable by slower response speeds. What is striking in this study, however, is the contrast between normal naming performance and extremely impaired word reading speed. It is clear that whatever the nature of the phonological deficit in the dyslexic individual, it is differentially taxed by reading relative to naming.

In contrast Fawcett and Nicolson (1994) do report slower naming speeds for dyslexics during single trial naming of colours, digits and letters relative to both chronological and reading age matched controls, but not relative to a learning impaired group matched for reading age. Deficits were found for three groups of dyslexics, with mean ages 8, 13, and 17. The authors conclude that naming speed deficits are apparent in a discrete trial format. One important difference between this study and that of Perfetti et al., (1978) is that Fawcett et al., (1994) used a constrained set of five items that were repeated randomly throughout the naming trial, while Perfetti et al., (1978) used a set of forty-two items. In addition, in neither study are details of the inter-stimulus interval made explicit so the rate at which items were presented may also have differed between groups. This is likely to be of importance given that in one of the few studies of adult single trial picture naming, rate of presentation was shown to significantly affect dyslexics’ performance. Wolff et al., (1990) report that as presentation rate increased so too did error rate in their dyslexic group. However, at slow rates of presentation the dyslexic readers were found to be unimpaired.
Unfortunately latency measurements were not recorded in any of the studies of adult dyslexics.

Together these results suggest that while picture naming is impaired in dyslexic individuals throughout childhood, such impairment is not detectable in adulthood, except at fast rates of presentation. It remains unclear whether naming speed is impaired, given the paucity of developmental studies and the lack of studies with an adult population. However, in view of the greater difficulty shown by dyslexic children with longer, lower frequency words on tasks of confrontation naming, it is likely that these stimuli would produce most difficulty in tasks of naming, even for adults. This will be investigated in Experiment 1.

2.9. Picture naming: Rapid automatic naming (RAN)

In rapid automatic or continuous naming a series of items must be named consecutively, and time to completion is measured. The classic rapid automatic naming (RAN) task, first conceived by Denckla and Rudel (1976a), required the naming of 5 stimuli as rapidly as possible 50 times in a serial manner. These stimuli were letters, colours, digits or pictured objects and were repeated randomly on a board. Following this classic study many researchers have adopted the RAN task both as a diagnostic tool and experimental measure in dyslexia research.

Like confrontation naming, RAN performance appears to be a good predictor of reading ability. Prospective studies conducted by Badian et al., (1990), Wagner, Torgesen and Rashotte (1994) and Wolf and Obregon (1992) found that very young children’s serial rapid naming skills were predictive of their reading success several years later. Similarly, Walsh, Price, and Gillingham (1988) found that poor naming skill at early grade levels was predictive of later reading problems.

Currently two main kinds of explanation have been put forward to account for poor performance on tasks of rapid serial naming. The first views this impairment as part of a pervasive problem at the level of phonological representation. Catts, (1986), Katz (1986) and Snowling and Hulme (1994) have all suggested that slow performance on this task stems from weakly specified or impoverished phonological representations.
for words, making access from the lexicon slower. More specifically Fowler (1991) has suggested that the segmental differentiation that occurs during normal phonological development may be deficient or delayed in children with dyslexia. The second kind of explanation for rapid naming deficits has been made by Wolf and her colleagues who have proposed a ‘double-deficit’ hypothesis for dyslexia (Wolf and Bowers, 1999). According to this hypothesis slow naming speed and poor phonological processes represent separate sources of reading disability that may occur independently or together. Their combined presence in a given individual is likely to lead to a profound reading impairment. They suggest two possibilities. According to one version of this hypothesis, slower naming speed arises as a consequence of lower level problems in visual processing which also disrupts letter pattern identification and the growth of orthographic knowledge. According to a second hypothesis, deficits in naming speed are conceptualised as one manifestation of more general processing speed deficits that may affect visual, auditory, and possibly motoric domains as well as orthographic and phonological systems.

In contrast to the normal performance shown by adult dyslexics on tasks of confrontation naming, almost all adult dyslexia studies of RAN performance have reported persistent deficits (Felton, Naylor and Wood, 1990; Pennington, Order, Smith, Green, and Haitl, 1990 and Brunswick et al., 1999). This is the case even when IQ and educational level are controlled (Felton et al., 1990) or matched (Brunswick et al., 1999). This contrast between normal performance with tasks of confrontation naming on the one hand, and impaired performance with tasks of serial rapid naming on the other awaits a full explanation. The differing demands of each format, which may go some way in accounting for this discrepancy, are considered in the following section.

2.10. Picture naming: Formats compared

Snapshots of a participant naming a given picture in a single trial and a RAN format would in many respects appear identical. In both instances the same visual form is presented for perceptual analysis, access to an object’s structural and semantic description is required, and an object’s name must be retrieved and articulated. Representation of these processes in a models such as Glaser’s (1992) would be
identical for both tasks. Yet adult dyslexics show robust impairments on tasks of serial naming but not for confrontation naming. Why?

The few attempts in the literature which have aimed to specifically explore this paradox generally make recourse to additional non-lexical demands posed by the RAN task. While there may be tacit agreement that a phonological weakness underlies poor performance on the RAN, this account has not been taken as a sufficient explanation of the dyslexic's slow speed. Instead the phonological deficit explanation has been subsumed into a broader more generalised automatisation impairment (Fawcett and Nicolson, 1994) or twinned with an equally disabling impairment in speed of processing (Wolf, 1999). In neither case is a perhaps more parsimonious possibility considered. That is, what differs most strikingly across these two formats is the context within which lexical retrieval proceeds. These two quite different theoretical standpoints will be considered in turn.

Wolf (1991) has played a primary role in the investigation of the RAN task both as a predictive measure of later reading ability, and as an index of both speed and phonological impairments in dyslexia. The efficacy of RAN in tapping these deficits is, she suggests, attributable to the similarity the task shares with reading. Naming in a serial continuous manner, for example, requires more subprocesses, including rapid scanning and sequencing that place greater demands on temporal integration. Given that these subprocesses are also required during text reading, the continuous naming format therefore represents a better index of reading skill. Indeed the single trial format “...may eliminate exactly those sources of variance that continuous naming speed shares with reading...” (Wolf, 1991, p. 127). This, she suggests, may explain why tasks of continuous naming have generally proved more reliable in differentiating groups of poor readers, and have been better predictors of reading performance. In particular it is hypothesized that “...naming speed deficits may be a ‘marker’ for the disruption of precise timing which could well affect the automatic induction of good quality orthographic codes and potentially their rapid connection to phonological representations” (Bowers and Wolf, 1993; p.69). This deficit in a precise timing mechanism affects the dyslexics' speed of processing and may represent a general impairment that may extend across several domains (Wolf, 1999; see also Wolff et al., 1990). Similarly, Fawcett and Nicolson (1994) in their study of single trial naming
speed also comment on the relatively robust results obtained from RAN naming procedures. They suggest that rapid tiring, place keeping, vigilance and error recovery may represent specific factors that contribute to a naming speed deficit on the RAN task – factors which are absent in a discrete trial format. In a similar vein to Wolf, they suggest that as a consequence rapid automatic naming “...provides a more sensitive index of pure processing speed...” (Fawcett and Nicolson, 1994, p. 642).

One criticism that may be levelled at both Wolf and colleagues (Wolf, 1991; Wolf and Bowers, 1999) and Wolff et al., (1990) is that they have simply conflated a behavioural measurement (speed / accuracy of response at faster presentation rates) with an analogous cognitive factor (speed of processing / rate of information processing). Slowness at the behavioural level is merely the observable consequence of many possible deficits in the naming system. A quite distinct account as to why the RAN task poses increased difficulty for the dyslexic individual could confine itself to purely phonological factors. Such an account has remained surprisingly undeveloped, with researchers tending to simply refer to the phonological deficit as a sufficient explanation of the dyslexics naming difficulty. The shortcoming of this position is that it fails to explain why the RAN format, in contrast to the discrete trial format, differentially taxes the phonological deficit. It is arguable that a process account might more parsimoniously account for dyslexics’ impairment on the RAN task. According to this position, it is only the process of lexical retrieval which is modulated by the rate at which naming proceeds. Increasing the rate of naming serves to increase the degree of competition from other phonological items, since the degree of activation of the target item must now be higher in order for it to be distinguished from recently named partially activated competitors.

The cognitive basis for the naming impairment in tasks of serial rapid naming therefore remains unresolved. A generalised speed of processing deficit has been put forward as a possible explanation. Here an alternative is proposed: that the RAN task poses particular difficulty for dyslexic individuals because of the fast rate at which lexical retrieval proceeds. It is proposed that the increased rate of lexical access, increases the level of phonological competition, which is in turn is inefficiently resolved by dyslexic readers.
2.11. The Spoonerism task

The term ‘spoonerism’ derived its name from the Reverend William Archibald Spooner (1844-1930), Dean and Warden of New College, Oxford who was reputed to commonly make errors in which the phonetic segments (usually the initial sounds) of two different words were switched – often with humorous consequences. While today many of these attributions are now believed to be apocryphal they still clearly demonstrate the nature of this speech error. Commonly quoted examples include such phrases as “You have hissed all my mystery lectures” when in fact Spooner meant to say “You have missed all my history lectures”; or famously, “Queer old dean” when referring to dear old Queen Victoria. These kind of unintended departures from planned utterances were given particular emphasis by Freud, who suggested that these and other kinds of speech errors were indicative of repressed thoughts or desires. However modern psychologists have instead used such slips of the tongue as the basis to investigate both the structure of lexical representations and speech production processes (Fromkin, 1973). The spoonerism in particular has been an especially popular type of verbal slip for psycholinguistic research given the clarity of its mutilation (MacKay, 1970).

While spoonerisms may occur naturally in spontaneous speech, techniques were developed to increase the frequency of which spoonerism errors were elicited in the laboratory. Word pairs that were to be read aloud were preceded by ‘interference’ word pairs. These were designed to resemble the phonology of the desired spoonerism pair more closely than the phonology of the subject’s intended target. For example when the target word pair ‘fruit fly’ was preceded by the interference words ‘flag – fraud’ participants were more likely to generate the spoonerism ‘flute – fry’. This technique has been useful in establishing the factors that influence the probability of spoonerism frequencies. Motley and Baars (1975) for example, using this technique demonstrated that the frequency of spoonerism production is affected by the phonotactic probability of the initial word structure and the lexical legitimacy of the error.

In contrast to such unintended spoonerism production, it was some time before experimental tasks were designed which explicitly required participants to switch
word sounds in a systematic fashion. While this task requires skill in verbal short-term memory, blending and non-word articulation it is primarily taken to reflect proficiency in phonological segmentation. Perin's (1983) seminal study was the first to employ a simple spoonerism task in which subjects were asked to switch the initial sounds of word pairs (in this case pop groups or names of famous singers). The aim of the study was to evaluate the relationship between phonemic segmentation ability and literacy skill in groups of good and poor readers. Perin reported that performance on this task was strongly related to spelling rather than to reading skill, and concluded that poor spellers – irrespective of their reading skill – had difficulty operating on the phonemic level of speech. The use of such spoonerism tasks in addition to other tasks requiring manipulation of phonetic segments of words (e.g. tasks of pig latin, phoneme insertion or deletion) are now commonly used as an index of phonological awareness in both clinical and research contexts. Studies investigating the phonological processing skills of dyslexic adults have demonstrated that deficits on tasks of word sound manipulation persist into adulthood (Felton, Naylor and Wood, 1990; Pennington, Van Orden, Smith, Green, and Haith, 1990). Tasks which specifically require word spoonerising have also been explicitly presented to adult dyslexics; accuracy of response is generally taken as the dependent variable (Hanley, 1997) but a few studies have measured both accuracy and speed of response (Paulesu, et al., 1996; Snowling, Nation, Moxham, Gallagher and Frith 1997; Brunswick et al., 1999). Dyslexic participants, even those who have reached a university level of education, make more errors and respond more slowly on these tasks. This has been taken to represent evidence of a persistent and continuing deficit in phonological processing in developmental dyslexia that is not mitigated by improvements in overall literacy ability (Brunswick et al., 1999).

2.12. Conclusions

Although the most apparent indications of dyslexia relate to reading and writing, it is evident that the difficulties of dyslexic individuals extend beyond literacy and include a variety of tasks which require phonological processing. Evidence for impairments in phonological repetition, picture naming and spoonerising have been reviewed. These impairments are unlikely to be attributable to difficulties in vocabulary, since even when vocabulary level is controlled relative impairments on these tasks persist.
Instead researchers have attributed repetition and naming difficulty to one of phonological retrieval. Specifically it has been suggested that phonological representations are degraded or poorly specified in the dyslexic, leading to difficulty in any task where these representations are accessed or manipulated.

Figure 2.10. Causal links among the different phonological processes and reading (from Snowling, 2000, p.59).

In this way the phonological impairment is postulated to represent a core deficit, accounting for poor performance on a variety of apparently disparate tasks. This is illustrated in Figure 2.10. (from Snowling, 2000; p.59). One hypothesis is that the phonological representations themselves are poorly or inadequately specified. It has been suggested that such a lack of specification, in terms of phonological encoding, while congruent with many of the experimental findings in the literature, is nonetheless lacking in explanatory power. For example, poor phonological representation does not account for the clear context sensitivity in tasks of naming – and in particular why naming items in a continuous rapid format particularly taxes dyslexic individuals. This has led to the proposal that dyslexia may be characterised by an additional deficit in speed of processing (e.g. Wolf, 1991) which extends beyond the linguistic domain. Nor does the representation hypothesis adequately explain why reading is strikingly more impaired than naming given that the same phonological representation is retrieved in each case.
In contrast, the competition hypothesis attributes poor phonological processing to the inefficient resolution of competition effects at the phonological level. The advantage of this perspective is that it predicts normal task performance on tasks where such competition is low. While this is possible for picture naming, reading an inconsistent orthography such as English will always entail a high degree of phonological competition. The experiments in this thesis have been designed to further investigate the cognitive basis of the phonological deficit in dyslexia by manipulating those factors that are hypothesised to influence phonological competition: modality (words vs. pictures), rate of naming, and word length.
3.1. Introduction

A number of functional imaging studies have now been carried out in an effort to characterise the neural systems affected in developmental dyslexia. These studies have been comprehensively reviewed elsewhere (Habib, 2000; Demb, Poldrack and Gabrieli, 1999). The focus of the chapter will be to critically evaluate those studies that have specifically investigated phonological processing in dyslexia. These studies have identified abnormal activation in dyslexic readers in three left hemisphere areas: (1) the angular gyrus, and adjacent regions including the supramarginal gyrus and the posterior aspect of the superior temporal gyrus (Wernicke's Area); (2) the left posterior inferior temporal lobe (BA37); (3) a set of left frontal regions. After a brief overview of several early studies, the evidence implicating each of these regions will be considered in turn. The main studies reviewed here are summarised in Table 3.1.

3.2. Early studies

In the context of well-documented behavioural evidence for a persistent impairment in phonological processing in dyslexia, imaging studies have aimed to identify the neural system underlying such a deficit. The first studies to evaluate phonological processing were undertaken early in the development of PET (Positron Emission Tomography). Gross-Glenn, Duara, and Loewenstein et al., (1991) in a PET study of glucose metabolism, employed a task of serial reading of single words. Decreases in the normal asymmetries of frontal and occipital regions in the dyslexic group were reported: the control group showed greater leftward asymmetry in the activation of the lingual gyrus, but more rightward asymmetry in the activation of frontal regions. A separate study, also employing PET with glucose uptake as the dependent measure, reported significantly higher rCBF (regional cerebral blood flow) by dyslexic subjects.
in bilateral medial temporal lobes during a task of auditory syllable discrimination (Hagman, Wood, Buchsbaum, Tallal, Flowers, and Katz, 1992). That neither of these results were subsequently replicated is most likely due to weaknesses in the experimental design (activation associated with baseline conditions were not subtracted), a failure to equate behavioural performance across groups, and to limitations of the technical and statistical power to reliably identify population differences.

Two other studies at this time implicated the left temporoparietal region (Flowers, Wood and Naylor, 1991; Rumsey, Andreason, Zanetkin, Aquino, King, Hamburger, Pikus, Rapoport and Cohen, 1992). Flowers et al., (1991) carried out a xenon inhalation study of rCBF during an orthographic task, where subjects were required to identify correctly spelled words of four letters presented aurally. Childhood reading impairment was related to excessive blood flow in a posterior temporoparietal region. In the study by Rumsey et al., (1992) – the first to use PET and $^{15}$O-labelled water in dyslexics – subjects were presented with pairs of one-, two-, and three- syllable words. Their task was to make a button press response if the pair rhymed. The baseline task required the detection of a low tone among a series of distracters. The dyslexic group performed the task more poorly, and showed significantly less activation in two left temporoparietal regions activated by rhyme detection in controls. Limitations of spatial resolution did not allow Talairach coordinates to be reported, but the areas were believed to fall within left middle temporal and parietal regions, which encompassed the angular gyrus. The authors explicitly argue for “a link between angular gyrus activity during phonologic processing and dyslexia”, a position which they later develop. The region of interest method employed by this study somewhat limits the scope of these results. The possibility that differences existed in other areas, outside the chosen regions can not be excluded. A second disadvantage is that the pre-selection of areas of interest artificially increases the probability of activation differences in the selected areas. The majority of later studies have therefore adopted a whole-brain voxel-based approach.
<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects</th>
<th>Task</th>
<th>Response</th>
<th>Inf. parietal (BA 59/40)</th>
<th>Superior temporal (BA 42/22)</th>
<th>Lateral frontal operculum</th>
<th>Medial Frontal operculum</th>
<th>Medial temporal (BA 21/37)</th>
<th>Inferior temporal / fusiform (BA 21/37)</th>
<th>Striatum/ Extrastriate (BA 17/18)</th>
<th>Corbællum</th>
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<tbody>
<tr>
<td>Rumsey et al., 1992</td>
<td>14 dyslexics 14 controls</td>
<td>Auditory syllable detection</td>
<td>Button press</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
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<tr>
<td>Paulesu et al., 1996</td>
<td>5 dyslexics 5 controls</td>
<td>Phonological STM</td>
<td>Button press</td>
<td>-46, 44, 24</td>
<td></td>
<td></td>
<td></td>
<td>-38, 4, 20</td>
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<tr>
<td>Rumsey et al., 1997</td>
<td>17 dyslexics 14 controls</td>
<td>Reading words Verbal</td>
<td></td>
<td>-28, -32, 44</td>
<td>-52, -30, 12</td>
<td>-54, -22, 4</td>
<td>-42, -28, 16</td>
<td>-2, -44, 24</td>
<td>12, -70, 24</td>
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<td></td>
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<td>Reading pseudowords Verbal</td>
<td></td>
<td>-50, -40, 24</td>
<td>-50, -32, 12</td>
<td>-40, -26, 20</td>
<td>-48, -62, 4</td>
<td></td>
<td>-6, -58, 24</td>
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<tr>
<td>Brunswick et al., 1999</td>
<td>12 dyslexics 12 controls</td>
<td>Reading: words and pseudowords Verbal &amp; button press</td>
<td></td>
<td>-64, 0, 26 D</td>
<td>-40, 4, 22</td>
<td>-42, -60, 12</td>
<td>-42, 48, 6</td>
<td>-2, -80, 18</td>
<td>-18, -70, 28                -48, -48, -26</td>
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<tr>
<td>Temple et al., 2001</td>
<td>24 dyslexics 15 controls</td>
<td>Letter rhyme decision Button press</td>
<td></td>
<td>-55, -67, 15</td>
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<tr>
<td>Paulesu et al., 2001</td>
<td>36 dyslexics 36 controls</td>
<td>Reading: words and pseudowords Verbal &amp; button press</td>
<td></td>
<td>-54, -50, 14</td>
<td>-60, -56, 0</td>
<td>-52, -60, 14</td>
<td>-52, -64, 6</td>
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Table 3.1: Reported left hemisphere differences in activation between control and dyslexic groups in both PET and fMRI studies. All co-ordinates indicate greater areas of activation in the control relative to the dyslexic group except those marked D which are areas of greater activation in the dyslexic group. ✓ indicates greater activation in the control group where Talairach coordinates have not been reported. *Significant hemispheric interaction with significantly greater left relative to right hemisphere activation in the control group, a pattern reversed in the dyslexic group.
3.3. Evidence implicating the left angular gyrus (BA39)

For well over a century the angular gyrus has been implicated in reading. Dejerine (1891, 1892) was the first to link this region to acquired deficits in reading and writing – alexia with agraphia – and to acquired deficits in reading only – alexia without agraphia. On the basis that individuals with lesions centred on the angular gyrus developed both deficits in reading and writing, Dejerine inferred that this region was associated with the stored knowledge of visual word forms. In contrast, individuals who presented with deficits only in reading but not in writing (alexia without agraphia) were shown to have lesions located in the left medial occipital region and the splenium of the corpus callosum. Geshwind (1965) postulated that a ‘disconnection’ between these lesion sites and the angular gyrus precluded access of the visual input to the language centre. The connections between the angular gyrus and Wernicke’s area were in turn seen as necessary for the visual word forms to map onto the phonological structures of the language (Geshwind, 1965). This historical lineage formed the basis of a very natural expectation: that those individuals with a developmental impairment in reading would also show abnormalities in the angular gyrus. As already noted, Rumsey et al., (1992) reported reduced activation in the left angular gyrus during a rhyming task. The four subsequent studies of dyslexics that have investigated reading and reading related tasks will be reviewed in turn: (i) Rumsey, Nace, Donohue, Wise, Maisog and Andreason, 1997; (ii) Shaywitz, Shaywitz, Pugh, Fulbright, Constable, Mencl, Shankweiler, Liberman, Skudlarski, Fletcher, Katz, Marchione, Lacadie, Gatenby and Gore, 1998; (iii) Temple, Poldrack, Salidis, Deutsch, Tallal, Merzenich and Gabrieli, 2000; (iv) Brunswick, McCrory, Price, Frith and Frith, 1999. The first three of these studies present evidence that the angular gyrus is specifically implicated in reading disability, a finding not supported by the fourth study (Brunswick et al., 1999) nor in a related paper (Paulesu, Demonet, Fazio, McCrory, Chanoine, Brunswick, Cappa, Cossu, Habib, Frith, and Frith, 2001). It will be suggested that abnormal activation in the angular gyrus, rather than representing the neuroanatomical locus of the dyslexics’ phonological impairment, is simply an index of their poorer reading accuracy. Reduced activation in the angular gyrus has been reported only when the performance accuracy of the dyslexic participants is impaired (Rumsey et al., 1992; Rumsey et al., 1997; Shaywitz et al., 1998; Temple et al., 2001) and not when performance accuracy was matched with that
of the control group (Brunswick et al., 1999; Paulesu et al., 2001). This possibility will be discussed in the context of neuroimaging data from the normal population that implicate the angular gyrus in *semantic* rather than phonological processing.

*(i) Rumsey et al., 1997:* The study by Rumsey and colleagues (1997) assessed word and nonword reading in 17 dyslexic and 14 control male adults. The data provided by this group was used for correlational analyses in two later papers (Horwitz, Rumsey, and Donohue, 1998; Rumsey, Horwitz, Donohue, Nace, Maisog and Andreason, 1999); these will be discussed following a discussion of the primary study.

Rumsey and colleagues (1997) used whole brain analysis to measure rCBF with oxygen 15 PET during two pronunciation tasks and two lexical decision tasks. In the first pronunciation task participants were required to read aloud a series of pseudowords constructed so that they did not resemble real words (e.g. 'chirl' and 'phalbap') while in the second pronunciation task participants were required to read aloud a series of irregular real words (e.g. 'choir' and 'cocoa'). In the two lexical decision tasks participants viewed pairs of items on either side of the monitor. In the first they made a phonological decision: participants were required to decide which of two pseudowords sounded like a real word if pronounced correctly (e.g. 'bape' or 'baik'). In the second they made an orthographic decision: to choose the correctly spelled word from a real word and a pseudoword distractor (e.g. 'hole' or 'hoal'). Responses were made silently by pressing a button held in either the right or left hand. Visual fixation on a cross hair represented the baseline condition. The dyslexic sample all had a history of reading impairment identified in childhood, and met DSM-IV criteria for developmental reading disorder, with at least average intelligence and good spoken language. The control participants were matched on the basis of handedness, age, social class and IQ.

The dyslexic readers showed relatively less activation in a range of areas; these are summarised in Table 3.1. For reading aloud, the dyslexic group showed reduced activation of the left superior temporal gyrus, the left angular gyrus, the middle temporal regions particularly on the right, the left precuneus and left fusiform gyrus. For the lexical decision tasks the dyslexic sample displayed more areas of deactivation relative to fixation, including the left prefrontal cortex, the left and right inferior,
middle and superior temporal gyri, the posterior cingulate gyrus and precuneus and in particular the angular / supramarginal region bilaterally. In those regions that were activated above fixation, significantly less activity was reported in temporal and inferior parietal cortex. Therefore across both reading and lexical decision tasks dyslexic participants showed reduced rCBF in mid to posterior temporoparietal cortex, including the angular/supramarginal region, the left superior temporal and middle temporal gyri, and in the left fusiform region. However, essentially normal activation was reported for the same tasks in the left inferior frontal regions. This, the authors suggested, is compatible with the hypothesis of bilateral involvement of posterior temporal and parietal cortices in dyslexia. The failure to detect differences in brain activation between the word and non-word versions of the task is also reported. The authors suggest that a common impairment underlies the difficulty in both kinds of reading task in dyslexia.

These same data provided the basis for two further papers (Horwitz et al., 1998; Rumsey et al., 1999) in which correlational analyses were reported. In the first by Horwitz and colleagues (1998), the authors aimed to establish the functional connectivity of the angular gyrus in both groups by evaluating inter-regional correlations of rCBF. A reference voxel was chosen on the basis of several previous studies of normal readers (BA39; -44, -54, 24). They report that the control group displayed significant positive correlations during pseudoword reading, between left angular gyral activity and several other left hemisphere areas including: inferior temporal gyrus (BA37); occipital gyrus (BA 19); lingual and fusiform gyri (BA18 and 20); superior temporal gyus (BA 22); and left inferior frontal gyrus (BA 45). Non-significant or weaker correlations were observed when the reference voxel was placed in the right angular gyrus. A comparable but less significant pattern was observed for the exception word condition in the control group. When degree of correlation was statistically compared across groups, dyslexic readers failed to display strong functional relationships with several of these left hemisphere regions including the: inferior frontal cortex; middle and inferior temporal cortex (BA 21/37); as well as superior temporal (BA 38) and occipitotemporal cortices (BA 19). This, it is argued, indicates a functional disconnection of the angular gyrus and these areas.
In a second paper, again using the same set of data from Rumsey et al., (1997), the same authors provide further support for the role of the angular gyrus in dyslexia by establishing correlations between blood flow and reading ability as measured outside the scanner (Rumsey et al., 1999). These correlations, while uniformly positive for the control group, were reported to be uniformly negative for the dyslexic group. While greater rCBF in the angular gyrus was associated with better reading in the control group, in the dyslexic group it was associated with worse reading skill. This, the authors suggest, reflects diametrically opposed relationships in the two groups. Performance accuracy during the scans produced a similar pattern of correlations with rCBF in the angular gyrus. As a control measure, correlations between the WAIS-R perceptual organisation factor and rCBF in this region were calculated. No significant correlations were found. On the basis of these results the authors again speculate on the presence of a functional lesion in the angular gyrus in dyslexia.

The evidence for disordered processing in the angular gyrus in these three papers was predicated on one data set and one set of dyslexic participants (Rumsey et al., 1997). A number of considerations however serve to undermine the basis for this conclusion. Firstly, the activation differences reported in the dyslexic participants were accompanied by highly significant deficits in task performance. Secondly, as the tasks were self-paced, the number of items viewed by each participant varied. This was reflected in a difference in the mean reaction times between the dyslexic and control subjects, again across all four tasks.

The consequence of widely differing levels of performance was, as the authors point out, a much more widespread and diffusely distributed spatial extent in the areas of activation and deactivation in the dyslexic sample. It is argued that while differences in spatial extent may be generalised to effects of difficulty level, localised differences appear more task-related. In practice, however, it is impossible to confidently partition activation differences arising from gross behavioural impairments from those attributable to differences in phonological processing. This is particularly the case given the degree of deficit displayed by the dyslexic sample, which led not only to more errors but to a much slower rate of stimulus presentation. These factors substantially affect the putative cognitive processes that the measurements of blood flow are taken to reflect (Price, Moore and Frackowiak, 1996; see Price and Friston,
1999). The question arises whether a control group of non-dyslexic poor readers, making a comparable number of errors or carrying out the task at a similarly slow pace would show a pattern of activation similar to that reported for the dyslexic group in this study. Such an inference would follow if activation in the angular gyrus reflected semantic processing and if the level of semantic processing varied with performance accuracy. A variety of functional imaging studies in the normal population have demonstrated the involvement of the angular gyrus in semantic processing. For example, this region is more active for reading words relative to reading nonwords (Brunswick et al., 1999), for reading the names of objects and famous people relative to letter strings (Gorno-Tempini, Josephs, Vandenberghe, Cappa, Kapur and Frackowiak, 1998), and for making semantic decisions on written words (living or nonliving?) relative to phonological decisions (two syllables or not?) with the same stimuli (Price, Moore, Humphreys, and Wise, 1997). Crucially, it is also activated during semantic decisions with non-orthographic stimuli: with pictures (Vandenberghe, Price, Wise, Josephs, and Frackowiak, 1996; Mummery, Patterson, Hodges, and Price, 1998) and auditorially presented words (Binder, Frost, Hammeke, Cox, Rao, Prieto, 1997). The reduced activation and abnormal correlations observed in the angular gyrus in the dyslexic participants may therefore be attributable to reduced levels of semantic processing that are a consequence of poor reading accuracy.

In previous studies of the normal population it has been shown that differences in rCBF can emerge as a result of different presentation rates in fixed rate designs (Price, Moore and Frackowiak, 1996). The self-paced nature of the study reported by Rumsey et al., (1997) and the behavioural differences which inevitably arose as a consequence, may have contributed to the correlations observed between the rCBF measured in the angular gyrus, and reading skill (Rumsey et al., 1999). In order to address this concern the authors calculated the correlation between rCBF and subject’s mean reaction times to determine if there was a general correlation with the rate at which the task proceeded and rCBF. This correlation failed to reach significance for either group, leading the authors to conclude that the relationship between reading skill and rCBF were not an artefact of subject induced differences in the rate of stimulus presentation. However, the failure to detect a correlation between rCBF and an approximate indication of presentation rate does not eliminate the concern that correlations in the angular gyrus and reading skill are merely secondary to dyslexia. Mean reaction time
represents a gross indication of exposure duration, which is likely to have varied across the course of the experiment. While some subjects may have presented with a consistent level of performance deviating little from a given pace, others may have shown considerable variability, responding sometimes slower and at other times quite rapidly. Both kinds of subjects may have had identical mean reaction times, yet this single measure would poorly characterise their very different experiences in the scanner.

In addition, mean reaction time does not take into account performance accuracy. Indeed the authors point out that performance accuracy also correlated with rCBF in the same manner as reading ability, with positive correlations in the control group and negative correlations in the dyslexic group. Such a finding in fact supports the view that performance accuracy itself (and not cognitive differences specific to dyslexia) may account for the observed correlations between rCBF and reading ability. The authors suggest that these correlations indicate 'diametrically opposed relationships in the two groups' with a positive correlation in the control group, and a negative correlation in the dyslexic group. Yet there is no apriori reason to suppose that reading ability and blood flow in a given region should be characterised by a linear function. If the data for both groups are plotted together they would reflect a U-shaped relationship which in turn may actually reflect performance accuracy. This is an empirical question that can be addressed by measuring rCBF across the range of reading ability in the normal population, in order to establish how levels of blood flow in the angular gyrus vary as a function of reading skill. Another point of concern regards the failure to report correlation scores for reading ability and rCBF in other brain regions. In Figure 1 of the paper (Rumsey et al., 1999), a single coronal slice (z=24) is shown, which indicates that significant correlations arose in other areas; these however are not mentioned in the text. The failure to report these correlations make it difficult to assess the particular significance of the angular gyrus with regard to reading skill.

(ii) Shaywitz et al., (1998): The role of the left angular gyrus has also been given particular emphasis in an fMRI study by Shaywitz and colleagues (1998). In an effort to systematically vary the level of phonological processing Shaywitz et al., (1998) presented a hierarchy of tasks to a group of 29 dyslexic readers and 32 control readers.
These were hypothesised to make progressively greater demands on phonological analysis. At the base of the hierarchy was a line orientation judgement task which required only visuo-spatial processing (e.g. Do \(\text{WW}\) and \(\text{WW}\) match?). In the second task, letter case judgement, (e.g. do bbBb and bbBb match?) the authors suggest that orthographic but not phonological processing is required since the consonant strings are phonotactically illegal. However, it is likely that some phonological processing was elicited given that the letters are readily nameable and highly familiar. Next, the letter rhyme task (Do T and V rhyme?) necessitated a phonological in addition to an orthographic component. A fourth task requiring a rhyme judgement of nonwords increased the phonological component further (e.g. Do ‘lete’ and ‘jete’ rhyme?). In addition, the fifth and final task required subjects to decide whether two words (e.g. ‘corn’ and ‘rice’) were in the same semantic category.

Behavioural performance of the dyslexic participants was significantly impaired on each of these tasks except for the initial line judgement task. Yet even for this baseline task they were tending to make more errors (5.1% vs. 3.0% for the control participants). With regards to the functional imaging data 17 regions of interest were identified in each hemisphere. Rather than look for patterns of activation differences across single tasks Shaywitz et al., (1998) aimed to identify reading group - task interactions. Four regions were noted: the superior temporal gyrus (posterior STG, Wernicke’s area); the angular gyrus (BA 39); striate cortex (BA 17); and inferior frontal gyrus (IFG, BA 44/45). In addition marginally significant interactions were reported for the inferior lateral extrastriate cortex (ILES) and the anterior inferior frontal gyrus (BA 46/47/11).

The four posterior areas, including Wernicke’s area, the angular gyrus, the striate cortex and the ILES, all demonstrated the same pattern of increasing activation across tasks in the control group. That is, an increase in activation going from the letter-case judgement to letter and nonword rhyme tasks. The dyslexic group failed to modulate activation in this way showing both overall lower levels of activation and no systematic increase across tasks.

These data are taken by the authors to represent evidence of a “...functional disruption in an extensive system in posterior cortex encompassing both traditional visual and
traditional language regions..." (Shaywitz et al., 1998, p. 2639). Like Rumsey et al.,
(1992; 1997) particular attention is drawn to the abnormal activation of the angular
gyrus within this system, which they state "...is considered pivotal in carrying out
those cross-modal integrations necessary for reading" (ibid. p. 2639). The frequency
of neuroanatomic lesions to this region in acquired alexia is noted. Shaywitz et al.,
(1998) argue that even though such a condition involves damage to an already existing
system, and dyslexia is a disorder which will produce cumulative effects over
development, the important point is that disruption of the angular gyrus represents an
abnormality within the same neuroanatomic system.

As in the Rumsey et al., (1997) study, however, the study by Shaywitz et al., (1998)
was characterised by a confound in task performance across dyslexic and control
groups. When rCBF differences co-occur with significant impairments in task
performance then it becomes impossible to confidently attribute such neural
differences to the impaired performance or to a postulated cognitive deficit. Once
again, the lower level of activation observed in the left angular gyrus in the dyslexic
group might simply reflect their lower levels of accuracy across tasks. A second
confound, specific to the Shaywitz et al., (1998) study, regards the failure to
appropriately match control and dyslexic participants. That the groups differed in
performance even of the case judgement task suggests that the control and dyslexic
participants differed not only in reading skill, but in cognitive abilities beyond those
expected by such an impairment. Normal performance by dyslexic participants on
tasks of physical matching of letters has been shown in the behavioural literature (e.g.
Ellis, 1981). Such a surmise is given further support by significantly lower full-scale
(FS) IQ of the dyslexic participants in this study (FSIQ: 91) relative to their control
group (FSIQ: 115). The degree of this discrepancy in overall cognitive ability renders
the origin of any differences in task specific rCBF changes uncertain. It is not
unreasonable to speculate that two control groups - who differed only in IQ - would
also show comparable differences in their pattern of neural processing. A final
consideration relating to the samples studied by Shaywitz and colleagues (1998)
regards the failure to indicate whether dyslexic and control groups had been matched
on age. While the age range is comparable for both groups (dyslexics: 16-54; controls:
18-63) at no point do the authors indicate that the groups were matched for mean age.
Like discrepancies in IQ, how differences in chronological age might affect rCBF measurements in these tasks is not known.

(iii) Temple et al., (2001): This recent fMRI study has assessed the neural correlates of phonological processing in a group of 24 dyslexic children (8-12 years old) relative to a group of 15 control children matched in age. In the experimental task the children were required to judge whether a pair of visually presented letters rhymed, making their response using a hand-held response button. Stimulus pairs were presented in blocks of five and were preceded by the prompt ‘rhyme?’ There were two baseline conditions. In the first, participants viewed two letters and pressed a button if the letters matched; in the second they viewed two lines from a possible set of three (| / \) and pressed a button if they were the same. These were also presented in blocks of five and were preceded by the prompt ‘same?’.

For rhyme letters vs match letters the control children showed activation in left frontal and temporo-parietal left hemisphere regions including the angular gyrus; in contrast the dyslexic children failed to activate the left temporo-parietal cortex. A region of interest analysis was then carried out centred at the control children’s peak voxel of activation in the angular gyrus. This indicated that the normally reading children had more activity in this region during the rhyme and letter conditions relative to the match lines baseline, but the dyslexic children had less activity for these conditions relative to the baseline. However a comparison of the match letter vs match lines conditions did not reveal significant differences across the groups in the angular gyrus. In view of the fact that the control and dyslexic children were not matched in general ability, it was possible that any differences were due to differences in IQ between the two groups. To address this concern the authors took subsets of 13 children from each group in order to create IQ matched groups. A comparison of these groups indicated that the angular gyrus was still significantly less activated in the group of dyslexic children.

Like both Rumsey et al., (1997) and Shaywitz et al., (1998), Temple et al., (2001) draw particular attention to the reduced activation observed in the dyslexic children in the temporo-parietal region centred on the angular gyrus. They conclude that the impaired neural responses in this region reflect abnormal phonological processing in
the dyslexic children. However, this conclusion is once again predicated on the assumption that differences in neural activation across the groups is not a function of differences in behavioural performance. In this study the dyslexic children were both significantly slower and significantly less accurate in the rhyme letter condition than their peers. The authors address this concern directly: “Inevitably, the coupling of such behavioural and neural impairment raises the question of whether the altered neural response is the cause or the consequence of the phonological impairment. The discovery in this study that the altered neural response, especially the absence of temporo-parietal activation during phonological performance, is present in childhood favours the view that the neural response is causal rather than a compensatory response” (Temple et al., 2001, p. 8; italics added). Sadly this defence is groundless. While the authors accept that differences in behavioural performance might give rise to differences in neural activation they point out that in their case this is unlikely since they observed such differences in a group of dyslexic children. There is every reason to suppose that children like adults who perform poorly will present with an altered pattern of neural responses.

A second concern with this study relates to the way in which the region of interest (ROI) was identified in relation to the peak of activation in the angular gyrus. By selecting a region of activation that is known to be robustly activated in the control group as a point of comparison the likelihood that a comparison group will show comparatively less activation in this area is artificially increased. The logic is as follows: if a locus of comparison is chosen a priori, based independently on previous findings, then it is possible that the control group may show (i) low or (ii) high activation in this region and that the dyslexic group may show (iii) low or (iv) high activation of this region. By eliminating one of these possibilities a posteriori – by choosing a region known to exclude (i) – then the probability of a Type 1 error becomes more likely. In the Temple et al., (2001) study the locus of the angular gyrus was identified on the basis of the activation of the control participants.

A third and final limitation of this study is that the control and dyslexic groups, while matched for age, were not matched for IQ. However Temple and colleagues repeated the analysis with a subset of subjects who were matched for IQ. The authors point out that the key region of interest – a left temporo-parietal region – showed reduced
activation in the dyslexic group irrespective of IQ. On this basis they suggest that IQ was “unrelated to the phonological deficit”. Yet the same authors point out that three regions differed significantly between the IQ and non-IQ matched dyslexics when compared with their controls. Contrary to the authors’ conclusions, this indicates that IQ does give rise to measurable, and indeed unpredictable, differences in brain activation. This highlights the need for a systematic investigation of how IQ interacts with individual aspects of language function – in both dyslexic and normal individuals.

(iv) Brunswick et al., (1999): Brunswick, McCrory, Price, Frith and Frith (1999) carried out two PET studies of reading with the aim of controlling the performance level of the control and dyslexic groups. In the first study 6 control and 6 dyslexic participants were asked to read aloud a series of words and pseudowords. In contrast to both Rumsey et al., (1997), Shaywitz et al., (1998) and Temple et al., (2001) performance accuracy was matched across control and dyslexic groups by employing only highly familiar short words in a straightforward reading task. In addition the design was a fixed pace to ensure identical presentation rates across all participants. For the second study, another group of 6 dyslexic and 6 control participants were recruited. Here the authors aimed to reduce the possibility of differences in cognitive strategy (which the dyslexic participants might invoke during explicit reading) by making reading incidental to a feature detection task. Participants were required to decide whether an ascender (a letter going above the midline of the word) was present in either a word, pseudoword or falsefont string depending on the condition. This feature detection task was closely modelled on that of Price, Wise and Frackowiak (1996) who demonstrated that the mere presence of words or pseudowords in the visual field automatically activates semantic and phonological processes even when the intention is not to read. In a related study Paulesu et al., (2001) combined the data from these 12 English dyslexics with a group of 12 French and 12 Italian dyslexics. Identical paradigms were established across orthographies (i.e. explicit reading and incidental reading) and again the performance of these dyslexics was matched with their respective control groups.

Both Brunswick et al., (1999) and Paulesu et al., (2001) failed to detect reduced activation in the dyslexic group in the region of the angular gyrus during the explicit
or incidental reading tasks. Importantly this was in the context of task performance that was matched across the dyslexic and control groups. Because concrete, highly familiar two syllable words had been employed, both the dyslexic and control participants in all three countries performed the word reading task at ceiling. The absence of differences in the temporo-parietal region in this context is therefore consistent with the view that reduced activation here is simply an index of poorer performance accuracy. These reduced levels of accuracy and/or slower rates of performance may in turn attenuate the level of semantic processing during the task. It is possible therefore that reported differences in this region are not in fact an index of impaired phonological processing in dyslexia but a general correlate of performance accuracy.

3.4. Evidence implicating the left posterior inferior temporal lobe (BA37)

A magnetoencephalography (MEG) study by Salmelin, Service, Kiesila, Uutela, and Salonen, (1996) provided evidence for disordered processing in the left inferior temporo-occipital region in Finnish dyslexic subjects during silent reading. This region becomes active as early as 180 ms after the presentation of a word and is therefore likely to represent very early stages in visual and/or phonological processing. Even up to 700ms post stimulus onset the dyslexics' activation of the left temporal lobe was significantly less than that of the control subjects. Unfortunately, because reading was silent, it was impossible to rule out the possibility that the failure to activate this region was a consequence of a failure to read the stimuli accurately. Rumsey et al., (1997) also reported reduced activation in the same region (BA37) during tasks of reading and lexical decision; however like Samelin and colleagues it was impossible to rule out the possibility that this difference arose as a result of differing levels of behavioural performance between control and dyslexic groups.

In the study by Brunswick et al., (1999) in which performance accuracy was matched, this pattern of reduced activation in the posterior inferior temporal lobe (BA37) was replicated in both the explicit and implicit reading tasks. Similarly Paulesu and colleagues (2001), who combined the data from these English dyslexics with that of French and Italian dyslexics, also reported reduced activation in this region in the context of normal levels of performance accuracy. The authors note that the reduced
activation in BA37 is consistent with a deficit in retrieving lexical phonology. Notably there are connections between the posterior inferior temporal region (BA37) and Wernicke's area (Di Virgilio and Clarke, 1997). It certainly appears likely that this region is crucially involved in the access or specification of phonological forms during naming by integrating semantic inputs with (whole-name) output phonology (e.g. in the naming of pictures, letters, colours, Price et al., 1997). This contrasts with the emphasis placed on sublexical processing in the psychological literature. It therefore appears that, at the neural level, dyslexics are characterised by abnormal activation of areas associated with lexical processing. Nevertheless, a lexical impairment is also supported by behavioural data that indicate longer word reading latencies by the dyslexics.

In both the Brunswick et al., (1999) and Paulesu et al., (2001) studies, dyslexic and control participants were carefully matched for age, IQ and as far as possible, for performance within the scanner, unlike previous studies which have shown abnormal left posterior inferior basal temporal activation (Samelin et al., 1996; Rumsey et al., 1997). However, while no differences in performance accuracy were reported during the explicit reading task, it is possible that control and dyslexic readers exhibited different reaction times during scanning - especially considering that such differences were found during the behavioural assessment battery. Without such reaction time data it is impossible to discount the possibility that such a difference in performance contributed to the reported activation differences. To address this concern the authors point out that the activation differences observed in BA37 during the task of incidental reading were independent of performance. Not only was reading not required for this task but incidental task performance was matched across control and dyslexic groups, for both speed and accuracy of response. This finding strengthens the contention that the reduced activation observed during the explicit reading task could not be attributable to a performance confound. In addition, the finding that the posterior inferior temporal lobe shows reduced activation in dyslexic individuals whether the orthography is highly transparent (as in Italian) or opaque (as in English or French) provides strong evidence that this region represents an area of primary dysfunction in dyslexic readers.
3.5. Evidence implicating the left hemisphere frontal regions

In the study by Shaywitz et al., (1998) one region was reported to show a greater level of activation in the dyslexic relative to the control group across the letter rhyming task, the nonword rhyming task and the semantic categorisation task: the inferior frontal gyrus. These greater levels of frontal activation observed in the dyslexic group (which were not observed by Rumsey et al., 1997) are interpreted as the neural manifestation of increased effort of the dyslexic readers in carrying out phonological processing. Brunswick et al., (1999) also reported a significantly greater level of activation in a comparable region - a left premotor area (BA 6/44) in the region of Broca's area, during explicit reading. Similar to Shaywitz and colleagues (1998), the authors suggested that this increased activation reflected the enforced use of an effortful compensatory strategy, involving sublexical assembly of articulatory routines. Indeed, in the incidental reading study where cognitive strategy was controlled, dyslexics did not show increased activation of Broca's area.

Paulesu, Frith, Snowling, Gallagher, Morton, Frackowiack, and Frith (1996) contrasted neural activation in which 5 dyslexic and 5 control participants during a rhyme judgement and a working memory task (both tasks and participants differed from those in Paulesu et al., 2001) They report evidence of a dysfunctional left insula in their dyslexic participants, a region which may represent an anatomical link between anterior and posterior language regions. The dyslexic sample exhibited frontal activation (Broca's area) during rhyme judgement and activation of the posterior superior temporal gyrus (Wernicke's area) during a working memory task. The controls however activated these areas and the insula during both tasks, leading the authors to suggest that dyslexia is a disconnection syndrome with the insula playing the role of a bridge between these neighbouring regions. Across both tasks the dyslexics' performance was matched with that of the control group. No replication of this finding has as yet been presented. Other studies that have found normal insula activation have not entailed a working memory component.

Although insula dysfunction has not been replicated by other studies (Rumsey et al., 1997; Shaywitz et al., 1998; Brunswick et al., 1999) the theoretical position that a functional or anatomical disconnection exists in the dyslexic reader remains. That is,
while the components of the language system in the dyslexic may be intact, they may be weakly interconnected within the language system as a whole. Horwitz et al., (1998) make a similar claim. The popularity of the disconnection hypothesis derives partly from the fact that it does not imply structural damage to a particular region. Instead it entails functional disruption resulting from impaired input or output to that region. To infer such a functional impairment it would be important to show that the region in question does activate normally during other tasks thereby demonstrating the absence of intrinsic damage.

3.6. Evidence for right hemisphere dysfunction

The role of the right hemisphere is given little attention in the studies reviewed so far. Visually based language tasks that have emphasized phonological processing have tended to produce left hemisphere differences. If hemisphere-specific differences are task dependent, then the employment of reading and phonologically explicit tasks may have failed to characterise the full extent of differences in the neural system of the dyslexic reader.

The role of the right hemisphere in dyslexia was specifically investigated in a task of tonal memory using PET (Rumsey, Andreason, Zametkin, King, Hamburger, Aquino, Hanahan, Pikus and Cohen, 1994). Dyslexic and control subjects, matched on age, gender, handedness, educational level and performance IQ listened to paired sequences of tones (three or four notes long). Their task was to press a button if the sequences in a pair were identical. The baseline condition was rest, where subjects were instructed to lie still with their eyes closed. Behaviourally the dyslexic group were found to be impaired, making significantly more errors. Relative to controls they also failed to activate three right fronto-temporal regions, for which Talairach coordinates were not made available. However, these regions are likely to reflect reduced activation in the right superior temporal gyrus, as well as right middle and inferior frontal gyri. These right hemisphere differences contrast with normal activation of left hemisphere regions and are interpreted in the context of a rapid temporal processing deficit.
3.7. Outstanding questions

Attention should be drawn to three key questions that currently remain unresolved in the literature. The first regards the functional differences reported in dyslexic readers in the region of the left angular gyrus. It has been noted that in all of the studies that have reported such a difference the dyslexic participants performed the phonological or reading task in question less accurately than their peers. If it is the case that activation of the angular gyrus reflects semantic processing, and this in turn correlates with performance accuracy, then two groups with comparable levels of performance should not manifest differences in this region. Such was the finding in Brunswick et al., (1999) and Paulesu et al., (2001). This requires replication in the context of more subtle measures of performance, particularly reading latency.

The second question relates to the reduced activation observed in the posterior temporal lobe (BA37) during reading, and reading-related tasks, that involve orthographic decoding. In view of the claim that this region represents a ‘Visual Word Form’ area (Cohen, Dehaene, Naccache, Lehéricy, Dehaene-Lambertz, Hénaff and Michel, 2000) it is possible that differences here are specific to tasks that entail orthographic processing. An alternative hypothesis would be that the reduced activation in this region by dyslexic participants reflects a more general impairment in phonological retrieval. Dyslexic children, in addition to their reading impairment, are also poor in retrieving picture names (e.g. Badian, McAnulty, Duffy and Als, 1990). If both these impairments stem from a common deficit in phonological retrieval then one might predict reduced activation in BA37 during reading and picture naming.

A final issue that needs to be addressed is whether the neuronal differences so far observed are a function of abnormal articulatory processing. The baselines used in many the studies to date have not included a specific task of articulation (for example, Brunswick et al., 1998 used rest as a baseline in the explicit reading task, while Rumsey et al., 1997 required subjects to look at a fixation point, also in an explicit reading task). If a subtraction paradigm is to be used, then it is vital to isolate those areas associated with the cognitive component of interest. This requires a high level baseline which incorporates all of the cognitive components of the experimental task except the component of interest. In a task of reading for example, it would be
important to control for basic visual processes by having subjects view a stimulus matched to the word for visual complexity, and articulate a word to control for general articulation and auditory processing (Moore et al., 1999). In this way those regions associated with phonological specification and retrieval are more likely to be isolated.
AN INVESTIGATION OF PHONOLOGICAL RETRIEVAL EFFICIENCY

Experiment 1: The effect of word length and frequency on picture naming and word reading

Introduction

A variety of studies have now shown that picture naming performance is a reliable predictor of reading skill (Jansky and de Hirsch, 1972; Wolf and Goodglass, 1986) and a well-documented correlate of developmental dyslexia (Denckla and Rudel, 1976b; Snowling van Wantendong and Stafford, 1988; Wolf, 1991). This naming impairment has been taken to reflect the dyslexic’s underlying deficit in phonological encoding and retrieval (Katz, 1986; Swan and Goswami, 1997a). However the vast majority of picture naming studies in dyslexia have been carried out with children. There have been extremely few studies investigating picture naming skill in the adult dyslexic, and even these have entailed only the administration of standardised confrontation naming tasks (Felton et al., 1990; Hanley, 1997). The present experiment sought to address three issues outstanding in the literature. Firstly, the empirical question of whether a subtle impairment in picture naming persists into adulthood, which is not detected in standard tasks of confrontation naming. Secondly, the current study aimed to contrast word reading with picture naming, in order to assess whether a common pattern of impairment characterised phonological retrieval in both tasks. This question is of particular relevance to theories that postulate a representational account of the phonological deficit in dyslexia. Thirdly, in light of claims regarding general impairments in efficiency or speed of processing in dyslexia (extending beyond the phonological domain), it was important to address the possibility that impairments in phonological retrieval were attributable to a general deficit in speed of processing.

With regard to the first issue, it is quite plausible that a more sensitive measure of retrieval efficiency (naming latency) and a manipulation of those factors which may
increase task difficulty (word length and frequency) might reveal persistent impairments in picture naming in adult dyslexics. On the basis of the developmental literature there is good evidence to suppose that manipulating the word properties of the stimuli in a confrontation format can increase the difficulty shown by dyslexic children. In a naming study with 8-year old children, impaired readers were reported to make significantly more errors with pictures with long low frequency names (Katz, 1986). Katz argues that words of lower frequency would have been encountered less frequently and are more likely to be incompletely represented at the phonological level. Similarly, objects with long names will also be more difficult to label since longer words require that more phonological information be represented and processed. While this study was limited to a comparison with chronological age controls, Swan et al., (1997a) employed reading age controls, as well as what they term 'garden-variety' poor readers (poor readers who show globally depressed IQ). Dyslexic children were found to be impaired relative to both chronological and reading age controls, indicating that their picture naming deficit was more severe than either their age or reading level would predict. While the dyslexics overall performance was comparable to the garden-variety poor readers, it differed in two key respects. Firstly their errors were particularly marked on polysyllabic and/or low frequency names. Secondly, the dyslexics, unlike the garden variety had greater difficulty naming known picture names. This pattern is interpreted as reflecting a specific difficulty in phonological retrieval. To date no previous study of adult dyslexics has investigated the effects of word length or frequency in a task of picture naming, or taken measurements of picture naming latency.

The second issue to be addressed by this study relates to the contrast between reading and naming. If it is assumed that in both tasks a common phonological representation is accessed, and that such phonological forms are inadequately represented, then phonological retrieval should be impaired across modalities.

According to the phonological representations hypothesis inadequacy of a given phonological representation accounts for the developmental retrieval difficulty in naming and reading (Swan and Goswami, 1997a). While it is recognised that retrieval difficulty of a given word may vary across tasks, it is unclear the extent to which difficulty interacts with the dyslexics putative deficit in phonological representation.
That is, if a common representation is degraded, then why would access be more difficult / less efficient in one retrieval context than in another? For example, Swan and Goswami (1997a) report that their group of dyslexic children were more accurate in reading target names than when naming the corresponding picture. They suggest that their dyslexics reading skills were sufficiently developed to take advantage of the grapheme-phoneme correspondences of the target words, thereby aiding phonological specification. Yet this pattern is reversed in adulthood where difficulties in reading persist in the absence of picture naming difficulties (e.g. Felton et al., 1990). The representational hypothesis provides no account of this apparent developmental shift.

In contrast the phonological competition hypothesis, as outlined in Chapter 2, accounts for this shift with reference to the differing degrees of phonological competition across tasks, and across development. Reading an inconsistent orthography such as English will always entail a relatively high degree of phonological competition; consider for example the sequence of letters, ‘o-u-g-h’ in ‘cough’ and ‘bough’. While logographic and visual strategies may be used, processing grapheme-phoneme correspondences and addressing the attendant phonological competition will always be necessary to efficiently retrieve a phonological representation when reading. A weakness in resolving phonological competition will render this retrieval process inefficient. While dyslexic children may successfully read a target word, the claim here is that this process will not achieve the level of efficiency attained by the non-dyslexic reader. According to a competition account reading efficiency (as opposed to accuracy) will always be impaired – even in the ‘compensated’ adult dyslexic. In contrast, the level of phonological competition which arises during picture naming is largely determined by the degree of semantic specification of a given item. Pictures that are well specified semantically will provide targeted activation of a single phonological form with only weak activation of phonological competitors via either semantic or phonological mediation.

The third issue to be addressed by the current experiment relates to the concern that any deficits found on tasks of phonological retrieval may be attributable to a general cognitive impairment, that extends beyond the domain of phonological processing. Nicolson and Fawcett (1990) have argued that developmental dyslexia is characterised by an automatisation impairment. They suggest that literacy is simply one of many
tasks where dyslexic individuals have been unable to achieve automatic performance. Impairments in balance, choice reaction time, and general motor skill they attribute to the same impairment in skill automatisation. Wolf and Bowers (1999) have also postulated that dyslexics may be characterised by a general impairment - in processing speed. This position has been discussed in Chapter 2. The possibility that such deficits characterised the current sample was assessed in two control tasks where a subset of the pictures used for naming were presented in a task of visual decision, and one of semantic decision. To perform these tasks rapidly, efficient visual and semantic processing are required in a choice reaction time decision. While an impairment on either of these tasks would not selectively support an automatisation or speed deficit hypothesis, they would be consistent with such claims. In addition, any such impairment would require a phonological deficit account to explain an impairment on an ostensibly non-phonological task.

Predictions:

**Phonological Representation Hypothesis:**
According to the representation hypothesis dyslexic adults should show continuing impairments in phonological retrieval during naming, in view of their inadequately specified phonological representations. This should be more apparent with long low frequency words. Reading, like naming, should also be impaired since both tasks access the same (degraded) underlying phonological forms. Items of low frequency should differentially impair dyslexic individuals across tasks since they are likely to lack sufficient experience of such words to establish well-specified phonological representations. Similarly, items with long names should impair dyslexics across tasks since longer names require more phonological information to be specified and retrieved. In the visual and semantic decision tasks the dyslexic participants would be predicted to show normal performance, since these tasks do not require phonological mediation.

**Phonological Competition Hypothesis:**
According to the competition hypothesis picture naming under slow single trial conditions should not be impaired in the adult dyslexic. If relatively familiar objects are to be named, then it is likely that these will have become well-specified at the semantic level. The consequence of this is that by adulthood activation of a given set
of semantic attributes will lead to the activation of only a single lemma that in turn becomes encoded at the phonological level. The level of phonological competition during naming should therefore be less than in childhood where semantic specification may be less precise.

For word reading, the competition hypothesis predicts that the dyslexic participants will be slower across all stimuli, but particularly with longer lower frequency words. This prediction is made because longer words will entail a greater level of competition. This is not the case in naming given that access is solely via semantics in which there is activation of the whole word form; accessing phonology via orthography directly elicits multiple competitors for each vowel slot. With less frequent words such competition is likely to be resolved less readily. The competition hypothesis also predicts that the visual and semantic decision tasks would be performed normally by the dyslexic group, since these tasks do not require phonological mediation.

General Impairment Hypothesis
If dyslexia is characterised by a general impairment in speed / efficiency of processing, then this should also affect those tasks where phonological processing is not invoked. According to this position, impairments would be expected on the visual and semantic decision tasks, as well on the tasks of reading and naming.

Method

Participants
Forty university students took part in the study; all were physically healthy with no history of neurological or psychiatric disorder. Twenty of the participants had received an independent assessment for dyslexia, and were characterised by a developmental history of literacy impairment. The remaining twenty control participants reported no history of language difficulty. All participants received a set of background measures: a full WAIS (Wechsler Adult Inventory Scale-Revised; WAIS-III) and standardised measures of reading and spelling (Wide Range Achievement Test - Revised (WRAT - R; Jastak and Wilkinson, 1984). As shown in Table 4.1 the dyslexic and control groups were matched for age, full-scale and performance IQ but differed in verbal IQ
[F(1,38) = 10.1; p < .01]. Analysis of the data from the standardised literacy test indicated impaired performance in the dyslexics relative to the controls for reading and spelling [WRAT reading (F1,38) = 48.0; p < .01); WRAT spelling (F1,38) = 33.3; p < .01)].

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dyslexics (n=20)</th>
<th>Controls (n=20)</th>
<th>n.s.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.0 (3.1)</td>
<td>21 (2.6)</td>
<td></td>
</tr>
<tr>
<td>IQ tests (WAIS-R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-scale</td>
<td>119.7 (7.0)</td>
<td>124.0 (9.7)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Performance</td>
<td>120.9 (10.4)</td>
<td>118.1 (10.6)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Verbal</td>
<td>116.0 (7.0)</td>
<td>125.0 (10.5)</td>
<td>**</td>
</tr>
<tr>
<td>Standardized literacy tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading: WRAT</td>
<td>93.3 (12.2)</td>
<td>113.7 (5.1)</td>
<td>**</td>
</tr>
<tr>
<td>Spelling: WRAT</td>
<td>92.2 (13.6)</td>
<td>112.9 (8.5)</td>
<td>**</td>
</tr>
</tbody>
</table>

Table 4.1. Behavioural profile of participants, Experiments 1 and 2; n.s. - non-significant; ** < 0.01.

**Visual and Semantic decision tasks**

**Materials**

The stimuli for each of these tasks were drawn from a set of 120 pictures from Snodgrass and Vanderwart (1980). For any given participant the picture stimuli used were not presented in the subsequent picture naming task. For the semantic task, 16 living things and 16 man-made objects were chosen. For the visual task 16 pictures were selected and 16 'nonsense objects' were created to approximate the pictures for visual complexity.

**Procedure**

Task order was counterbalanced across participants for the semantic and visual tasks. Identical procedures were adopted in each. In the semantic task, the experimenter explained that a series of pictures would appear on the screen one at a time. Subjects were asked to press the button 'L' if the picture corresponded to a living thing, responding as quickly and accurately as possible. They were asked to make no
response if the picture was non-living. Any queries regarding the procedure were then clarified by the experimenter. The participant then pressed a key to begin; the instructions were reiterated on screen: “Press the button ‘L’ when the picture is of a living thing, e.g. an animal or a vegetable. You need make no response when the picture is a man-made object. Try and respond as quickly and accurately as possible. Press any key to begin”. Response times and accuracy were recorded. For the visual condition the same procedure was adopted. However in this case the participants were instructed to press the button ‘L’ only if a real object appeared on the screen, ignoring nonsense objects; otherwise the instructions were the same. In both conditions, stimulus presentation was randomised with each stimulus presented twice. In both tasks, stimuli disappeared once a response was given (with an upper limit of 1500ms), with a 2000ms interval between successive stimuli. An Apple Mac Performa (LC930) computer was used, with Superlab software to present the stimuli and record response latency.

**Picture naming and word reading tasks**

**Materials**

In total 120 names were selected from the Snodgrass and Vanderwart set (Snodgrass and Vanderwart, 1980). These words are listed in Table 4.2, while the stimulus characteristics for each word class are presented in Table 4.3. A factorial design combined word length and frequency in both a word reading and a picture naming task. This gave four cells for each task: Short high frequency; Short low frequency; Long high frequency; Long low frequency. Pictures were all scaled to measure between 5 - 8cm in width and 5 - 8 cm in height. Words were presented in Courier font, size 72 to approximately match the visual angle of the pictures.

Word length was defined in terms of the number of syllables, letters, and phonemes. Words of short length (SL) were all monosyllabic, with 2-4 phonemes, and between 3-5 letters. In contrast long length names (LL) were between 2-4 syllables, 5-9 phonemes and consisted of between 6-10 letters. Long and short words were matched for frequency (Celex database) both verbal and written (only the combined value is shown); age of acquisition; imageability; familiarity; visual complexity and name
<table>
<thead>
<tr>
<th>Short High Frequency</th>
<th>Short Low Frequency</th>
<th>Long High Frequency</th>
<th>Long Low Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>comb</td>
<td>harp</td>
<td>typewriter</td>
<td>mermaid</td>
</tr>
<tr>
<td>hen</td>
<td>dice</td>
<td>mushroom</td>
<td>giraffe</td>
</tr>
<tr>
<td>fox</td>
<td>toad</td>
<td>umbrella</td>
<td>pumpkin</td>
</tr>
<tr>
<td>plug</td>
<td>snail</td>
<td>tomato</td>
<td>wizard</td>
</tr>
<tr>
<td>bee</td>
<td>kite</td>
<td>diamond</td>
<td>kangaroo</td>
</tr>
<tr>
<td>sword</td>
<td>clown</td>
<td>lemon</td>
<td>pineapple</td>
</tr>
<tr>
<td>fork</td>
<td>saw</td>
<td>helicopter</td>
<td>gorilla</td>
</tr>
<tr>
<td>pond</td>
<td>flute</td>
<td>candle</td>
<td>lobster</td>
</tr>
<tr>
<td>sock</td>
<td>shawl</td>
<td>submarine</td>
<td>parachute</td>
</tr>
<tr>
<td>duck</td>
<td>pear</td>
<td>monkey</td>
<td>microwave</td>
</tr>
<tr>
<td>drum</td>
<td>web</td>
<td>pencil</td>
<td>waistcoat</td>
</tr>
<tr>
<td>snake</td>
<td>pram</td>
<td>suitcase</td>
<td>necklace</td>
</tr>
<tr>
<td>goat</td>
<td>vase</td>
<td>rabbit</td>
<td>scissors</td>
</tr>
<tr>
<td>belt</td>
<td>owl</td>
<td>barrel</td>
<td>penguin</td>
</tr>
<tr>
<td>flag</td>
<td>broom</td>
<td>basket</td>
<td>tortoise</td>
</tr>
<tr>
<td>crown</td>
<td>swan</td>
<td>elephant</td>
<td>volcano</td>
</tr>
<tr>
<td>pan</td>
<td>axe</td>
<td>envelope</td>
<td>violin</td>
</tr>
<tr>
<td>lamp</td>
<td>crab</td>
<td>piano</td>
<td>squirrel</td>
</tr>
<tr>
<td>pipe</td>
<td>frog</td>
<td>trousers</td>
<td>strawberry</td>
</tr>
<tr>
<td>cake</td>
<td>peg</td>
<td>glasses</td>
<td>lettuce</td>
</tr>
<tr>
<td>boot</td>
<td>purse</td>
<td>potato</td>
<td>spider</td>
</tr>
<tr>
<td>sheep</td>
<td>nun</td>
<td>camera</td>
<td>microscope</td>
</tr>
<tr>
<td>cow</td>
<td>jug</td>
<td>jacket</td>
<td>trumpet</td>
</tr>
<tr>
<td>bell</td>
<td>bike</td>
<td>cigarette</td>
<td>telescope</td>
</tr>
<tr>
<td>knife</td>
<td>ant</td>
<td>soldier</td>
<td>carrot</td>
</tr>
<tr>
<td>ship</td>
<td>deer</td>
<td>mountain</td>
<td>banana</td>
</tr>
<tr>
<td>key</td>
<td>torch</td>
<td>telephone</td>
<td>microphone</td>
</tr>
<tr>
<td>box</td>
<td>stool</td>
<td>television</td>
<td>dentist</td>
</tr>
<tr>
<td>chair</td>
<td>barn</td>
<td>finger</td>
<td>sandwich</td>
</tr>
<tr>
<td>dress</td>
<td>ski</td>
<td>window</td>
<td>tractor</td>
</tr>
</tbody>
</table>

Table 4.2. Stimuli used in the word reading and picture naming tasks. Pictures for these stimuli were taken from Snodgrass and Vanderwart, (1980).
agreement. Since all of the pictures used came from the Snodgrass and Vanderwart set (1980) these values could all be drawn from a published set of norms (Morrison, Chappell and Ellis, 1997).

High frequency (HF) words were defined as those words with an occurrence above 250 per 17.9 million while low frequency words (LF) occurred below 250 times per 17.9 million. Picture familiarity, another index of frequency also differed significantly between the high and low frequency word sets. Given the close relationship between age of acquisition and frequency (in addition to the constraints regarding the number of stimuli required for the current experiment) these related factors could not be separated. However, the pictures corresponding to the word names were matched across low and high frequency lists for: imageability; visual complexity; and name agreement (Morrison, Chappell and Ellis, 1997).

<table>
<thead>
<tr>
<th>Linguistic characteristic</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF</td>
<td>LF</td>
</tr>
<tr>
<td>No. letters</td>
<td>3.9</td>
<td>4.0</td>
</tr>
<tr>
<td>No. phonemes</td>
<td>3.3</td>
<td>3.2</td>
</tr>
<tr>
<td>No. syllables</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Mean frequency</td>
<td>663</td>
<td>135</td>
</tr>
<tr>
<td>Age of acquisition</td>
<td>41</td>
<td>64</td>
</tr>
<tr>
<td>Imageability</td>
<td>6.3</td>
<td>6.1</td>
</tr>
<tr>
<td>Familiarity</td>
<td>3.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Visual complexity</td>
<td>3.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Name agreement</td>
<td>1.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Table 4.3. Characteristics of the stimuli used in Experiment 1. Frequency counts drawn from the Celex database, other parameters taken from Morrison, Chappell & Ellis, 1997. HF = high frequency; LF = low frequency.

**Procedure**

The stimuli were divided into two sets, A and B. Half the participants saw set A as pictures and set B as words; the remaining participants saw set A as words and set B as
pictures. In this way no subject read and named the same items. Stimuli were divided into 8 blocks of 15 (4 of words: SL HF; SL LF; LL HF; LL LF and 4 of pictures: SL HF; SL LF; LL HF; LL LF). The order of conditions counterbalanced across participants. Stimuli appeared on the screen until a response was detected; a 2-second inter-stimulus interval then preceded onset of the next item. Reaction time was measured using a Mac microphone and Superlab programming software on an Apple Mac Performa (LC930). Responses were recorded onto tape and concurrently scored by an experimenter seated behind the participant.

Participants were told that in this task they would be presented with a series of words and pictures appearing on the computer screen that they should name as fast and accurately as possible. They were then instructed to press any key to begin and follow the instructions on screen: “You will now see a series of words. Read aloud each one as soon as they appear on the screen. Try and respond as quickly and accurately as possible. Press any key for a practice trial”. Five practice words were then given. Any questions were clarified with the experimenter at this point before further instructions appeared on the screen: “Well done. Next you will see some more words. Again, read aloud each one as soon as they appear on the screen. Try and respond as quickly and accurately as possible. Press any key to begin”. Word stimuli were then presented one at a time. Four blocks of 15 words each were presented in this way, with reminder instructions between each. The next block was initiated by the participant when ready by pressing any key. After a short break participants were presented with a practice trial for the picture condition. The procedure which then followed mirrored that of the word condition previously.

Results

Semantic and Visual decision tasks

The latency data (shown in Table 4.4) were entered into a 2 (Group) × 2 (Task) ANOVA with Group as the between-subjects factor and with repeated measures on the semantic and visual tasks. The analysis indicated no main effect of group, but a significant effect of task \(F(1,38) = 5.0; p < .05\) with both groups responding faster in the Visual condition. There was no interaction between group and condition. There were no differences in
accuracy across tasks which was near ceiling for both groups; in addition, there was no interaction across groups (Semantic: Controls: 96.56%; Dyslexics: 95.60%; Visual: Controls: 95.13%; Dyslexics: 94.10%).

**Reading and Naming: Combined analysis**

The reaction time from the word reading and picture naming tasks were initially combined in a single analysis to evaluate the effects of 2 (Group) × 2 (Modality) collapsed over Length and Frequency. The analysis indicated no significant effect of Group overall. However, there was a significant effect of Modality \((F_{1,38}) = 226.8; p < .01\) reflecting the fact that participants read faster than they named. A significant Modality × Group interaction, \((F_{1,38}) = 8.0; p = .01\) was also found. Inspection of the means (Reading: Controls = 457.1 msec; Dyslexics 550.5 msec; Naming: Controls = 778.5 msec; Dyslexics = 774.5 msec) indicated that differences across groups were entirely confined to the reading condition. This indicates that the dyslexic participants differed only when reading and not when naming. The effect of Group, Length and Modality were then explored in two analyses for Reading and Picture Naming separately.

**Reading**

The data from the reading task were entered into a 2 (Group) × 2 (Word Length) × 2 (Word Frequency) ANOVA with Group as the between-subjects factor and with repeated measures on Length and Frequency. The reaction time in milliseconds was taken as the dependent variable; the means and standard deviations across groups and conditions are shown in Table 4.4 and plotted in Figure 4.1. The analysis yielded main effects of Length \((F_{1,38}) = 18.4; p < .01\), Frequency \((F_{1,38}) = 9.5; p < .01\) and Group, \((F_{1,38}) = 10.5; p < .01\) with dyslexic subjects showing slower response times overall. Post-hoc tests indicated that the dyslexics were slower for all words types \((p < .01)\).

There were also significant two-way interactions between Group and Word Length \((F_{1,38}) = 5.2; p < .05\) and Group and Word Frequency \((F_{1,38}) = 4.2; p < .05\). Post-hoc testing of the Group and Length interaction revealed that only the dyslexic group showed a significant length effect: they were significantly faster at reading short words than long words \((p<.01)\). The control group showed no difference in performance between short and
long words. Similarly only the dyslexic group showed a significant frequency effect: they were significantly faster at reading high frequency words than low frequency words (p<.01). The control group showed no difference in performance between high frequency and low frequency words.

To assess the generality of the by-subjects analysis a by-items analysis was also conducted. The item analysis of variance produced the same pattern of results indicating slower reading by the dyslexic participants (reading group: item analysis: (F(1,116) = 515.9; p <.01). There were significant effects of length [(F1,116) = 47.1; p <.01] and frequency [(F1,116) = 22.9; p <.01] which were more pronounced in the dyslexic participants [Group X Length: [(F1,116) = 12.7; p <.01; Group X Frequency: [(F1,116) = 12.5; p <.01].

**Picture Naming**

The data from the picture naming task was also entered into a 2 (Group) X 2 (Word Length) X 2 (Word Frequency) ANOVA with Group as the between-subjects factor and with repeated measures on Length and Frequency. As with the word reading task, reaction time in milliseconds was taken as the dependent variable; the means and standard deviations across groups and conditions are shown in Table 4.4 and plotted in Figure 4.2. The analysis yielded only a main effect of Frequency [(F1,38) = 2.5; p <.01] with both groups slower in naming pictures with low frequency names than high frequency names (p <.05). There were no effects of Group. A by-item analysis produced the same pattern of results indicating only a main effect of Frequency [(F1,118) = 4.5; p <.05] and no effects of Length or Group.
<table>
<thead>
<tr>
<th>Control tasks (latencies, msec)</th>
<th>Dyslexics (n=20)</th>
<th>Controls (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semantic decision</td>
<td>500.1 (67.2)</td>
<td>505.1 (49.4)</td>
</tr>
<tr>
<td>Visual decision</td>
<td>470.8 (56.2)</td>
<td>499.1 (57.7)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Retrieval tasks (latencies, msec)</th>
<th>Dyslexics (n=20)</th>
<th>Controls (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Word Reading:</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Short HF                          | 508.5 (91.0)     | 445.2 (58.2)   | **  
| Long HF                           | 562.6 (135.1)    | 463.4 (55.3)   | **  
| Short LF                          | 554.2 (129.8)    | 455.5 (77.5)   | **  
| Long LF                           | 617.0 (179.2)    | 473.6 (79.4)   | **  
| **Picture Naming:**               |                  |                |
| Short HF                          | 730.6 (174.1)    | 755.2 (122.6)  | n.s. |
| Long HF                           | 776.7 (166.0)    | 758.5 (103.7)  | n.s. |
| Short LF                          | 808.3 (197.1)    | 797.1 (118.8)  | n.s. |
| Long LF                           | 814.7 (180.3)    | 816.2 (146.4)  | n.s. |

Table 4.4. Task Performance of the dyslexic and control groups in Experiment 1: reading, naming, semantic and visual decision. n.s. = non-significant; ** p< 0.01.
Figure 4.1. Word reading latencies (msec) for dyslexic and control participants. Short = monosyllabic words; Long = bisyllabic words. HF = High frequency; LF = Low frequency. All error bars indicate one standard error of the mean.

Figure 4.2. Picture naming latencies (msec) for dyslexic and control participants. Short = monosyllabic words; Long = bisyllabic words. HF = High frequency; LF = Low frequency. All error bars indicate one standard error of the mean.
Error analysis

i. Word reading: reading accuracy was at ceiling for both groups. There were a total of 2 errors across all control participants, and 7 errors in the dyslexic group, 5 of which were made by the same participant. All errors were slight mispronunciations of the target (e.g. "vace" for vase) or lexical errors (e.g. “school” for “stool”).

ii. Picture naming: A proportion of the responses in both groups were classified as alternative responses (AR); such responses were not classified as errors. These responses were either a fuller form of the picture name (e.g. “spider’s web” for web; “clothes peg” for peg) or an alternative, but equally acceptable name for the picture presented (e.g. “saucepan” for pot; “magician” for wizard). The dyslexic group made significantly fewer such responses [F(1,38) = 13.5; p < .01] than those made by the control group (Dyslexics: 1.5% ; Controls: 3.75%). This suggests that the dyslexic group were less likely to deviate from the standard names associated with these pictures. A response that was not classified as an acceptable alternative to the picture name constituted an error. An error coding procedure was adapted from adult studies of picture naming in aphasia (e.g. Kohn and Goodglass, 1985). Fewer categories were used, reflecting the more limited range of errors observed: (1) No Response (for refusals and “don’t know”), (2) Perceptual Error (e.g. “stick” for flute), (3) Semantic Error – Superordinate Category (e.g. “musical instrument” for flute; “gem” for diamond), (4) Semantic Error – Inclass (e.g. “harp” for violin) (5) Semantic / Perceptual Error – Inclass (e.g. “shoe” for boot; “baboon” for monkey; “duck” for swan). Seven errors were not classifiable with this system; these reflected either circumlocutions or associative responses. Error rate was extremely low for both groups and provided insufficient data for statistical analysis. For comparison, percentage errors for each class and group are shown in Table 4.5. Given that the perceptual-semantic errors were most common it appears that most errors reflected an inaccuracy of labelling since these responses were both visually and semantically related to the target item. Errors, alternative responses, and microphone failures were excluded from the reaction time analysis.
<table>
<thead>
<tr>
<th>Error Category</th>
<th>Percentage Error</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dyslexics (n=20)</td>
<td>Controls (n=20)</td>
</tr>
<tr>
<td>(1) No response</td>
<td>0.17</td>
<td>0.25</td>
</tr>
<tr>
<td>(2) Perceptual error</td>
<td>0.17</td>
<td>0.05</td>
</tr>
<tr>
<td>(3) Semantic error: superordinate</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>(4) Semantic error: inclass</td>
<td>0.17</td>
<td>0.8</td>
</tr>
<tr>
<td>(5) Semantic Perceptual error: inclass</td>
<td>2.5</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Table 4.5 Mean percentage of coded errors on the Picture Naming task.

Discussion

The dyslexic and control groups were well matched in age, educational background and on non-verbal measures of IQ. On the verbal measure of IQ and on the standardised literacy measures dyslexic participants were impaired.

The dyslexic group were as fast and accurate as the control group during picture naming - even for long low frequency words. Word length or word frequency did not differentially impair the dyslexics. During reading, however, the dyslexic group were significantly impaired with all word types, and were differentially affected by word length and frequency. This selective pattern of deficit across tasks of phonological retrieval sits uncomfortably with any strong version of the phonological representation hypothesis. If a common representation were accessed in both tasks of naming and reading one would expect a common impairment across tasks - with common effects of length and frequency. Such a pattern was not found. As currently formulated the representational theory of dyslexia neither predicts or explains this interaction between task modality and performance.

The semantic and visual decision tasks tapped speed of response in a choice reaction time setting, which required rapid perceptual and object structural processing. The finding that the dyslexic participants performed normally on both tasks in terms of accuracy and speed of response is not consistent with a general impairment in speed of response or in non-phonological aspects of picture processing.
According to the phonological competition account any impairment in the dyslexic group will always be contingent on the degree of phonological competition invoked in a given task. English orthography, given its opaque nature, will always entail a high degree of phonological competition of sublexical phonological codes, even for the simplest of words. Increasing word length will increase the degree of phonological competition by increasing the number of competing phonological codes activated. Decreasing word frequency reduces the strength of activation of the target phonological form, producing a relative increase in the degree of phonological competition (Metsala, 1997b). While these factors directly affect reading, they have only a weak effect on naming. The visual and semantic representations of words will have become sufficiently well encoded by adulthood to reduce the effect of semantically or phonologically mediated competition: a visually presented item will strongly activate a single lemma and its associated lexeme.

Is it the case then that dyslexic individuals, by adulthood, will have attained perfectly normal picture naming skills? Certainly under slow paced single trial naming conditions, they have been shown to be as accurate and as efficient in naming as their non-dyslexic peers. However, according to the competition hypothesis, factors that will specifically increase the degree of phonological competition during naming should provide a context where the dyslexics’ deficit in retrieval is revealed. One way this may be achieved is by increasing the rate at which naming proceeds. Similarly, if one increases the number of competitors of similar phonological structure then the relative degree of competition should also increase. These factors are manipulated in the next experiment in order to determine if by adulthood dyslexic adults have fully compensated for their earlier impairments in picture naming.
Experiment 2: The effect of phonological neighbourhood during a task of Rapid Automatic Naming.

Introduction

While adult dyslexics have been reported to show normal confrontation naming ability, a number of studies have reported persistent difficulties when pictures are named serially (e.g. Felton et al., 1990). In the classic rapid automatic naming (RAN) task a series of 5 items – colours, pictures, or digits – are named in a list totalling 50 items. This indicates that the format within which picture naming occurs can significantly affect performance. The greater difficulty shown on tasks of continuous naming by dyslexic children has been attributed to a variety of non-phonological factors such as complex scanning and sequential response (Stanovich, Feeman and Cunningham, 1983). Both Wolf (1991) and Fawcett and Nicolson (1994) make similar points. While there is some agreement that a phonological weakness underlies poor performance on the RAN, this account has not been taken as a sufficient explanation of the dyslexic’s slow speed. Instead the phonological deficit explanation has been subsumed into a broader more generalised automatisation impairment (Fawcett and Nicolson, 1994) or twinned with an equally disabling impairment in speed of processing (Wolf, 1999). However, as discussed in Chapter 2, it is plausible that the process of lexical retrieval is modulated by the context of continuous naming. By requiring participants to rapidly name a series of pictures, the activation of previous items may have had insufficient time to decay, increasing both noise, and the degree of competition from other phonological items. According to the phonological competition hypothesis this would increase naming time. Similarly, a proponent of the phonological representation hypothesis might argue that increasing the rate of naming serves to place greater stress on the specification of already poorly encoded phonological representations.

While the RAN task might be particularly useful diagnostically, it has been a poor experimental tool to differentiate between contrasting theoretical positions. The current experiment aimed to replicate impaired performance on the RAN task in a group of adult
dyslexics who had been shown to be unimpaired in naming pictures in a single trial format. But more crucially, it aimed to manipulate a specific linguistic factor - phonological neighbourhood density - that would generate *differential predictions* for each of the competing theories so far discussed.

Every word in a given language will have a number of phonological neighbours – i.e. words that sound similar to that word. How a phonological neighbour is defined is a somewhat arbitrary decision, since there are varying degrees of similarity that might be chosen as a criterion. In the current experiment a neighbour was defined as a word which differed from the target word by only one phoneme (e.g. cat vs. mat). Words with a high number of neighbours are termed as having a dense phonological neighbourhood, while words with few phonological neighbours are termed as having a sparse phonological neighbourhood. These alternatives are figuratively displayed in Figure 4.1.

![Figure 4.1](image)

**Figure 4.1.** Illustration contrasting a word from a dense phonological neighbourhood (A) with a word from a sparse phonological neighbourhood (B).

According to certain developmental theories of phonological representation, the density of a given phonological neighbourhood and frequency of exposure may partly determine the quality of phonological representations (Walley, 1993; Walley, Michela and Wood; Metsals, 1997). For example, phonological segments of words from dense neighbourhoods will be represented by many different lexical exemplars. It is suggested that this increases the degree of information specification of those items at the phonological level resulting in more detailed representations. In contrast, the phonological specification of words with few neighbours is likely to be poorer, since the phonological
segments of those words are represented in only a few exemplars. That words from sparse
neighbourhoods (which have less common phonological forms) are less well specified is
consistent with the observation that dyslexic children require more input with such words
relative to control children, in a gating task of word identification (Metsala, 1997a). If this
supposition is correct (i.e. that words from dense phonological neighbourhoods are better
specified), then the representation hypothesis would predict faster naming speed with
those words with a high number of neighbours, since those words would be most likely to
be best represented – and thus, most likely to be efficiently retrieved.

In contrast, the competition hypothesis would make the opposite prediction. An effect of
phonological neighbourhood density, for example, has been shown in spoken word
identification, with high frequency words from sparse neighbourhoods identified more
quickly in a gating paradigm than high frequency words from dense neighbourhoods
(Metsala, 1997b). This is consistent with the idea that there is increased competition with
lexical items that have more phonological neighbours. It is hypothesised that this effect
may also influence word retrieval. When a word is activated in a dense phonological
neighbourhood then there will be a high number of competitors that will receive spreading
activation – and this should slow naming in the dyslexics. A word in a sparse
phonological neighbourhood will have fewer competitors, and this should reduce the level
of phonological competition, facilitating naming in the dyslexic.

According to a general impairment hypothesis, there should be no difference between the
words from sparse or dense phonological neighbourhoods, since these do not make
differential demands on more general cognitive processes such as attention.

In the current experiment two lists of picture names, which differed only in phonological
neighbourhood density, were administered to control and dyslexic readers in a rapid
naming format. Otherwise these lists were matched for frequency, familiarity, age of
acquisition, imageability, visual complexity and name agreement. It was predicted that the
dyslexics would show slower naming on both word lists. However the predicted pattern of
impairment across lists differs for each of the theoretical accounts under consideration.
Method

Participants
The same set of 40 participants, recruited for the previous experiment also carried out the RAN tasks.

Materials
A total of 10 pictures were selected from the Snodgrass and Vanderwart set (Snodgrass and Vanderwart, 1980). These were divided into two sets of five pictures, one which consisted of pictures with a dense phonological neighbourhood (DPN: Hat; Bed; Pan; Moon; Nut) and one with a sparse phonological neighbourhood (SPN: Dog; Shirt; Jug; Fish; Peg). The picture names in the dense phonological neighbourhood list had significantly more phonological neighbours (DPN mean=23.8; SPN mean=11.3; p<.01) and in addition these neighbours were of a higher mean frequency (DPN mean=342.8; SPN mean=22.8; p<.01). While these parameters differed significantly, the selected set of pictures were carefully matched in terms of frequency: both verbal (number of occurrences per 1.3 million: DPN mean=45.6; SPN mean=34.8; n.s.) written (number of occurrences per 16.6 million: DPN mean=1570; SPN mean=1291; n.s.) and overall frequency (number of occurrences per million: DPN mean=90.3; SPN mean=70.0; n.s.). These values were based on frequency counts from the CELEX database. The actual pictures used were also matched for rated familiarity (DPN mean=3.5; SPN mean=3.6; n.s.). In addition age of acquisition (DPN mean=45.9; SPN mean=40.3; n.s.), imageability (DPN mean=6.4; SPN mean=6.3; n.s.), visual complexity (DPN mean=2.0; SPN mean=2.6; n.s.) and name agreement (DPN mean=0.9; SPN mean=1.0; n.s.) were all matched across the dense phonological neighbourhood and sparse phonological neighbourhood lists. The values of these parameters were all drawn from a set of published norms for the Snodgrass and Vanderwart set (Morrison, Chappell and Ellis, 1997).

Procedure
Prior to beginning the task, participants were shown the list of pictures to be used in the task; the experimenter pointed to each picture, naming each individually to ensure
common name agreement during the task. Both DPN and SPN lists consisted of 5 rows each of 10 pictures in length, after Denckla and Rudel (1976a). The subject was asked to name each picture working as fast as possible across each row, and moving onto the next row without pausing. The task was initiated once the word “begin” was spoken by the experimenter; at this point timing was also started with a stop watch. Timing was stopped when the last picture had been named, and the total time was noted. Order of presentation of the DPN and SPN lists were randomised; both lists were also presented twice and the mean time across both presentations calculated.

Results

The mean time (in seconds) for task completion (calculated for each participant by averaging over two trials), was taken as the dependent variable. These data were entered into a 2 (Group) × 2 (List) repeated measures ANOVA; the group means and associated standard deviations are shown in Table 4.6, and plotted in Figure 4.4.

<table>
<thead>
<tr>
<th></th>
<th>Dyslexics (n=20)</th>
<th>Controls (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPN list (sec) [Dense Phonological Neighbourhood]</td>
<td>33.9 (6.9)</td>
<td>28.8 (3.9)</td>
</tr>
<tr>
<td>SPN list (sec) [Sparse Phonological Neighbourhood]</td>
<td>31.5 (6.5)</td>
<td>28.8 (3.8)</td>
</tr>
</tbody>
</table>

Table 4.6 RAN task performance across control and dyslexic groups: speed to name 50 items from dense vs. sparse phonological neighbourhoods. Standard deviations shown in parentheses.

![Figure 4.4](image)

Figure 4.4. Task time in seconds for the control and dyslexic groups with items from sparse (SPN) and dense (DPN) phonological neighbourhood lists.
The analysis indicated a main effect of group \([F_{1,38} = 5.6, p<.05]\), with slower responses by the dyslexics and a main effect of List \([F_{1,38} = 5.3, p<.05]\), with faster times on the SPN list. A Group \(\times\) List interaction indicated that the effect of list type was confined to the dyslexic group \([F_{1,38} = 4.7, p<.05]\) who showed faster naming times on the SPN list than on the DPN list, which was not true for controls. While performance on the RAN task correlated with the WRAT measure of reading in the dyslexic group \((r=0.73 \text{ DPN list} \text{ and } r=0.63 \text{ SPN list}; p<.01)\) no such correlation was found in the control group \((r=0.37 \text{ DPN list} \text{ and } r=0.36 \text{ SPN list}; \text{n.s.})\) nor in either group with the single trial picture naming task in Experiment 1.

**Discussion**

The results indicate slower picture naming speed in a continuous rapid format for a group of dyslexic adults, who in a single trial context show normal naming performance. This suggests that an underlying impairment in picture naming persists into adulthood, but that this impairment is not detectable in a slow pace single-trial naming format. The high correlation of RAN performance with reading indicates that the dyslexics’ impairment is more directly indexed in this continuous format than in a single trial naming format. Manipulation of phonological neighbourhood density was shown to significantly affect task performance only in the dyslexic group. In particular it was shown that picture names from dense phonological neighbourhoods were slower to name than comparable picture names with few phonological neighbours. This result is not predicted by a general processing impairment account of dyslexia and is in fact the reverse of that predicted by a representation account. In contrast, slower naming with items from dense phonological neighbourhoods is consistent with the competition hypothesis which postulates that increasing phonological neighbourhood density increases the degree of phonological competition during selection — an increase to which the dyslexic reader is particularly sensitive.
General Discussion

The primary aim of these experiments was to investigate the process of phonological retrieval in a group of adult dyslexics and establish which factors influence the efficiency of this process. The results indicate that the adult dyslexic is not characterised by a global impairment in phonological retrieval. Rather they manifest a striking pattern of selective impairment that varies as a function of task format, and of the linguistic properties of the items to be retrieved. Reading but not picture naming is impaired in a slow, discrete trial format. Yet picture naming is impaired in a fast, continuous format – especially with words from dense phonological neighbourhoods. It is proposed that the critical cognitive factor which underlies this impairment relates to the degree of phonological competition generated during the retrieval process.

What is remarkable is that even short high frequency words such as ‘hen’ or ‘cake’ are read inefficiently by dyslexic adults, who otherwise are characterised by a superior level of intellectual ability, reflected in their elevated IQ scores and their entrance into university. This indicates that while remediation and extensive exposure to the printed word can result in a high degree of reading accuracy, reading efficiency remains stubbornly poor. Reduced efficiency reading long more complex words would be unsurprising; what is surprising is that such inefficiency also applies to mapping the simplest of grapheme-phoneme correspondences in a regular monosyllabic word. Yet the complexity inherent in an opaque orthography such as English arguably affects such words – even when such complexity is ostensibly absent. This is because a given grapheme, especially if it is a vowel, is associated with multiple phonemes. It is suggested that such a grapheme will lead to the partial activation of all its associated phonemes, irrespective of the lexical context, producing varying degrees of phonological competition. In this respect, reading a word in English might be likened to a Stroop task, where there is a temporally and spatially integrated stimulus eliciting activation of competing response sets – during reading these are sublexical in nature whereas in a normal Stroop task competing lexical responses are activated. Such phonological competition does not characterise a regular orthography such as Italian, where the grapheme-to-phoneme mappings are highly regular. Here, only a single set of sublexical
codes are activated by a given word, without competition. Hence, reading difficulty of Italian dyslexic adults is comparably mild – and may go unnoticed. Only subtle differences in reading speed, detectable under laboratory conditions, may differentiate such individuals.

This view that dyslexia is characterised by a failure to efficiently resolve phonological competition is consistent with the findings of the current experiments. It is suggested that reading any word in an inconsistent orthography such as English, will *necessarily* invoke a high degree of phonological competition. As such, dyslexic readers rarely attain normal efficiency of response (as indexed by reading latency) even if reading accuracy is satisfactory, although as reading experience accumulates throughout adulthood, reading speed is likely to improve. In contrast, retrieving the name of a given picture *may or may not* invoke phonological competition, and so dyslexic readers *may or may not* be impaired on a task of picture naming. It is suggested that occurrence of such competition crucially depends on naming rate, on the degree of semantic specification, and on the number of phonological neighbours surrounding that item. Naming items at a fast pace (in a single or in a continuous format) serves to increase the level of phonological competition, since selection of each item must proceed in the context of the activation associated with the previously selected item and its neighbours. By adulthood items used in these experiments are likely to have been fully specified at the semantic level, reducing the likelihood of inappropriate semantic alternatives being encoded at the phonological level which may occur in childhood. The observation that the dyslexics were less likely to produce acceptable alternative responses, to those normally associated with the pictures, suggests that they are less likely to activate semantic alternatives. One possibility is that they compensate for their phonological difficulty by exerting a greater level of inhibition at the semantic level in order to reduce the amount of input, and thus competition, at the phonological level. Finally, if a given word is situated in a dense phonological neighbourhood then the level of spreading activation to potential competitors will be high. It is in these conditions - of a large number of partially activated items - that selection of the ensuing target must be made. If these factors do influence the level of phonological competition during lexical selection then the performance of dyslexic individuals will vary accordingly. The phonological competition hypothesis therefore contends that the
difficulties shown by dyslexic individuals are context specific and are explained with reference to the *process* of lexical selection.

In contrast, the phonological representation hypothesis fails to accommodate the results presented here. Firstly, if it is the case that a given representation is inadequately specified, then its retrieval should be compromised during reading and naming. Yet it has been shown that retrieval difficulty is confined to reading under single trial conditions (Experiment 1). Secondly such an account has yet to explain how retrieval of a poorly specified representation during naming is confined to a rapid continuous format (Experiment 2). Finally, a representational account would predict more accurate representation – and therefore more accurate retrieval – of words with larger numbers of phonological neighbours. Yet it is precisely such words, from dense phonological neighbourhoods, that dyslexic adults retrieve least efficiently.

The results of these behavioural experiments raise several questions with regard to the neuroanatomical basis of the reading impairment in dyslexia. Previous neuroimaging studies have almost exclusively employed orthographic stimuli in an effort to directly assess reading processes in dyslexia. However, both process and representational accounts of the phonological deficit contend that a common cognitive impairment underlies the difficulty in both reading and naming. If this is the case then the brain regions identified as showing abnormally reduced activation during reading should show a similar pattern during picture naming. Such neurofunctional evidence would complement the existing psychological evidence in supporting an impairment in phonological processing which extends beyond literacy.
A PET INVESTIGATION OF PHONOLOGICAL RETRIEVAL

Experiment 3: A PET Study of Picture Naming and Word Reading

Introduction

Over the past decade, significant advances have been made in identifying the neural basis of the phonological impairment in dyslexia. Functional imaging studies of language processing have been reviewed in Chapter 3 and by Demb, Poldrack and Gabrieli (1999) and by Habib and Demonet (2000). These describe studies which report abnormal activation in a set of left hemisphere temporo-parietal regions. While these studies have employed a variety of paradigms they share one common feature: the use of orthographic stimuli (Flowers et al., 1991; Gross-Glenn et al., 1991; Paulesu et al., 1996; Salmelin et al., 1996; Rumsey et al., 1997; Shaywitz et al., 1998; Horwitz et al., 1998; Brunswick et al., 1999). Three exceptions to this pattern have used auditory word presentation (Hagman et al., 1992; Rumsey et al., 1992; McCrory et al., 2000) in tasks of rhyme judgement or repetition. Entirely absent from the literature however are investigations of naming. In the light of robust developmental evidence for a picture naming deficit in dyslexia this is a somewhat surprising omission.

Children, even before they learn to read, can put a name to a picture. This elementary process in the use of language provides an early measure of a child's semantic and phonological knowledge. In addition, because picture naming shares a number of component processes with reading, it provides a means to index literacy skill. Naming performance in kindergarten, for example, represents a powerful predictor of later reading performance (Jansky and de Hirsch, 1972; Wolf and Goodglass, 1986). With regard to dyslexia the functional overlap between the naming and reading systems is apparent throughout development. Dyslexic children show early impairments on tasks of picture naming (e.g. Badian, McAnulty, Duffy and Als, 1990) that persist into
adolescence and adulthood (e.g. Felton, Naylor and Wood, 1990). It is widely agreed that a common deficit in phonological processing can account for these naming difficulties and the reading impairments of dyslexic individuals (e.g. Katz, 1986; Swan and Goswami, 1997a).

If it is the case that a common difficulty in phonological processing or representation underlies the dyslexics’ impairments in reading and naming, then a clear prediction emerges: a common neurological basis should characterise this phonological impairment across tasks. This prediction is made on the basis that both reading and naming share a common cognitive component - phonological retrieval - even though these tasks present with clear visual and semantic differences (see Figure 5.1).

![Figure 5.1. A cognitive model of the processing components involved in reading and picture naming.](image)

The neural basis for the cognitive processes engaged in phonological retrieval have been investigated in conjunction analyses in the normal population. Tasks of reading,
letter, colour and picture naming have implicated a common neural system incorporating both the left posterior inferior temporal lobe and the left frontal operculum. This system is hypothesised to reflect a modality-independent system of phonological retrieval (Price and Friston, 1997). So when participants read words and when they name pictorial representations of those words this system is activated (Moore and Price, 1999). While there are regions of activation associated with word-specific and object-specific processing, retrieving or computing phonological output, appears to have a common neurological locus across tasks (Price and Friston, 1997; Moore and Price, 1999). An alternative functional characterisation of the posterior inferior temporal lobe disputes this general role in phonological retrieval (Cohen, Dehaene, Naccache, Lehéricy, Dehaene-Lambertz, Hénaff and Michel, 2000). Cohen and colleagues (Cohen et al., 2000) propose that this region is in fact a specialised ‘Visual Word Form’ (VWF) area. This claim is based on observation that irrespective of whether words are presented to the left or right hemifield the activation in the posterior temporal lobe is strictly confined to the left hemisphere. They speculate that the human VWF area ‘...comprises a distributed representation of the visual shapes of letters sufficient to represent unambiguously specific alphabetic strings’ (Cohen et al., 2000, p. 305). The question therefore arises whether the reduced activation of this region reported for dyslexic adults reflects a deficit specifically associated with orthographic processing.

According to the position of Cohen et al., (2000), such an abnormal pattern of processing would be taken to reflect a phonological impairment specific to reading. Yet the psychological literature provides extensive empirical support for the view that the phonological processing impairment in dyslexia extends beyond literacy. Language processing impairments in dyslexia are, for example, apparent before school age (Scarborough, 1990), affect later verbal memory (Nelson and Warrington, 1980), non-word repetition (Snowling, 1981) and, of course, picture naming. To date the reduced activation observed in dyslexic individuals in the posterior inferior temporal area has been taken to reflect such a general phonological processing impairment (Rumsey et al., 1997; Brunswick et al., 1999; Paulesu et al., 2001). However, in view of the exclusive use of orthographic stimuli by these studies, such a generalisation still awaits explicit empirical support. In other words, the observed differences in this region may entirely reflect differences contingent on orthographic decoding,
consistent with its postulated role as the Visual Word Form area (Cohen et al., 2000). Given that behaviourally the phonological deficit in dyslexia extends beyond reading, and given the neuro-imaging evidence which suggests a role for BA37 in general phonological retrieval (Price and Friston, 1997; Buchel et al., 1998; Moore and Price, 1999) an alternative hypothesis naturally arises. That is, in dyslexia, reduced activation of the posterior inferior temporal lobe reflects an impairment in the general processes of phonological retrieval – i.e. processes that are not specific to reading.

The use of orthographic material in imaging studies of adult dyslexics has also presented researchers with a methodological paradox: designing a task on which dyslexics will perform normally, but which will nevertheless reflect their underlying deficit in phonological processing. It has been established that even well-compensated adult dyslexics show slower latencies when reading short high frequency words (Brunswick et al., 1999). The key issue here is the difficulty that arises when interpreting differences at the neural level, if at the behavioural level, the performance of two groups differs significantly. For example, in both Rumsey et al., (1997) and Shaywitz et al., (1998) the dyslexic’s behavioural performance on the scanning tasks were significantly impaired. It is of course likely that a proportion of the reported activation differences in the dyslexic group were attributable to qualitative impairment in phonological processing. Yet, logically, poor behavioural performance alone would be sufficient to explain - if not all - then at least a subset of these differences. Brunswick et al., (1999) aimed to address this confound by presenting a simple task (reading aloud) that employed simple stimuli (short high frequency words). No differences in reading accuracy were reported between the dyslexic and control groups. However, naming latency was not measured, leaving open the possibility that the dyslexics’ performance was in fact compromised, but simply not detected. In a second task of implicit reading, accuracy and speed of response were matched across groups. These measurements indexed performance on a visual search task, to which reading was incidental. This design managed to reduce the complications of a behavioural confound by engaging dyslexic participants in a non-language task on which they were unimpaired. The limitation of such an approach, however, is that the behavioural measures taken do not allow us to assess the efficiency of the underlying linguistic processes engaged.
Picture naming, for several reasons, may represent an ideal paradigm to overcome these concerns. While picture naming is markedly impaired in dyslexic children (e.g. Katz, 1986; Swan and Goswami, 1997a) confrontation naming is normal in dyslexic adults (e.g. Felton, Naylor and Wood, 1990). Only when naming proceeds in rapid succession, either in a sequence (e.g. Felton et al., 1990) or singly (Wolff et al., 1990) do dyslexic adults manifest a performance deficit. Experiment 1 demonstrated that even when word length and frequency are manipulated and sensitive latency measurements taken, dyslexic participants are just as fast and as accurate as their peers in naming pictures in a slow-paced, single-trial format. In contrast, Experiment 2 demonstrated that the same individuals are impaired in naming comparable stimuli in a speeded continuous format. This pattern suggests that although dyslexic adults manifest a developmental improvement in picture naming, a cognitive impairment in phonological retrieval persists - but this impairment is only behaviourally manifest under speeded conditions. In this way picture naming may represent a solution to the methodological paradox: naming entails the cognitive component of interest (phonological retrieval), but, under normal conditions, does not give rise to a detectable behavioural impairment. Apart from the difficulties in matching task performance, functional imaging studies of dyslexia have often been characterised by another methodological limitation: failure to appropriately match control and dyslexic groups for age and IQ. While strict matching is routinely carried out in some cases (Rumsey et al., 1992; 1994; 1997; Paulesu et al., 1996; Brunswick et al., 1999) it is by no means the normative procedure for studies of functional imaging (e.g. Shaywitz et al., 1998; Temple et al., 2001; Demb, Boynton and Heeger, 1998).

The current study aimed to address each of these concerns in an investigation of the neural correlates of picture naming and word reading. Participants were carefully selected so that the control and dyslexic participants were matched for: i. IQ, age and educational level and ii. accuracy and speed of word reading and picture naming outside the scanner. Such matching procedures aimed to reduce the likelihood that any observed differences in neuronal activation arose as a consequence of differences in sample selection or behavioural performance. Rather any differences could be more confidently attributed to qualitative or quantitative differences in phonological processing.
For both conditions, a high level baseline was developed, in order to isolate the neural substrate underlying phonological retrieval. It was predicted, in line with previous studies, that this substrate would primarily encompass the left posterior inferior temporal lobe (BA37). This same region shows attenuated activation in developmental dyslexics during tasks that entail orthographic decoding. The current study provided an opportunity to replicate this finding, but in addition, formulate a further prediction: that such reduced activation would be found during picture naming, where phonological retrieval occurs in the absence of any orthographic decoding. Such a result would indicate a general impairment in lexical retrieval, consistent with a core deficit in phonological processing or representation.

Method

Participants
Eighteen participants from Experiment 1 were recruited, all right-handed males. 10 control subjects were matched with 8 dyslexic subjects for age, verbal, performance and full scale IQ using the full form of the Wechsler Adult Inventory Scale-Revised (WAIS-III; see Table 1). In order to minimise group differences on the picture naming and word reading tasks - and thus minimise behavioural confounds during scanning - subjects were selected on an earlier assessment of their behavioural performance in a discrete trial picture and word reading task (see below). Reading and spelling ability were tested using the Wide Range Achievement Test - Revised (WRAT - R; Jastak and Wilkinson, 1984).

Background measures
All participants at least one month before scanning had been presented with the picture and word stimuli in a blocked discrete trial format in which they were asked to name a series of pictures and words as fast and as accurately as possible (see Experiment 1). Latency and accuracy measurements were taken. The control and dyslexic participants were selected so that they could be matched on these parameters. These participants were also administered a task of Rapid Automatic Naming (RAN) in which five pictures are repeated in a series of fifty items. The pictures had to be named as rapidly as possible in a continuous fashion and the total time recorded. Two control tasks were also administered to assess response latencies during two picture processing tasks that
required participants to make a simple semantic decision (living – non-living) and a visual decision (real – nonsense object) as fast and as accurately as possible. These tasks were designed to assess form processing and semantic access independently of phonological processing demands.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dyslexics (n=8)</th>
<th>Controls (n=10)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.0 (0.9)</td>
<td>20.3 (2.9)</td>
<td>n.s.</td>
</tr>
<tr>
<td>IQ tests (WAIS-R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-scale</td>
<td>123.9 (10.9)</td>
<td>125.1 (9.7)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Verbal</td>
<td>119.5 (6.0)</td>
<td>124.4 (6.8)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Performance</td>
<td>124.6 (6.7)</td>
<td>120.8 (13.4)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Standardized literacy tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading WRAT (standardized scores)</td>
<td>88.1 (14.4)</td>
<td>112.7 (4.7)</td>
<td>**</td>
</tr>
<tr>
<td>Spelling WRAT (standardized scores)</td>
<td>85.9 (14.6)</td>
<td>107.8 (6.5)</td>
<td>**</td>
</tr>
<tr>
<td>Verbal memory tasks (max=19)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WAIS digit span</td>
<td>7.4 (1.2)</td>
<td>12.5 (2.4)</td>
<td>**</td>
</tr>
<tr>
<td>WAIS letter-number sequencing</td>
<td>8.1 (1.6)</td>
<td>12.2 (3.5)</td>
<td>**</td>
</tr>
<tr>
<td>Background measures (latencies, msec)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picture naming</td>
<td>740.4 (195.8)</td>
<td>736.6 (87.0)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Word reading</td>
<td>514.9 (122.5)</td>
<td>479.8 (68.5)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Semantic decision</td>
<td>499.7 (61.7)</td>
<td>492.3 (34.2)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Visual decision</td>
<td>438.1 (37.7)</td>
<td>490.6 (73.5)</td>
<td>n.s.</td>
</tr>
<tr>
<td>RAN picture naming (seconds)</td>
<td>36.6 (6.5)</td>
<td>28.9 (3.8)</td>
<td>*</td>
</tr>
</tbody>
</table>

Table 5.1. Participants: Behavioural profile n.s. - non-significant; * < 0.05; ** < 0.01

Figure 5.2. Examples of stimuli used: i. Words; ii. Falsefont; Picture; Nonsense shape.
Stimuli

The same set of 120 stimuli from Experiment 1 was employed for this imaging study. As in Experiment 1, half were presented as words and half were presented as line drawings (see Figure 5.1 for examples). Participants viewed the same items in the same modality as in Experiment 1; no subject read and named the same item. Pictures were all scaled to measure between 5 - 8 cm in width and 5 - 8 cm in height. Words were presented in lower case Courier font, size 72. Meaningless control stimuli were carefully designed for both modalities (see Figure 5.2). False font was modified to match the Courier font as closely as possible. Two sets were created: one to match the short words in mean letter length (3-5) and one to match the long words in mean letter length (6-10). A set of stimuli was also created to act as visual controls for the pictures. These consisted of nonsense line drawings, which were rated by 8 students (who did not partake in either study) for i. real object likeness, and ii. visual complexity. A nonsense shape was excluded if two or more raters indicated that either part or all of the shape reminded them of a real thing of any kind; in this way distracting semantic associations were minimised. The visual complexity rating for the nonobjects (2.92; s.d.=0.8) were matched to the rating for the real objects (2.88; s.d.=0.8; calculated from the published scores of Morrison et al., 1997).

Activation tasks

The scanning period involved two experimental conditions, and two baseline conditions: i. word reading; ii. picture naming; iii. false fonts; iv. nonsense shapes. There were four word-reading and four picture-naming conditions. 15 stimuli were presented per scan, each for 500 msec with a fixed interstimulus interval of 2000 msec. Subjects were asked to name or read aloud each item when they appeared on the screen; accuracy was scored by the experimenter, and the latency recorded. Stimuli were not repeated between scans, or within the first 'uptake' phase of the scan. For the short false font condition participants were instructed to view each string and respond 'yes' to each item, while in the long false font condition they responded 'okay yes'. These conditions were designed to match visual input and articulation during the short and long word conditions respectively. Similarly in one nonsense shape condition, participants were instructed to view each shape and respond 'yes' to each item, while in the other condition they responded 'okay yes'. These conditions were designed to match picture naming with the short and long words respectively. These baselines are
similar to those employed by previous studies (e.g. Bookheimer, 1995; Moore and Price, 1999) to control for the visual processing of the words and pictures. The additional verbal response was designed to control for the articulation and auditory feedback in the naming and reading conditions. All stimuli were presented on a 17-in monitor suspended above the scanner bed, at a distance of approximately 24 inches from the subject.

**PET scanning procedure**

Regional cerebral blood flow was measured using a CTI Siemens Ecat HR+ PET scanner (CTI Inc., Knoxville, Tenn., USA). Data were acquired with inter-detector collimating septa retracted (Townsend, Geissbuller, Defrise, Hoffman, Spinks, Bailey, Gilardi and Jones, 1991). Following a transmission scan, twelve consecutive scans were obtained for each subject implemented with an exposed 68Ge/68Ga source, to correct for attenuation. Each activation scan involved the intravenous administration of 5 mSv of $^{15}$O-labelled water ($H_2^{15}$O) at the constant rate of 10 ml/minute. From the start of each scan background radiation was measured for 30 seconds, after which the infusion was given. The activation task was started approximately 30 seconds later, 10 seconds prior to the onset of the acquisition period. Acquisition lasted for 90 seconds. After correcting for background activity, the true counts accumulated during this period were taken as an index of cerebral blood flow (Fox and Mintun, 1989). This protocol conforms to guidelines established by ARSAC UK and was approved by the Medical Ethics Committee of the Institute of Neurology.

**Data analysis**

*Behavioural data*

Sample characteristics and performance on the battery of psychometric measures were quantified and compared between groups using factorial analyses of variance.

*PET data*

The PET data were analysed using SPM99 (Wellcome Department of Cognitive Neurology, London; Friston, Holmes, Worsley, Poline, Frith, and Frackowiak, 1995a) on a SPARC1 workstation (Sun Microsystems Inc., Surrey, UK). Head movements, which occurred during the course of the PET scan, were corrected by realigning the time series.
with the first scan. The reconstructed transaxial PET images were spatially normalized for brain size and shape (Friston, Ashburner, Poline, Frith, Heather, and Frackowiak, 1995b) so that the spatially normalized images consisted of 2x2x2 mm voxels. These images were subsequently smoothed in three directions with a Gaussian filter (FWHM) of 16x16x16 mm. This smoothing had the effect of increasing signal-to-noise ratio and allowing for normal between-subject variation in gyral anatomy. Analyses were performed in MATLAB Version 4.2c (MathsWorks Inc., MA, USA). Data were analyzed using subject-specific repeated measures ANCOVA with images scaled to a grand mean of 50. Statistical parametric maps of adjusted mean rCBF were produced for each condition/group along with adjusted error variance data for each.

A random effects analysis was carried out in order to evaluate common and differential areas of response in the Dyslexic and Control groups so that (a) the variance estimate was between subject rather than within subject and (b) the degrees of freedom related to the number of subjects rather than the number of scans. Average images of Reading – Falsefont and Picture Naming – Nonsense shapes were generated for each subject with the effects collapsed over word length in order to gain statistical power. Two analyses were carried out: 1) a main effect analysis allowing for identification of regions that were activated for both groups; 2) a conjunction analysis of the common activity and the differential activity of the two groups. The activated areas reported in the main effect analysis for picture naming - nonsense shapes consisted of voxels that survived correction for multiple comparisons of p< 0.05. The activation in the posterior inferior temporal lobe during word reading did not reach a corrected level. However, activation was predicted in this area on the basis of previous studies (e.g. Brunswick et al., 1999). A small volume correction (10mm sphere) was therefore permitted based on the peak co-ordinates of the region previously shown to be less active in dyslexics (-42, -60, -12: Brunswick et al., 1999).

Results

Background measures

The dyslexic and control groups were matched on reading and naming speed on the same stimuli to be used in the scanning task. Such pre-selection aimed to reduce the possibility of group differences in performance during the PET scan itself. An
assumption of the current study, therefore, is that the dyslexics’ qualitative impairment in phonological retrieval would be detected at the neural level even at a slow pace of presentation where behavioural performance was ostensibly normal. This assumption is supported by the finding that the selected participants were impaired when pictures were named at a rapid rate in a continuous format (see Table 5.1), a finding that is consistent with previous reports in the adult dyslexic literature (Felton et al., 1990). The implication is that the dyslexics phonological retrieval processes during picture naming are impaired, but such an impairment is simply not behaviourally manifest under slow paced conditions. The dyslexic participants were unimpaired in both the semantic decision and visual decision tasks.

**Behavioural measures during PET**

Both accuracy and latency of response were recorded for the word reading and picture naming tasks during scanning. As shown in Table 5.2 picture naming speed and word reading speed did not differ significantly across the control and dyslexic groups (p>.05). Likewise both groups performed with comparable levels of accuracy. Accuracy was at ceiling for the word reading condition in both groups: there were only three errors in total, all made by the same dyslexic participant. Alternative but correct responses in the picture naming task were not scored as errors (e.g. ‘boat’ for ‘ship; ‘saucepan’ for ‘pan’). The somewhat slower response times during scanning (relative to participants’ response times outside the scanner) can be attributed to the fact that during scanning participants were asked to name or read each item as they appeared and were not instructed to give speeded responses.

<table>
<thead>
<tr>
<th></th>
<th>Dyslexics (n=8)</th>
<th>Controls (n=10)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy (% Correct)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word reading</td>
<td>99.4 (1.7)</td>
<td>100 (0)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Picture naming</td>
<td>95.8 (8.0)</td>
<td>98.8 (5.2)</td>
<td>n.s.</td>
</tr>
<tr>
<td><strong>Latency (msec)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word reading</td>
<td>715.6 (110.5)</td>
<td>708.1 (87.5)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Picture naming</td>
<td>808.0 (99.0)</td>
<td>871.5 (104.9)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

**Table 5.2.** Behavioural measures during PET scanning: accuracy and latency of response. Standard deviations shown in parentheses.
Table 5.3. Brain areas activated during reading and naming across groups. Network of rCBF activation for control and dyslexic participants during reading and naming, after baseline subtraction. All effects established from random effects analyses. Conjunction values significant at a voxel corrected level (p<.01). Reported activation differences in the posterior inferior temporal lobe in a previous study of dyslexia (Brunswick et al., 1999) and in a cross cultural comparison of normal readers (Paulesu et al., 2000).

**PET results: Naming**

The set of areas activated in both dyslexic and control groups for naming relative to the nonsense shape condition were identified in a random effects conjunction and are shown in Table 5.3. In line with previous studies, these regions encompass the bilateral aspect of the posterior inferior temporal lobe (Bookheimer et al., 1995; Moore and Price, 1999). Note that no frontal activation survives the strict threshold adopted; this reflects the fact that processes of articulation are shared by both the baseline and naming tasks. A random effects analysis was also used to identify those areas significantly more active in the control relative to the dyslexic group during naming. The left posterior inferior temporal activation (-46, -54, -16) was found to be significantly less in the dyslexic group (p<.01, small volume corrected; see Table 5.3.
and Figure 5.3). This finding demonstrates that dyslexics manifest reduced activation here not only for reading (Brunswick et al., 1999) but also for phonological retrieval during naming. There were no areas significantly more activated in the dyslexic group.

**PET results: Reading**

The random effects main effect analysis for reading across the two groups did not produce any regions where significance was corrected for the number of comparisons made. This is most likely attributable to the high level baseline which matched the reading task both in terms of visual, articulatory and auditory processing demands. In view of our prediction that the posterior inferior temporal lobe is specifically engaged in phonological retrieval, a small volume correction (10mm sphere) was carried out for this region based on the co-ordinates of our previous study (Brunswick et al., 1999; -42, -60, -12). This indicated (i) activation for reading relative to falsefont in the normal group (p<.05, corrected) and (ii) significantly reduced activation for the dyslexic readers relative to the control group (p<.01, corrected; see Table 5.3 and Figure 5.3).

**Figure 5.3.** Region of greater activation in the control group in the posterior inferior temporal lobe (BA37), during i. Picture naming, and ii. Word reading.
 Regions showing interactions of task with group

Critically there were no regions of significant interaction between Group (Controls vs. Dyslexics) and Task (Naming vs. Reading).

Discussion

At the behavioural level dyslexic adults are unimpaired on a slow paced picture naming task; at the neural level, however, they present with significantly reduced activation in the left posterior inferior temporal lobe (BA37). This demonstrates not only the sensitivity of neuroimaging as an investigative tool, but crucially, it establishes that the previously reported abnormality in this region is not contingent on orthographic decoding. Rather, reduced activation in BA37 reflects a general phonological processing impairment that affects lexical retrieval when reading (Brunswick et al., 1999), or when naming a picture. The implications of these findings at both the neural and the cognitive level will be explored in turn, followed by a discussion of how these considerations might be integrated within a single neurocognitive framework.

Reduced activation of the posterior inferior temporal lobe (BA37) in dyslexic participants has been reported in tasks that entailed orthographic decoding (Rumsey et al., 1997; Brunswick et al., 1999). In light of the current finding that such reduced activation is also manifest during a task of picture naming, this finding can now be interpreted as a correlate of disordered phonological computation or retrieval. Such an interpretation is consistent with the cognitive characterisation of dyslexia, which postulates that a common deficit in phonological processing underpins the behavioural impairments in picture naming and word reading (Swan and Goswami, 1997a). More generally these results bear on how we characterise the role of the posterior inferior temporal lobe. They are not consistent with a functional characterisation of this region as a ‘Visual Word Form’ area (Cohen et al., 2000) since both control and dyslexic participants strongly activated this region when picture naming relative to a high level baseline. In contrast, these findings are consistent with the suggestion that the posterior inferior temporal lobe is engaged in the specification or retrieval of phonological information irrespective of modality of access. As noted previously, this region is implicated in picture, colour, letter and word naming as well as during tasks
of verbal fluency, all of which require phonological access (Price and Friston, 1997; Moore and Price, 1999; see Price, 2000 for a review). The activation of BA37 by congenitally blind readers of Braille has provided further support for such a modality-independent characterisation (Buchel et al., 1998). It is perhaps the strategic location of this region, between the visual cortex and the more anterior temporal cortex, that has accorded BA37 the role of an association area, integrating converging input from a number of brain regions (Buchel et al., 1998) and in turn relaying the output to left frontal regions.

These findings also illustrate a more general argument that relates to how we associate cognitive function with a particular neural system. To date a convincing array of evidence has implicated the left posterior inferior temporal lobe in word reading (see Price, 2000, for a review). Such evidence has in turn been taken as a basis to infer a unique and exclusive role for this region as a visual word form area (Cohen et al., 2000). Yet activation of a given area during a given task is not a sufficient basis to infer that its role is specific to that task alone. Let us take the task of writing to illustrate the point. The demonstration that a motor area of the left hemisphere is involved in writing output could be taken as a basis for its role as the 'grapho-motor area'. Yet such a position would not be tenable if it was demonstrated that other tasks, which require access to rehearsed and fine-grained motor movements, also activate the same region. Writing, like reading, is likely to be parasitic on pre-existing neural substrates that are engaged by other tasks. This is not surprising given that these are, in evolutionary terms, extremely recent (and still by no means universal) human activities. What is critical is to identify the cognitive component shared across tasks. The finding that the posterior inferior temporal lobe is implicated in word reading and picture naming, and that dyslexic individuals show reduced activation across both tasks, is consistent with a role in general phonological specification or retrieval, whether or not orthographic decoding is required. On this basis several novel predictions can be made. For example, dyslexic participants should show reduced activation of this region when naming environmental sounds, since this task also requires phonological retrieval. Likewise, illiterates should show significant activation of the posterior inferior temporal lobe during picture naming. Such a finding would represent strong support for the modality independent hypothesis, since stored orthographic word forms would be entirely absent under these conditions.
Cross cultural studies of reading have demonstrated the involvement of BA37 in English, Italian and French readers, and in addition shown how the level of activation in this region is contingent on the transparency of the orthography (Paulesu et al., 2000; Paulesu et al., 2001). Increased activation in the left posterior inferior temporal lobe, for example, has been reported in English relative to Italian readers for pseudowords (Paulesu et al., 2000; see Table 5.3). While this finding might again be taken to reflect processes specific to orthographic processing it may equally reflect phonological processes associated with resolving the phonological competition during reading. That English readers activate this region more strongly would be consistent with this interpretation, given the much higher level of ambiguity in the English orthography. Such ambiguity serves to slow even skilled adult readers of English, relative to their Italian peers (Paulesu et al., 2000). That reduced activation is observed in this same region in dyslexic readers – whether they are English, French or Italian, (Paulesu et al., 2001) – may reflect a qualitative difference in how they address such phonological competition. Indeed, the fact that such processes are of less relevance in a transparent orthography (where the level of phonological competition is significantly lower) may also help account for the more mild behavioural impairment seen in Italian dyslexics (Paulesu et al., 2001).

This characterisation of the phonological deficit in dyslexia as one of inefficient phonological processing, contrasts with the conventional assumption that the phonological deficit in dyslexia can be attributed to the quality of the phonological representations (e.g. Snowling et al., 1989; Swan and Goswami, 1997b). The suggestion proposed here is that dyslexics difficulty lies in their functional access of a given phonological form. That is, phonological representation is intact but successfully accessing those representations is a fragile process. This fragility stems from inefficiency in resolving phonological competition when several phonological representations are simultaneously activated. The degree of phonological competition elicited is contingent on the nature of the stimulus whose associated phonological form must be accessed, and on the context in which that access occurs. Reading, even a single word, for example, entails the activation of multiple phonological codes that in turn compete for selection. When reading the word ‘cat’ (/kæt/), the correct vowel /æ/ is activated, but an alternative, the vowel /a/ as in ‘car’ (/kar/) will also receive a
degree of spreading activation. This example illustrates a general characteristic of reading in an opaque and inconsistent orthography such as English: that phonological competition is inherent in the process. But phonological competition is just not confined to reading. Naming will entail spreading activation to associated competitors (O'Seaghdha and Marin, 1997), a phenomenon accentuated if the naming rate is rapid. The faster the turnover of activated and inhibited phonological forms in the phonological lexicon, the greater the level of phonological competition that will accrue. This follows, since the selection of each item must take place in the context of the residual activation of the previous item(s). This account is consistent with the observation in the current study that the dyslexics remain impaired on continuous rapid naming, even if they can efficiently name pictures in a single trial format; similarly, dyslexic adults are impaired at naming pictures at faster rates even when they are presented in a single trial format (Wolff et al., 1990). In this way the need to postulate an additional, non-linguistic processing impairment in dyslexia to explain the rapid naming deficits (e.g. Wolf and Bowers, 1999) becomes redundant.

In addition to these theoretical considerations two methodological points warrant mention. The first regards the importance of matching groups for IQ. This issue was partly addressed in a recent fMRI study of dyslexic children (Temple et al., 2001). A group of IQ-matched and non-IQ matched dyslexic children were compared with a group of unimpaired children. The authors point out that the key region of interest – a left temporo-parietal region – showed reduced activation in the dyslexic group irrespective of IQ. On this basis they suggest that IQ was “unrelated to the phonological deficit”. Yet the same authors point out that three regions differed significantly between the IQ and non-IQ matched dyslexics when compared with their controls. Contrary to the authors’ conclusions, this indicates that IQ does give rise to measurable, and possibly unpredictable, differences in brain activation. The fact that the region of interest was spared in this case is hardly reassuring. Until there is a systematic investigation of how IQ interacts with individual aspects of language function – in both dyslexic and normal individuals – a cautious approach to sample selection is surely the prudent option. While smaller group sizes may be the consequence, appropriate statistical procedures can still be employed to establish reliable differences; the false negatives (or positives) attributable to differences in IQ are currently impossible to identify. The second issue regards the difficulties that arise
if behavioural differences characterise the dyslexics’ performance during the scanning task. In those studies that have reported differences in the left angular gyrus (Rumsey et al., 1997; Shaywitz et al., 1998; Temple et al., 2001) the performance of the dyslexic readers has always been impaired relative to that of the controls. In this study, as in Brunswick et al., (1999) behavioural performance was matched and no differences were found in this region. However, in spite of the matched levels of behavioural performance in the current study significant differences in neural activation were detected. In this case, it appears that the measurement of neural activity indexed differences in cognitive processing, in a way that behavioural measurements did not. This finding demonstrates the possibility of developing experimental paradigms that elicit minimal difficulty for dyslexic individuals but which nonetheless incorporate the cognitive process of interest. By so doing, the risks of generating group differences in performance, and by implication behavioural confounds, are greatly reduced.

It is proposed that a common neural locus, engaged in phonological retrieval, underlies dyslexics’ impairment in reading and naming. In this study the dyslexic participants showed reduced activation relative to their peers when reading and when naming pictures aloud in the posterior inferior temporal lobe (BA37). This finding is consistent with dyslexics’ deficits in retrieval when naming pictures (Experiment 2). This finding demonstrates that the differences in the posterior inferior temporal lobe are not specific to orthographic decoding but reflect an impairment in more general processes of phonological retrieval.
A PET STUDY OF PHONOLOGICAL REPETITION

Experiment 4: Abnormal functional activation
during a simple word repetition task

Introduction

While a developmental history of reading and spelling impairment typically characterises the dyslexic individual, the impact of the disorder extends beyond the domain of literacy. Speech processing tasks which place no demands on orthographic decoding, such as word repetition, have revealed subtle but robust impairments (e.g. Snowling, 1981; Snowling, Goulandris, Bowlby and Howell, 1986; Brady, Poggie, and Rapala, 1989; see Brady, 1997, for a review). These impairments, like the difficulties observed in reading, may arise from a core deficit in the quality of phonological processing or representation (Hulme and Snowling, 1992; Snowling, 2000). The present study aimed to investigate the pattern of brain activation in a group of adult developmental dyslexics, during speech processing.

It has long been known that dyslexics are prone to mispronounce long words (such as 'statistical' or 'parallelogram', Miles, 1974). While repetition studies employing short monosyllabic words have sometimes failed to find group differences (Lieberman, Meskill, Hilton, and Schupack, 1985) longer words result in poorer performance in less skilled readers (Brady, et al., 1989; Catts, 1986, 1989). Other than manipulating the length of stimuli, phonological difficulty can be increased by the use of pseudowords. Shown significantly impaired pseudoword repetition in poor readers when they are compared to younger children matched for reading age (Stone and Brady, 1995).†

These represent more or less novel phonological sequences that cannot be repeated solely on the basis of existing lexical entries. Several studies have now given the significant correlations reported between pseudoword repetition and vocabulary (Gathercole and Baddeley, 1989; 1990) lexical knowledge may well be implicated during repetition. Differences in vocabulary knowledge, however, fail to account fully for the difficulties experienced by dyslexic children during repetition, since impairments persist even when vocabulary knowledge has been controlled (Stone et al., 1995).

Impairments of pseudoword repetition have also been reported in adult illiterates (Reis and Castro-Caldas, 1997). The study of illiteracy provides a unique point of comparison with developmental dyslexia: in one instance a visuo-phonological reading system has never been established, while in the other, development of such a system has been dysfunctional. A PET study of illiterates requiring word and pseudoword repetition reported differences between these conditions (Castro-Caldas, Petersson, Reis, Stone-Elander, and Ingvar, 1998). Behaviorally dyslexic adults are known to show difficulty repeating pseudowords (Apthorp, 1995); it is possible therefore that any differences at the neural level may be enhanced with such stimuli.

Investigation of the neural basis of dyslexia has generally implicated reduced activation in the left hemisphere. Studies involving the visual presentation of print have consistently shown reduced activation of several regions in the left posterior temporal and/or parietal cortex and in particular of the posterior basal temporal lobe (Rumsey, Nace, Donohue, Wise, Maisog, and Andreason, 1997; Shaywitz, Shaywitz, Pugh, Fulbright, Constable, Mencl, Shankweiler, Lieberman, Skudlarski, Fletcher et al., 1998; Brunswick, McCrory, Price, Frith and Frith, 1999). Reduced activation in the basal temporal lobe (BA37) is hypothesized to specifically reflect impaired lexical retrieval in the dyslexic reader (Brunswick et al., 1999). Tasks explicitly tapping phonological awareness, such as rhyme judgement for auditorily presented words (Rumsey, Andreason, Zametkin, Aquino, King, Hamburger, Pikus, Rapoport and Cohen, 1992) or visually presented letters (Paulesu, Frith, Snowling, Gallagher, Morton, Frackowiak and Frith, 1996; Shaywitz et al., 1998) have also tended to indicate a left hemisphere locus of disordered processing.
The study reported in this chapter aimed to investigate whether speech stimuli would elicit the pattern of left hemisphere differences reported for reading (Rumsey et al., 1997; Shaywitz et al., 1998; Brunswick et al., 1999) and naming (Experiment 3). Repetition provides a behavioural task known to tax dyslexics even in adulthood, if difficult stimuli are employed (Catts, 1989). However, simple words and pseudowords that dyslexic adults find easy to repeat may provide a sensitive measure of differences in neural activation, since explicit behavioural confounds are avoided. Such a paradigm would shed light on how the language system of the dyslexic naturally responds to speech.

Eight developmental dyslexic subjects and six unimpaired readers were recruited for the study. Each subject received an extensive battery of behavioural tests to evaluate levels of reading and spelling and particularly phonological processing ability. All subjects were then scanned using PET. Two-syllable, concrete, highly familiar nouns, and two-syllable pseudowords created by changing the internal consonants of the words, were presented auditorily in a blocked design and subjects were asked to repeat them (for examples, see method). Such simple stimuli were used to minimize error in repetition performance and ensure that activation differences could not be attributable to gross behavioural differences. The present study, requiring repetition, complements a previous study in which the same stimuli were presented visually for reading aloud, at the same rate (Brunswick et al., 1999).

**Method**

**Participants**

Eight right handed adult males with developmental dyslexia and six male controls with no history of reading impairment were recruited from the same universities. All participants were physically healthy and none reported a history of neurological or psychiatric disorder. The dyslexic readers all had a documented history of reading difficulty identified in childhood or adolescence; all had gained entrance into university. Both groups were well matched for educational level, age, full-scale, verbal and performance IQ, as shown in Table 6.1 on page 130.
Background measures

i. General ability: Full-scale, verbal and performance IQ were determined using short forms of the Wechsler Adult Inventory Scale-Revised (WAIS-R).

ii. Word recognition and decoding: Reading and spelling ability were tested using the National Adult Reading Test (NART; Nelson, 1983) and the Wide Range Achievement Test - Revised (WRAT - R; Jastak and Wilkinson, 1984). Speed and accuracy of single word reading was measured using a voice-key. The word lists consisted of highly familiar, two- and three-syllable, regular words (see Appendix I.i. and I.ii. for a full list of the word and nonword stimuli). The pseudo-words were created from the words by maintaining the 'word envelope' whilst changing internal consonants (e.g. satin -> samin). Participants were asked to name the word as soon as they had recognized it.

iii. Phonological Processing and Verbal Memory: Phonological processing was assessed using several measures. In the Spoonerism task (to assess phonological segmentation and manipulation ability: after Perin, 1983) subjects were asked to switch the initial sounds of two words to make two new words or nonwords. For example 'basket – lemon' became 'lasket – bemon'. Full details of the stimuli and instructions are provided in Appendix I.iii. A measure of phonemic fluency was taken with a semantic fluency control task to assess efficiency of phonemic lexical access (Frith, Landerl, and Frith, 1995). A further task (Phonological list) required subjects to spot pseudo-homophones (e.g. shurt, soop) among pseudoword distracters (e.g. goom, shill). A control task (Orthographic list) weighted orthographic processing by requiring subjects to spot correctly spelled words (e.g. rail, nerve) among pseudo-homophone distracters (e.g. crain, cole). Verbal memory was assessed using both the WAIS digit span subtest and a specially constructed list of short, one-syllable words and long, five-syllable words. Finally, a digit-naming task was administered to measure naming speed (Spring and Davis, 1988). More details of all the fluency, memory and digit naming tasks are provided in Appendix I.iii.

Activation tasks

The scanning period involved three experimental conditions: two activation conditions (repeating aloud auditorily presented words and pseudo-words with eyes closed) and a
passive (eyes closed) rest condition. The words were bi-syllabic, regular nouns, (e.g. valley, body, carrot) or unfamiliar pseudowords (e.g. vassey, bofy, cappot) created from the words by changing the internal consonants. Stimuli used during scanning were new and had not been presented during the pre-test. Stimuli were digitized and presented via headphones binaurally with SoundEffects run on an Apple Power Macintosh computer. Each stimulus was presented for 1s, with an inter-stimulus interval of 2s. The three experimental conditions were presented in a fixed counter-balanced design (ABCCBAABCCBA); each condition was presented four times. This study followed a factorial design with reading ability (dyslexic versus non-dyslexic) as the between-group factor and with task (repeating words, repeating pseudowords and rest) as the within-group factor. Participants’ performance was scored.

**PET scanning procedure**

Regional cerebral blood flow was measured using a CTI Siemens Ecat HR+ PET scanner (CTI Inc., Knoxville, Tenn., USA). Data were acquired with inter-detector collimating septa retracted (Townsend, Geissbuller, Defrise, Hoffman, Spinks, Bailey, Gilardi and Jones, 1991). Following a transmission scan, twelve consecutive scans were obtained for each subject implemented with an exposed 68Ge/68Ga source, to correct for attenuation. Each activation scan involved the intravenous administration of 5 mSv of 15O-labelled water (H215O) at the constant rate of 10 ml/minute. From the start of each scan background radiation was measured for 30 seconds, after which the infusion was given. The activation task was started approximately 30 seconds later, 10 seconds prior to the onset of the acquisition period. Acquisition lasted for 90 seconds. After correcting for background activity, the true counts accumulated during this period were taken as an index of cerebral blood flow (Fox and Mintun, 1989). This protocol conforms to guidelines established by ARSAC UK and was approved by the Medical Ethics Committee of the Institute of Neurology.

**Data analysis**

**Behavioural data**

Sample characteristics and performance on the battery of psychometric measures were quantified and compared between groups using factorial analyses of variance.
**PET data**

As in Experiment 3, all data were analysed with SPM (see page 114). Two types of analysis were carried out, a random effects analysis, and an analysis of subject specific effects. Random Effects: a random effects model was employed, so that (a) the variance estimate was between subject rather than within subject and (b) the degrees of freedom related to the number of subjects rather than the number of scans. Average images of repetition-rest were generated for each subject with the effects collapsed over word and pseudoword repetition. Effects for dyslexic and normal readers were modelled separately allowing the identification of regions that were differentially activated by one or other group. A significance threshold (p<0.05) that was corrected for the entire search volume was used. Subject specific effects: each dyslexic subject was treated as a separate study within the same fixed effects design matrix. This enabled subject specific effects to be identified. In addition, regions that were consistently activated for each dyslexic and control subject were identified. This was achieved using conjunction analysis that sums over the individual effects and eliminates regions where there are significant differences between subjects (Price and Friston, 1997). To ensure that each subject showed significant activation we also eliminated areas where one or more of the subjects failed to activate at a threshold of p<0.08. This was achieved by using the inclusive masking procedure in SPM. In order to determine differences between each dyslexic subject and the normal group regions that were consistently more active for each of the controls relative to each of the dyslexics were identified using the inclusive masking option in SPM, with a threshold of p<.08 for each interaction.

**Results**

*Background Measures*

As shown in Table 6.1 overleaf, no significant between-group differences emerged in full-scale IQ, performance IQ or verbal IQ. Analysis of the data from the standardised literacy tests revealed impaired performance of the dyslexics relative to the controls for reading [NART (F (1, 12) = 4.2; p = 0.06); WRAT (F (1, 12) = 6.1; p < 0.05)], and spelling (F(1, 12) = 17.1; p < 0.05). On the timed word recognition tests the dyslexics were less accurate than the controls only with pseudowords (words: F (1, 12) = 1.0; p = 0.3; pseudowords: F (1, 12) = 9.0; p <0.05), but were significantly slower reading
both words and pseudowords (words: $F (1, 12) = 5.3; p < 0.05$; pseudowords: $F (1, 12) = 7.2; p < 0.05$).

The dyslexic readers were significantly impaired on the phonological measures (see Table 6.2). For the spoonerism task, a non-parametric analysis indicated that the dyslexic readers made more errors than the controls ($p < 0.05$) and took longer to complete the task ($p < 0.05$). They also took significantly longer than controls to complete the digit naming task ($F (1, 12) = 10.2; p < 0.01$) and there were significant differences in auditory short-term memory, with dyslexic participants demonstrating poorer word recall ($F (1, 12) = 8.0; p < 0.05$) and recall of digit strings ($F (1, 12) = 27.8; p < 0.001$). In a task requiring the detection of pseudo-homophones among pseudoword distracters (Phonological list) dyslexic participants were impaired, being both slower ($F (1, 12) = 9.9; p < 0.01$) and less accurate ($F (1, 12) = 4.8; p = 0.05$). On a control task (Orthographic list) dyslexic participants were both as fast ($p = 0.1$) and as accurate ($p = 0.6$) as the controls. Similarly the dyslexic readers were impaired on a task of phonemic fluency ($F (1, 12) = 4.7; p = 0.05$) while performing normally for semantic fluency.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dyslexics (n=8)</th>
<th>Controls (n=6)</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.0 (2.8)</td>
<td>22.8 (3.2)</td>
<td>n.s.</td>
</tr>
<tr>
<td>IQ tests (WAIS-R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-scale</td>
<td>112.4 (10.9)</td>
<td>114.8 (7.3)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Verbal</td>
<td>105.6 (9.0)</td>
<td>112.7 (5.3)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Performance</td>
<td>118.3 (14.7)</td>
<td>113.2 (9.8)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Standardized literacy tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading NART (errors; max=50)</td>
<td>26.3 (10.6)</td>
<td>16.0 (7.1)</td>
<td>$p = .06$</td>
</tr>
<tr>
<td>Reading WRAT (standardized scores)</td>
<td>100.8 (9.4)</td>
<td>112.5 (7.9)</td>
<td>*</td>
</tr>
<tr>
<td>Spelling WRAT (standardized scores)</td>
<td>91.5 (15.2)</td>
<td>110.5 (10.0)</td>
<td>*</td>
</tr>
<tr>
<td>Single word/ pseudoword reading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy (max= 40):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words</td>
<td>39.0 (2.5)</td>
<td>40 (0)</td>
<td>n.s</td>
</tr>
<tr>
<td>Pseudowords</td>
<td>33.8 (4.2)</td>
<td>39 (0.9)</td>
<td>*</td>
</tr>
<tr>
<td>Latency (msecs):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words</td>
<td>752.6 (111.6)</td>
<td>626.3 (84.4)</td>
<td>*</td>
</tr>
<tr>
<td>Pseudowords</td>
<td>1132.2 (259.0)</td>
<td>820 (130)</td>
<td>*</td>
</tr>
</tbody>
</table>

Table 6.1. Participant characteristics: reading abilities. n.s. - non-significant; * < 0.05; ** < .01; *** < 0.001
These results indicate that the dyslexic and control readers were matched on age and educational attainment, as well as on standardised measures of full scale, performance and verbal IQ. On standardised tasks of reading and spelling the dyslexic participants showed performance levels in the average range for the total population; however, relative to their university peers, the dyslexics were impaired on these measures and on a range of tasks specifically tapping phonological ability. Tasks weighting orthographic or semantic processing failed to differentiate the groups. This pattern of results is similar to that seen in a large number of studies on developmental dyslexia as reviewed by Snowling and Nation (1997) indicating the persistence of a core phonological deficit.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dyslexics (n=8)</th>
<th>Controls (n=6)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoonerisms (errors; max. = 12)</td>
<td>3.1 (3.8)</td>
<td>0.5 (1.2)</td>
<td>*</td>
</tr>
<tr>
<td>Spoonerisms (seconds / pair)</td>
<td>16.5 (13.7)</td>
<td>7.9 (1.8)</td>
<td>*</td>
</tr>
<tr>
<td>Digit naming: 50 digits (seconds)</td>
<td>21.8 (5.3)</td>
<td>14.5 (2.0)</td>
<td>**</td>
</tr>
<tr>
<td>Auditory STM (mean correct; max=6)</td>
<td>3.0 (0.6)</td>
<td>3.9 (0.7)</td>
<td>*</td>
</tr>
<tr>
<td>WAIS digit span (max=19)</td>
<td>8.1 (1.4)</td>
<td>12.3 (1.6)</td>
<td>***</td>
</tr>
<tr>
<td>Orthographic list</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean correct (max=15)</td>
<td>14.0 (1.0)</td>
<td>14.2 (0.7)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Time (seconds / 30 words)</td>
<td>51.0 (25.7)</td>
<td>33.1 (7.1)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Phonological list</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean correct (max=15)</td>
<td>12.9 (0.8)</td>
<td>13.8 (0.7)</td>
<td>*</td>
</tr>
<tr>
<td>Time (seconds / 30 words)</td>
<td>70.8 (19.3)</td>
<td>45.0 (5.7)</td>
<td>**</td>
</tr>
<tr>
<td>Fluency task (words in 30 secs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semantic</td>
<td>27.3 (7.5)</td>
<td>32.3 (10.8)</td>
<td>n.s</td>
</tr>
<tr>
<td>Phonemic</td>
<td>21.3 (4.6)</td>
<td>27 (5.3)</td>
<td>p=.05</td>
</tr>
</tbody>
</table>

Table 6.2. Participant characteristics: phonological abilities n.s. - non-significant; * < 0.05; ** < 0.01; *** < 0.001

*Behavioural measures during PET*

There were no significant differences in repetition accuracy between groups. This was expected given that simple and short stimuli had been specifically employed to minimise gross behavioural confounds. No subject made any errors during word repetition; during pseudoword repetition there were a total of three errors in the dyslexic group and no errors in the control group.
PET results

Word and pseudoword differences: Contrary to our predictions, no areas were found to be significantly more activated for pseudowords than words relative to rest in either group. By contrast, one area of the left inferior parietal lobe (BA39: -52, -48, 26) was significantly more activated for words relative to pseudowords ($z = 3.1; p<.001$) irrespective of group. Eight of the fourteen subjects displayed this trend. There was no significant interaction between group and condition. Activation associated with the word and pseudoword conditions is therefore combined, unless otherwise stated.

Regions of activation common to dyslexics and controls: Figure 6.1 represents graphically the areas of common activation between the control and dyslexic groups during the repetition of words and pseudowords relative to rest. As shown, both groups demonstrated activation of an extensive bilateral network comparable with previous studies of word repetition (Howard, Patterson, Wise, Brown, Friston, Weiller and Frackowiak, 1992; Price, Wise, Warburton, Moore, Howard, Patterson, Frackowiak and Friston, 1996; Wise, Greene, Büchel and Scott, 1999). This included the superior and middle temporal gyri, cerebellum, the frontal operculum and precentral regions as well as activation of the thalamus and other subcortical structures.

![Figure 6.1: Common activation for dyslexic and control groups: words & pseuds - rest.](image)

The results of a more stringent analysis, shown overleaf in Figure 6.2, delimits those areas which were activated consistently for words relative to rest in every subject (see methods). As shown, only a region in the auditory cortex of the right hemisphere was consistently activated across all 14 subjects.
Figure 6.2. Consistent activation across dyslexic and control subjects for words – rest. Individual conjunction analysis.

Areas of differential activity: The random effects model indicated no areas of greater activation in the dyslexic group but several areas of increased activation in the control relative to the dyslexic group, significant at \( p < 0.05 \), corrected for the number of comparisons. These included the right superior temporal region and post-central gyrus and left cerebellum (see Table 6.3 & Figure 6.3).

<table>
<thead>
<tr>
<th>Region</th>
<th>Talairach Coordinates (mm)</th>
<th>Height</th>
<th>Extent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x  y  z</td>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>a. R. postcentral / anterior STG (BA 4/42)</td>
<td>44 -18 32</td>
<td>4.1</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>58 -12 10</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>2. L. cerebellum</td>
<td>-18 -44 -48</td>
<td>4.7*</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Table 6.3. Areas of greater activation in the control relative to the dyslexic group for words and pseudowords combined, relative to rest (random effects analysis; see Figure 6.3). Z scores significant at \( p < .001 \) uncorrected; * = \( p < 0.05 \), corrected for entire search volume. R = right; L = left; STG = superior temporal gyrus.

Figure 6.3. Greater activation for control relative to dyslexic group: words & pseudowords-rest. Random effects model.
The subject specific analysis highlighted the right anterior superior temporal gyrus (BA22) as the only area to show consistently reduced activation across all 8 dyslexic subjects. Percentage increase in activation for words relative to rest is plotted for this region in Figure 6.4, to show the reduced activation in all 8 dyslexic subjects relative to all 6 control subjects.

![Figure 6.4](image)

**Figure 6.4.** The area of the right anterior superior temporal lobe (52, -8,8) identified by the subject specific analysis, as consistently more active in the control group relative to each dyslexic subject. Percentage activation for word repetition relative to rest for this area is plotted for each subject (1-14).

**Discussion**

The present study investigated word repetition in a group of adult dyslexics, using stimuli that elicited no measured behavioural differences. However, differences in brain activation suggest this task was performed differently by dyslexics. These subjects showed reduced activation relative to a control group in several right hemisphere areas, and in particular in an area of right secondary auditory cortex. The latter result was found to be remarkably robust, differentiating all eight dyslexic subjects. A recent MEG study reported reduced dipole moments in this region when dyslexic children listened to incidentally presented speech syllables during a visual task (Heim, Eulitz, and Elbert, 1999). This finding raises several questions. Firstly, do the impaired responses in the right anterior temporal cortex reflect impaired cognitive or impaired neuronal processing? Secondly, how can these differences in auditory processing be interpreted, given our understanding of the right auditory cortex in the
normal population? The third, more general issue to be addressed, is how this pattern of right hemisphere differences can be understood in relation to the left hemisphere differences reported for reading.

To explore whether the deviant activation observed during repetition could be characterised in terms of dysfunction in the right anterior superior temporal cortex the data from the current study was combined with those from a corresponding reading study (Brunswick et al., 1999) which used identical sets of words with dyslexic and control subjects. In that study subjects also activated bilateral auditory cortices, as they processed the sound of their own voice when reading. The combined analysis indicated a significant condition x study x group interaction, in the right anterior superior temporal lobe (words: z=4.5; pseudowords: z=3.5; p<.001), with normal responses during reading and abnormal responses during repetition. The finding that this region can be activated normally in some instances implies that any deviance only arises when specific processes are engaged. Repetition, for example, requires that subjects attend actively to the incoming speech sounds, whilst ignoring the sound of their own voice. At present, an understanding of why activation of this region varies in dyslexics when they attend to speech can only be gained with reference to studies of the normal population.

Studies with normal participants have shown that both the right and left primary and secondary auditory cortices are involved in the acoustic processing of speech in normal subjects (Price et al., 1996; Wise et al., 1999). These report bilateral activation when subjects listen to words as well as when they repeat them. The involvement of the right hemisphere in speech-specific (rather than low level auditory) processing has been demonstrated by studies in which the activation associated with complex sounds is subtracted from that associated with speech (Zatorre, Evans, Meyer, Gjedde, 1992; Zatorre, Meyer, Gjedde and Evans, 1996). A recent study employed complex non-speech stimuli in order to identify speech specific regions (Mummery, Scott, Ashburner and Wise, 1999). Such regions were found to be bilateral and located more anteriorly in the superior temporal sulci. The peaks of activation, like those of Zatorre et al., (1992), encompassed the same area of right secondary auditory cortex found to differentiate the dyslexics in the present study (see Table 6.4 for details of these and other studies). This points to a difference in speech processing in our dyslexic sample.
The pattern of activation in the auditory cortices when normal subjects listen to speech can be significantly modulated by the attentional or cognitive demands required by the task. Precisely the same auditory input may elicit very different patterns of activation depending on the context in which it is presented. For example, in a recent fMRI study, passive listening to syllables was contrasted with listening to the same stimuli,

<table>
<thead>
<tr>
<th>Study</th>
<th>Target task</th>
<th>Reference Task</th>
<th>Increase (↑)</th>
<th>Decrease (↓)</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price et al., 1996</td>
<td>word repetition</td>
<td>rest</td>
<td>↑</td>
<td></td>
<td>56</td>
<td>-8</td>
<td>4</td>
<td>4.9</td>
</tr>
<tr>
<td>Zatorre et al., 1992</td>
<td>L: passive speech</td>
<td>L: passive noise</td>
<td>↑</td>
<td></td>
<td>60</td>
<td>-14</td>
<td>0</td>
<td>4.3</td>
</tr>
<tr>
<td>Zatorre et al., 1996</td>
<td>phonetic discrimination</td>
<td>L: passive noise</td>
<td>↑</td>
<td></td>
<td>59</td>
<td>-16</td>
<td>0</td>
<td>3.1</td>
</tr>
<tr>
<td>Mummery et al., 1999</td>
<td>L: passive speech</td>
<td>L: complex noise</td>
<td>↑</td>
<td></td>
<td>54</td>
<td>-6</td>
<td>0</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>-12</td>
<td>4</td>
<td>4.3</td>
</tr>
<tr>
<td>Zatorre et al., 1996</td>
<td>phonetic discrimination</td>
<td>pitch discrimination</td>
<td>↓</td>
<td></td>
<td>59</td>
<td>1</td>
<td>0</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>phonetic</td>
<td></td>
<td></td>
<td>55</td>
<td>-2</td>
<td>2</td>
<td>3.8</td>
</tr>
<tr>
<td>Current Study</td>
<td>word repetition</td>
<td>rest</td>
<td>C→D</td>
<td></td>
<td>52</td>
<td>-8</td>
<td>8</td>
<td>C: 7.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D: 5.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.4. Studies showing activation and deactivation of the right anterior superior temporal gyrus. L = listening; C = controls; D = dyslexics.

but this time with instructions to detect the presence of a target syllable. Bilateral increases in primary and secondary auditory cortex were observed in the second task, even though the stimuli were identical across conditions (Janke, Mirzazade, and Shah, 1999). Such general attentional demands may be contrasted in turn with tasks in which subjects are asked to attend to specific aspects of the speech stream. For instance, phoneme discrimination or phoneme monitoring in word pairs can be contrasted with passively listening to the same pairs of words. In this case left-lateralized activation is elicited (Zatorre et al., 1992; Zatorre et al., 1996). The implication is that the left hemisphere underpins processes, elicited by consciously attending to the phonetic or phonological aspects of speech. Similarly, processing of rapid frequency changes are believed to be a property of the left hemisphere. Evidence for this surmise comes from dichotic listening studies and studies of split brain patients (Studdert-Kennedy and Shankweiler, 1970; Levy and Trevarthen, 1977) and more recently from functional
imaging studies (Belin, Zilbovicius, Crozier, Thivard, Fontaine, Masure and Samson, 1998).

Which aspects of speech then, are processed in the right hemisphere? Zatorre et al (1996) have reported decreases in the right anterior superior temporal cortex during active phonetic judgements relative to passive listening (see Table 6.4). This implies that some information processing which occurs normally during passive listening is de-emphasized when subjects attend to the phonetic aspects of speech. It is possible that certain aspects of speech - for example, prosody, pitch or voicing - are processed automatically on the right during passive listening or pitch discrimination (Zatorre et al., 1996). These aspects are de-emphasized during phonetic tasks where they are less relevant - leading to a relative CBF decrease. This decrease, seen normally when subjects explicitly attend to phonemic structure, is comparable to that shown by dyslexics in the present study during repetition. The reduced levels of activity in dyslexics may imply that they de-emphasize processing of non-phonetic aspects of speech during repetition - in order to enhance attention to the phonetic structure of attended speech. Compensation may therefore proceed through the reduced processing of less relevant acoustic information rather than by a relative increase in phonological processing itself.

The third issue to be addressed is how these right hemisphere differences can be reconciled with the left hemisphere differences reported for reading. In the context of a highly dynamic language system it would be erroneous to suppose that a common impairment will be consistently associated with a single anatomical locus. Such an impairment is likely to interact with task-specific processes, and therefore give rise to a pattern of differences in one task and not in another. In repetition, unlike reading, the phonetic plan of a word is largely specified by the input. A deficit in phonological processing may therefore necessitate that greater attentional resources are accorded to the phonetic aspects of the speech to be repeated. That is, irrelevant or acoustically competing information is suppressed. This may in itself serve to compensate for impaired phonological processing even with no increase in left hemisphere regions associated with phonological processing. By contrast, in reading, the specification and ordering of speech sounds as well as the assignment of stress must be entirely derived from stored phonological information. A task which requires manipulation or retrieval
of such phonological information appears to implicate the posterior areas of the left inferior temporal gyrus and the left frontal operculum, which are consistently implicated in naming tasks (see Price, 1998). Indeed the left posterior inferior temporal gyrus is most consistently reported to be abnormal when dyslexics read (e.g. Salmelin, Service, Kiesila, Uutela and Salonen, 1996; Rumsey et al., 1997; Brunswick et al., 1999). In other words, the same underlying cognitive deficit can account for two ostensibly separate sets of neuronal abnormalities, even when task performance is matched.

Future studies are necessary to address a range of outstanding issues. The differences observed in the present study have been interpreted as specifically relating to input rather than articulatory processing. No cortical right hemisphere differences were found during a study of reading even though the articulatory demands were the same as in the present study (Brunswick et al., 1999). Furthermore, the study of Heim and colleagues with dyslexic children (Heim et al., 1999), in which listening was passive, also indicated reduced activation in the auditory cortex of the right hemisphere. These considerations render any explanation based on disordered articulation unlikely. They also suggest that any attentional bias applies only to externally generated speech. Nevertheless, a future study is necessary to examine the effects of passive listening in a group of dyslexic adults, in order to confirm that these right hemisphere differences are indeed input specific.

That no group differences were observed between the word and pseudoword conditions in this study is comparable to a similar result for reading (Rumsey et al., 1997; Brunswick et al., 1999). This implies that these stimuli are processed by a common neural substrate in both controls and dyslexics. Given that the pseudowords used in this study were highly word-like one might predict that differences would emerge when pseudowords are made less word-like.

It is proposed, therefore, that dyslexics during both reading (e.g. Brunswick et al., 1999) and repetition share a common deficit in phonological processing. How this deficit manifests in functional neuroimaging investigations is highly context specific, and depends on the demands of the experimental task. In repetition, the lower levels of activation in the right anterior superior temporal lobe may reflect an attentional bias
in the dyslexic group, towards phonetic aspects of the auditory input. Specifically, reduced processing of non-phonetic aspects of speech may allow greater salience to be accorded to phonological aspects of attended speech.
EXPLORING THE PHONOLOGICAL AWARENESS DEFICIT

Experiment 5: A discrete trial spoonerism task

Introduction

Phonological awareness tasks assess an individual’s ability to access and manipulate the sound structure of spoken words. This awareness is metacognitive in nature and requires conscious reflection (Gombert, 1992) and has been shown to be highly correlated with later reading performance (e.g. Wimmer, Landerl, Linortner, and Hummer, 1991; Huang and Hanley, 1995). Studies of dyslexic children have reported a consistent pattern of impaired performance on such tasks, particularly at the phonemic level (Bradley and Bryant, 1978; Bowey, Cain, and Ryan, 1992; Bruck et al., 1990). For example, dyslexic children have been shown to be impaired in spotting the odd word out in triplets or in making a same / different judgement of words that differ in a single phoneme. These difficulties have been shown to persist into adulthood (Bruck, 1992; Elbro, Nielsen, and Peterson, 1994; Pennington, Van Orden, Smith, Grenn, and Haith, 1990). The relation between phonological awareness and reading, even after twenty years of research, remains controversial. Initially the acquisition of phoneme awareness was viewed as necessary to successfully map between written and spoken words (Liberman and Shankweiler, 1979). However the demonstration that illiterate adults were unable to carry out a phonological awareness task until after they had learnt to read led to the suggestion that phonemic awareness was in fact a consequence of literacy (Morais, Cary, Alegria and Bertelson, 1979). More recently the relationship between reading and phonemic awareness has been characterised as reciprocal in nature (Perfetti, Beck, Bell and Hughes, 1987; Wimmer et al., 1991).
One challenging phonological awareness task employed with adults is the spoonerism task (Gallagher, Laxon, Armstrong and Frith, 1996; Paulesu, Frith, Snowling, Gallagher, Morton, Frackowiak and Frith, 1996; Snowling, Nation, Moxham, Gallagher and Frith, 1997; Landerl, Wimmer and Frith, 1997; Brunswick, McCrory, Price, Frith and Frith, 1999). Here a participant is asked to switch the initial sounds of two words; for example, ‘jon lennon’ becomes ‘lon jennon’. The tasks used in these studies have been characterised by a number of methodological limitations. For example, the measure is the total time taken to perform an entire list of spoonerism pairs rather than the individual trial time of a single pair (e.g. Brunswick et al., 1999), and in some cases only accuracy is used as an index of performance (e.g. Landerl and Wimmer, 2000). By definition, reported total times have included the time taken by the experimenter to present the word-pairs to participants. This is likely to vary not only across stimuli but also across individuals, and leaves the experimenter open to the risk of bias and inconsistency. Finally, in those studies where mean spoonerism times have been reported, these times have been error inclusive. That is they represent the mean time taken across correct and incorrect pairs. Such an approach may serve to conceal the dyslexics’ true pattern of performance: for example, it is possible that dyslexic participants, when they perform a spoonerism accurately, are just as fast as controls, but are slowed on those trials on which they make errors.

The consistent finding of poor performance of dyslexic children and adults on tasks of phonological awareness has provided a core rationale for the phonological representation hypothesis. According to this position, the phonological representations of dyslexic individuals are poorly specified, or have not become fully segmented at the phonemic level (e.g. Snowling and Hulme, 1994; Swan and Goswami, 1997b). In the spoonerism task, as in other tasks of phonological awareness, participants are required to explicitly manipulate word segments. While such manipulation is both introspective and requires the involvement of other cognitive processes (e.g. working memory) task performance has been explicitly equated with the underlying quality of phonological representation (e.g. Swan and Goswami, 1997b). The logic is as follows: an individual with high quality representations will have restructured those representations at different linguistic levels – most particularly at the phonemic level – allowing access and manipulation of segments of word sounds with relative ease. If dyslexic readers have failed to reorganise their representations at the phonemic level then such
manipulation will be effected with difficulty. While such an interpretation is possible, the basis for such an inference is tenuous: a poor score on a task where word segments are manipulated is taken as evidence that such segments are absent at the representational level.

Recent evidence, however, has undermined the view that dyslexic individuals are characterised by a pervasive deficit in phonemic segmentation. Both dyslexic children (Landerl and Wimmer, 2000) and dyslexic adults (Griffiths and Frith, 2001) have been shown to successfully segment words into onsets and rhymes. In a reanalysis of the results of a spoonerism task with 12-year old English and German dyslexic children, Landerl and Wimmer (2000) reported largely intact segmentation ability in their sample. Using a revised scoring procedure they were able to award credit to those responses where successful onset-rime manipulation occurred, even when the whole response may not have been correct. Difficulties, they suggest, were not attributable to poor segmentation but rather to the additional phonological memory and processing requirements of the spoonerism task. They point out that the standard scoring of the spoonerism task (Perin, 1983) massively underestimates dyslexic children’s competence with onset-rime segmentation. The phoneme awareness deficit, they conclude, while evident only in the early stages of reading acquisition, still disrupts the acquisition of phonological recoding in word reading. Similarly, a recent study of dyslexic adults, Griffiths and Frith (2001), found that performance was at ceiling when participants were required to delete the onset phoneme of a word and replace it with a phoneme provided by the experimenter.

The account, proposed here, assumes that the phonological representations are fully specified, but what is impaired is the functional access to those representations: the phonological competition hypothesis. Arguably, tasks of phonological awareness do not index the quality of phonological representation, but rather the efficiency by which word segments are selectively activated, sustained and manipulated in phonological memory. Selective access of an individual phoneme is difficult since in everyday speech we are not required to isolate individual phonemes of words as these rarely possess (on their own at least) any meaningful value. Only when we learn to read does an individual phoneme become meaningful in its own right, since it becomes associated with an individual component of written language – the grapheme. Rather
than outputting words solely in an holistic fashion we become capable of identifying
the individual phonemic units of a word. This requires selective activation of an
individual phonemic component; a challenging task given that a phoneme will be
activated in concert with the set of phonological ingredients that constitute that word.
If dyslexic individuals are less efficient in resolving the competition of such
simultaneously active phonemes it follows that such selective activation will be
impaired.

This alternative explanation is based on the assumption that there are multiple
phonological codes active during a phonological awareness task, and that selection of
individual codes takes place in the context of such competition. In a spoonerism task,
for example, we are required to sustain the activation of two word representations at
the phonological level and sequentially place components of those representations into
an output buffer. Even with ‘fully specified’ phonological representations to perform
the spoonerism task well, we must engage efficient phonological processes: to
activate, select and inhibit. Like in reading, such processes are most taxed when
multiple codes are competing simultaneously.

If it is the case that the spoonerism task is challenging for dyslexic adults because of a
difficulty in processing phonological competition, then factors that increase that
competition should serve to further impair performance. One such factor is word
length. The first study to employ the spoonerism task as an index of phonological
processing reported that poor spellers make more errors when spoonerising longer
words in contrast to shorter words (Perin, 1983). No such manipulation has been
carried out with dyslexic adults. Both a representation and competition account would
postulate least difficulty with short high frequency words. According to the rationale
of the representation account, such words should be highly familiar to dyslexic adults
and this exposure is likely to have led to better specification through repeated usage.
In contrast, according to the competition account, shorter words entail the activation of
fewer phonological codes, thereby generating less competition.

The effect of length can be explicitly evaluated by contrasting monosyllabic and
disyllabic words. As outlined in Chapter 2, according to a competition account, longer
words would increase the number of concurrently activated phonological codes that
compete for allocation to the word shape frame. This would both slow selection and increase the likelihood of error. A similar prediction would follow from the representations hypothesis but on the basis of a different rationale: long words are likely to be less well represented than short words and are less likely to be fully segmented at the phonemic level (Swan and Goswami, 1997b). If both accounts make the same predictions with regard to length, how might they be differentiated? One possibility would be to compare performance within a set of disyllabic words. For example, two sets of disyllabic words could be contrasted that differ only in length by one or two phonemes and which are otherwise matched for frequency, syllable and letter length. While it is possible that a systematic relation between representational quality and phoneme length may exist, such a relationship does not obviously follow from the representational account. In contrast, the grounds for a relation between phonological competition and phoneme length are clear. Increasing the number of phonemes in the spoonerism pair will increase the number of contemporaneously active phonological codes - and hence the level of phonological competition.

Task load is a second factor that may influence the level of phonological competition and as a consequence the functional availability of phonological representations. For example, providing a long interval between trials may elicit lower levels of phonological competition in contrast to immediate presentation following a participant’s response to the previous trial (as in Brunswick et al., 1999 and in Experiment 4). Similarly, requiring participants to produce only one word of the spoonerism pair may reduce the amount of phonological manipulation (and therefore encoding) required during the task (Landerl and Wimmer, 2000). To investigate this possibility the current study employed ten spoonerisms used previously, in Experiment 4, and in Brunswick et al., (1999). A group of ten participants drawn from these studies had fully transcribed responses. This permitted re-scoring so that errors could be based only on the first word of each spoonerism pair. If it is the case that the functional availability of phonological information is variable (consistent with a process account in which functional access to the representation is a dynamic process) then a reduction in task load should increase the level of accuracy during the spoonerism task. It is hypothesised that the faster rate of presentation in the previous studies (Experiment 4 and Brunswick et al., 1999) would lead to a higher level of
phonological competition and therefore a higher rate of error than if the same items were presented at a slower rate (as in the current study).

**Predictions**

Previous studies that have investigated spoonerism performance in adult dyslexics have only employed words of two syllables or greater (Snowling et al., 1997; Brunswick et al., 1999). Studies that have used monosyllabic words in other tasks of phonological awareness (such as phoneme deletion) have reported normal performance in adult dyslexics (e.g. Griffiths and Frith, 2001). On this basis it was predicted that the participants in the current study should successfully access the phonemic level of representation in the case of short familiar words. The representation hypothesis would predict that dyslexic adults should be capable of spoonerising such words as efficiently as their peers since these words are likely to be 'fully segmented'. In contrast, the competition hypothesis would predict that dyslexic adults will be slower than their peers on the spoonerism task – even if such words are normally specified. This follows since it is postulated that dyslexic adults are less efficient at resolving the phonological competition that arises when several sublexical codes compete for the same position. This process of phonological specification will therefore be slower even if the output is correct. Furthermore, increasing word length even by one phoneme should serve to increase the number of contemporaneously active phonological codes during the task. This should serve to impair the dyslexic participants. Such a prediction does not readily follow from a representational account. Finally it is predicted that differences in task load will influence performance accuracy in dyslexic participants. The level of phonological competition may be increased by a fast presentation rate (due to interference from activation elicited by the previous trial) and by increasing output demands (due to the activation of a greater number of phonological nodes). Performance accuracy is predicted to be higher at slower rates and when output demands are lower (as in the current study) in contrast to previous studies in which the rate of presentation was faster and the output demands greater (Experiment 4; Brunswick et al., 1999).
Experiment 5

Method

Participants
Thirty-two university students were recruited for the study: sixteen had been diagnosed with developmental dyslexia in childhood or adolescence, while the remaining participants reported no current or developmental literacy or language impairment. All were physically healthy with no history of psychiatric or neurological disorder. A set of standardised tasks were administered, including a full WAIS (Wechsler Adult Inventory Scale-Revised; WAIS III) together with standardised measures of reading and spelling (Wide Range Achievement Test – Revised; WRAT-R, Jastak and Wilkinson, 1984). The results of these assessments are shown in Table 7.1. These indicate that the control and dyslexic groups were matched for Performance IQ. However the dyslexic participants were impaired on the WAIS Verbal IQ measure \[ F(1, 30) = 17.74; p<.01 \] which contributed to the overall depression in Full Scale IQ \[ F(1, 30) = 8.40; p<.01 \]. Significant impairments were found only in four subtests: Arithmetic \[ F(1, 30) = 6.59; p<.05 \], Coding \[ F(1, 30) = 3.92; p=.06 \], Information \[ F(1, 30) = 4.23; p<.05 \], and Digit Span \[ F(1, 30) = 54.7; p<.01 \], typical of the characteristic ACID profile thought to be due to phonological impairment (Vargo, Grosser and Spafford, 1995). Mean standard scores across all subtests are shown in Table 7.1. As expected, the dyslexic participants were also impaired on the standardised measures of reading and spelling \[ \text{WRAT reading (F1,30) = 46.07; p < .01); WRAT spelling (F1,30) = 37.06; p < .01} \].

Stimuli and Apparatus
Thirty-six spoonerism pairs were devised (see Table 7.2). Half consisted of monosyllabic pairs (e.g. top-day; lip-bar) that were all CVC in structure; the remaining half were bisyllabic in length (e.g. motor-tiger; paper-satin) and were CV- in onset structure (i.e. they were all without clusters). Ten of the long spoonerism pairs were taken from a previous study (Brunswick et al., 1999; indicated by an * in Table 7.2 below). The stimuli were designed to ensure that all correct responses generated by this procedure (as listed in Table 7.2) were non-words.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Dyslexics (n=16)</th>
<th>Controls (n=16)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td>20.6 (1.3)</td>
<td>20.5 (2.2)</td>
<td>n.s.</td>
</tr>
<tr>
<td><em>IQ tests (WAIS-R)</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-scale</td>
<td>119.9 (7.8)</td>
<td>128.3 (8.5)</td>
<td>**</td>
</tr>
<tr>
<td>Verbal</td>
<td>116.0 (7.8)</td>
<td>126.9 (6.7)</td>
<td>**</td>
</tr>
<tr>
<td>Arithmetic</td>
<td>12.1 (2.8)</td>
<td>14.4 (2.3)</td>
<td>*</td>
</tr>
<tr>
<td>Digit Span</td>
<td>8.3 (2.0)</td>
<td>13.3 (1.9)</td>
<td>**</td>
</tr>
<tr>
<td>Information</td>
<td>12.9 (2.4)</td>
<td>14.3 (1.1)</td>
<td>*</td>
</tr>
<tr>
<td>Comprehension</td>
<td>13.8 (2.0)</td>
<td>13.8 (1.0)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Letter-Number Sequencing †</td>
<td>8.9 (1.6)</td>
<td>13.3 (2.6)</td>
<td>**</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>13.8 (2.2)</td>
<td>14.3 (1.6)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Similarities</td>
<td>14.6 (2.0)</td>
<td>14.9 (2.0)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Performance</td>
<td>121.6 (10.2)</td>
<td>124.2 (12.6)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Block Design</td>
<td>15.0 (1.7)</td>
<td>15.2 (2.2)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Matrix Reasoning</td>
<td>13.6 (1.9)</td>
<td>14.4 (2.3)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Picture Arrangement</td>
<td>12.9 (2.4)</td>
<td>12.7 (3.7)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Digit Coding</td>
<td>10.7 (3.0)</td>
<td>12.7 (2.8)</td>
<td>p=.06</td>
</tr>
<tr>
<td>Picture Completion</td>
<td>13.2 (2.7)</td>
<td>12.1 (2.0)</td>
<td>n.s.</td>
</tr>
<tr>
<td><strong>Standardized literacy tests</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading WRAT (standardized scores)</td>
<td>96.6 (8.8)</td>
<td>115.3 (4.6)</td>
<td>**</td>
</tr>
<tr>
<td>Spelling WRAT (standardized scores)</td>
<td>94.3 (11.3)</td>
<td>113.7 (5.9)</td>
<td>**</td>
</tr>
</tbody>
</table>

**Table 7.1.** Behavioural profile of participants showing the IQ results from the WAIS III battery, including standard subtest scores, and standardised measures of reading and writing. Mean scores are presented with standard deviations in parentheses. † The Letter-Number Sequencing subtest is a new measure of verbal short term memory in WAIS III, reported here for interest. This score was not used however in the calculation of IQ. n.s. - non-significant; * p<.05; ** p <.01.
<table>
<thead>
<tr>
<th>Set</th>
<th>Long Spoonerism Pair</th>
<th>Response</th>
<th>Short Spoonerism Pair</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A Turtle - Button *</td>
<td>Burtle</td>
<td>Dot - Bus</td>
<td>Bot</td>
</tr>
<tr>
<td>2</td>
<td>A Doctor - Bubble</td>
<td>Doctor</td>
<td>Cup - Bow</td>
<td>Bup</td>
</tr>
<tr>
<td>3</td>
<td>A Kennel - Pony</td>
<td>Pennel</td>
<td>Lip - Bar</td>
<td>Bip</td>
</tr>
<tr>
<td>4</td>
<td>A Paper - Satin *</td>
<td>Saper</td>
<td>Fan - Leg</td>
<td>Lan</td>
</tr>
<tr>
<td>5</td>
<td>A Needle - Feather</td>
<td>Feedle</td>
<td>Tub - Lid</td>
<td>Lub</td>
</tr>
<tr>
<td>6</td>
<td>A Motor - Pillow</td>
<td>Pocker</td>
<td>Gun - Lap</td>
<td>Lun</td>
</tr>
<tr>
<td>7</td>
<td>A Sofa - Tiger *</td>
<td>Totor</td>
<td>Log - Pan</td>
<td>Pog</td>
</tr>
<tr>
<td>8</td>
<td>A Medi - Razor *</td>
<td>Rofa</td>
<td>Rug - Pit</td>
<td>Pug</td>
</tr>
<tr>
<td>9</td>
<td>A Lemon - Basket *</td>
<td>Bemon</td>
<td>Top - Day</td>
<td>Dop</td>
</tr>
<tr>
<td>10</td>
<td>B Garlic - Radish *</td>
<td>Rarlic</td>
<td>Law - Dig</td>
<td>Daw</td>
</tr>
<tr>
<td>11</td>
<td>B Barrel - Table</td>
<td>Tovel</td>
<td>Gas - Dog</td>
<td>Das</td>
</tr>
<tr>
<td>12</td>
<td>B Ribon - Silver *</td>
<td>Sibbon</td>
<td>Pip - Joy</td>
<td>Jip</td>
</tr>
<tr>
<td>13</td>
<td>B Mustard - Salad *</td>
<td>Sustard</td>
<td>Hit - Jar</td>
<td>Jit</td>
</tr>
<tr>
<td>14</td>
<td>B Fabric - Pocket *</td>
<td>Fabric</td>
<td>Fun - Jet</td>
<td>Jun</td>
</tr>
<tr>
<td>15</td>
<td>B Window - Temple</td>
<td>Tindow</td>
<td>Son - Mud</td>
<td>Mon</td>
</tr>
<tr>
<td>16</td>
<td>B Napkin - Forest</td>
<td>Fapkin</td>
<td>Fig - Map</td>
<td>Mig</td>
</tr>
<tr>
<td>17</td>
<td>B Rattle - Football</td>
<td>Fattle</td>
<td>Box - Mix</td>
<td>Mox</td>
</tr>
</tbody>
</table>

Table 7.2. Long and short spoonerism pairs with associated correct responses. Set A: bisyllabic words of shorter phoneme length. Set B: bisyllabic words of longer phoneme length.
* Pairs used previously in Experiment 4 and in Brunswick et al., (1999).

The set of long spoonerism pairs were in turn divided into two sets: one in which the word pairs were between 8 - 9 phonemes in total length and one in which the word pairs were between 10 - 12 phonemes in total length (Set A; mean phoneme length: 8.3; Set B: mean phoneme length: 10.4; p<.01). These sets were matched for mean letter length of each spoonerism pair (Set A=12; Set B=11; p>.05) and for mean frequency per pair (Kucera-Francis: Set A= 24.2, s.d.=26.0; Set B= 35.7, s.d.=35.6; p>.05). All spoonerism pairs were recorded and digitised by the same male speaker. These were then digitally manipulated to ensure a duration per pair of 2000msec (for both short and long words) with a fixed inter-word interval within each pair of 1000msec. Such standardisation ensured that for each trial, all participants heard precisely the same stimulus.
The experiment was carried out on a Macintosh LC computer, in conjunction with an external Macintosh microphone to record verbal responses. A headphone set (Panasonic model RP-HT342) was used to present the digitised spoonerism pairs.

Procedure
Prior to the experimental trials, the concept of Spoonerisms was introduced and defined in the following way: "A Spoonerism is where you have two words and you swap over the beginning sounds of each word to make two novel words. For example, the words RED/PEN become PED/REN. Can you hear what I've done? I've taken the /r/ sound from RED and the /p/ sound from PEN and swapped them around to produce PED/REN". The participant was then told that in this task they would be asked only to produce the first word of such a pair – in this case, PED. Participants were then provided with a practice trial ("What do the words DESK/HAT become?") presented verbally by the experimenter.

The format of the task was then described in more detail. A pair of words would be presented over a pair of headphones. Immediately a question-mark would appear on the screen. Participants were to listen to the word pair and say aloud the correct response as soon as possible. Immediately after the offset of the second word a question mark appeared on the screen and remained on the screen until a verbal response was detected. On detection of a response the question mark disappeared and the next trial was initiated automatically 8 seconds later. Latency of response was recorded automatically by the computer. The experimenter sat behind the participant, noting each response and the occurrence of any accidental microphone triggers. Each participant was familiarised with this format in 3 practice trials: listening to a spoonerism pair and saying aloud their response. All participants succeeded in at least two of these practice trials before progressing. After the participant had completed the practice trials, and felt comfortable with the procedure, the first block of 12 trials was initiated by a key press response. Each block consisted of half short pairs and half long pairs presented alternately. There were 3 blocks, giving a total of 36 trials. A short break was provided between each block.
Results

The mean percentage of incorrect responses was calculated for each group and are presented in Table 7.3 and Figure 7.1 as a function of Length. Given the low error rate and the lack of a normal distribution, groups were compared with a non-parametric Mann-Whitney U-test. Mean error rates are with respect to length are plotted in Figure 7.1 for both groups. For short words, the percentage of correct responses by dyslexic participants did not differ reliably from control participants ($U=88$, $z=-1.7$; $p>.05$) although there was a tendency for more errors in the dyslexic group (Controls: 0.7%; Dyslexics: 4.5%). In the long word condition however, dyslexic participants made significantly more errors than their peers ($U=199$, $z=-2.7$; $p<.01$; Controls: 3.5%; Dyslexics: 12.8%). Both groups made significantly fewer errors in the short word condition (Wilcoxon Signed Rank Test: Controls, $z=2.2$; $p<.05$; Dyslexics: $z=-2.8$; $p<.01$).

![Figure 7.1. Mean percentage error for the Control and Dyslexic groups in both the Short and Long conditions. All error bars indicate standard error of the mean.](image)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dyslexics</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Error</td>
<td>S.D.</td>
</tr>
<tr>
<td>Short Word Pairs</td>
<td>4.5%</td>
<td>(6.5)</td>
</tr>
<tr>
<td>Long Word Pairs</td>
<td>12.8%</td>
<td>(11.1)</td>
</tr>
</tbody>
</table>

Table 7.3. Mean percentage error and standard deviations (S.D.) in the Control and Dyslexic groups as a function of Length.
Figure 7.2. Latency of response (msec) for the Control and Dyslexic groups in both the Short and Long conditions. Error bars indicate mean standard error.

Figure 7.3. Latency of response (msec) for the Control and Dyslexic groups with the shorter set of two-syllable words (Set A) and the longer set of two syllable words (Set B) in the spoonerism task. Error bars indicate mean standard error.

The reaction time data are shown in Table 7.4 and plotted with respect to length in Figure 7.2. Only data from correct trials were analysed. In addition, microphone failures were excluded (2.7% of trials). Data points greater than two standard deviations from the group mean were classified as outliers and were also excluded (4.0% for each group). The remaining data were entered into a repeated measures ANOVA with Group as the between-subject factor (Dyslexic vs. Control) and repeated measures on Length (Short vs Long) in addition to a by-item analysis. The by-subject analysis indicated a main effect of length, with slower responses in the Long condition [F(1,30) = 8.6; p < .01]. A Length x Group interaction indicated a
differential effect across groups, with a greater effect of longer stimuli in the dyslexic group \([F(1,30) = 5.4; p < .05]\). A comparable pattern was found in the by-item analysis. This indicated a main effect of Group \([F(1,34) = 675.6; p<.01]\) and a main effect of Length \([F(1,34) = 31.1; p<.01]\) in addition to a Length x Group interaction \([F(1,34) = 31.4; p<.01]\).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dyslexics</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean RT</td>
<td>S.D.</td>
</tr>
<tr>
<td>Short Word Pairs</td>
<td>1717.0</td>
<td>903.5</td>
</tr>
<tr>
<td>Long Word Pairs</td>
<td>2163.2</td>
<td>1275.8</td>
</tr>
</tbody>
</table>

Table 7.4. Mean response times (msec) and associated standard deviations (S.D.) for the Control and Dyslexic groups as a function of Length.

In order to evaluate the effect of phoneme length, the mean reaction time was calculated for each participant for each set of bisyllabic words: Set A, consisting of spoonerism pairs less than 9 phonemes in length (Dyslexics: 2086msec, s.d.=1354.6; Controls: 750.2msec, s.d.=268.0) and Set B, consisting of spoonerism pairs greater than 10 phonemes in length (Dyslexics: 2365.8msec, s.d.=1136.0; Controls: 788.9, s.d.=318.0). These data, plotted in Figure 7.3, were analysed in a repeated measures ANOVA, with Group as the between-subject factor (Dyslexic vs. Control) and repeated measures on Condition (Set A vs. Set B). This analysis indicated a main effect of Group \([F(1,30) = 18.3; p < .01]\) with faster responses by the control participants, and a main effect of Condition \([F(1,30) = 8.7; p < .01]\) with faster responses with Set A (of shorter phoneme length) relative to Set B (of longer phoneme length). A significant Group x Condition interaction \([F(1,30) = 5.0; p < .05]\) reflected the greater effect of longer stimuli in the dyslexic group.

In order to evaluate the effect of presentation rate and the task requirements the performance of the dyslexic participants in the current study were contrasted with a group of ten dyslexics (drawn from Brunswick et al., 1999 and the dyslexics assessed in Experiment 4) matched for performance IQ with the dyslexics in the current study (previous participant’s performance IQ: 115; current participant’s performance IQ 121; p>.05). For both groups errors were scored on the first word only, on those ten items used with all previous and current participants (marked with an asterisk in Table
7.2). The rate of error of the participants in the previous studies (30%) was found to significantly greater than the error rate of the participants in the current study (8.8%; t (24)=2.5; p<.05).

It is of interest that the speed of spoonerism performance correlated significantly with spelling ability in the dyslexic group (r=0.5; p<.05) but not in the control group (r=0.1; n.s). It is possible that in some dyslexics stronger orthographic skills contribute to improved performance on the spoonerism task (Perin, 1983).

Discussion

The current study employed a novel paradigm of spoonerism presentation that allowed measurement of both accuracy and speed of individual trial responses. According to the first prediction dyslexic participants would be slower than their peers even on those trials where their responses were entirely accurate. This was found to be the case with the dyslexic participants taking over one second longer on average per word pair. An account that postulates inefficiency in the processes of phonological access can more readily account for this slow performance even if the correct response is given. A representation account, which places the emphasis on whether or not segmentation has occurred, implies that once segmented, a given representation should be normally accessed. Secondly, it was found that the dyslexic participants were particularly sensitive to phonemic length. Increasing the mean number of phonemes of each word in the spoonerism pair from 4 to 5 was found to impair the dyslexic participants, who were significantly slowed with the longer words. This finding supports the view that it is the number of phonological codes contemporaneously active during the task critically influences dyslexics performance. Finally the lower rate of error in the dyslexic group under conditions of lower task load (here in relation to presentation rate and task output requirements) is consistent with the view that the functional availability of phonological information is variable. It is not the case that a lexical item becomes fully ‘segmented’ then rendering its phonemic components available. Rather, phonological representations are dynamic entities that may be manipulated with varying degrees of efficiency depending on the level of phonological competition.
In addition to these findings, the particularly high level of performance accuracy by the dyslexics in the current study should be noted. In the short word condition for example dyslexics had an accuracy rate of 95%. Within a representational framework this would suggest that 'phonemic segmentation' has occurred for these words. Adult dyslexics have also been shown to be at ceiling with comparable stimuli in a similar task of phonological awareness (Griffiths and Frith, 2001). If it is the case that these short highly familiar words are available in segmental form then why are they accessed more slowly in reading (Experiment 1) and why are they manipulated more slowly in the spoonerism task? To postulate that the phonological representations are 'poorly specified' fails to reconcile this contrast between accuracy and speed of performance.

A number of arguments in defence of the representational position might be presented. For example, although phoneme segmentation can occur one might argue that the quality of the phonological representation in dyslexics is still poorer, to the extent that access is slowed. The difficulty with such an argument is that it is too vague to provide sufficient explanatory power. It fails to explain why word reading is more impaired than picture naming; or why small differences in phoneme length can significantly affect spoonerism performance. More crucially, however, such an argument would require a clear definition of what was meant by representational 'quality' and how this might be experimentally assessed. If one assumes that a representation is fully segmented, then the notion of 'quality' assumes a rather vague significance. A second defence of the representational position might be to invoke a difficulty in phonological access in addition to a lack of phonological segmentation. That is, the errors made by the dyslexics would indicate that phonological segmentation has not occurred fully, while slower response times indicate impaired 'phonological retrieval'. Such a position would be difficult to maintain if it could be shown that a process account alone would be sufficient to explain the data. Such is the claim of the phonological competition hypothesis.

A second limitation of the representational account is evident in its failure to predict the relationship between processing speed and phonemic length. Take for example the increased difficulty with regard to accuracy and speed of response found with long words. Longer words will inevitably increase the number of phonological codes
activated during the task – and hence the level of phonological competition. A representational account would presume that such longer words are more likely to be less well represented in dyslexic individuals, and therefore more difficult to manipulate. However, the manipulation of phonemic length within the set of long words renders such an explanation unlikely. The phonological representation hypothesis would have to assume an intimate relation between phonological specification and word length to explain this finding. That is, an increase in word length - of even one phoneme – would lead to that word being more poorly specified. Alternatively, an additional explanation would have to be invoked (for example in terms of short-term memory load). In contrast the relationship between phoneme length and processing speed follows naturally from a competition account.

A third limitation of the representation account is its failure to explain the variability of performance accuracy. In this study the dyslexic participants made significantly fewer errors (9%) on the same items, than dyslexic participants in previous studies (30%), who had experienced a much faster rate of presentation. This comparison is limited, however, given that different participants were used in each case and different task demands were implicated. A future study might address these concerns by only varying the rate of presentation and using the same set of stimuli. An increased rate of error at faster rates of presentation would provide strong support for the competition account, since it would demonstrate the dynamic and variable nature of phonological representation.

The current study also aimed to address the methodological limitations of previous studies. Firstly, word pairs were recorded and digitised in a standard format, so each individual would be presented with precisely the same stimuli. Secondly, responses to individual trials were measured automatically by computer with millisecond accuracy. The advantage of such an approach is that it allows the detection of even small differences in performance – across groups, and across experimental manipulations. Finally, concurrent scoring by the experimenter allowed error trials to be removed from any subsequent reaction time analysis.
THE IMPORTANCE OF BEING VERBAL
An investigation of phonological processing
in a task of target switching

Introduction

This thesis has been limited to an investigation of phonological processing in dyslexia. However, within the field of dyslexia several groups of researchers postulate that the phonological deficit is in fact secondary to a more general processing deficit. It has been suggested that dyslexia may be accounted for by impaired functioning of the visual system (Lovegrove, Martin, and Shaghuis, 1986). For example, dyslexics have been shown to be impaired on tasks requiring the perception of motion coherence with visual arrays of random dot kinematograms (e.g. Cornelissen, Richardson, Mason, Fowler and Stein, 1995). In the auditory domain, it has been proposed that dyslexics have impaired auditory processing, specifically with regard to tasks that require temporal processing (Tallal, 1980). At a more general processing level, it has been claimed that dyslexic individuals have impaired cerebellar function, which in turn gives rise to an impairment in ‘automatisation’. This is postulated to impact not only on literacy skill but also on tasks of co-ordination and attention (Nicolson and Fawcett, 1990).

The suggestion inherent in each of these claims – that the deficit in dyslexia extends beyond language processing – has remained controversial. Those who propose such an approach do not revoke the phonological deficit; rather they incorporate it into a lower echelon of a given causal hierarchy. The studies that provide the empirical support for these claims have been criticised on both theoretical and methodological grounds (see Snowling, 2000 for a recent overview). For example, it has been suggested that the observed impairments across these disparate domains may be attributable to co-morbidity in a subgroup of the dyslexic sample. Take the proposal by Nicolson and Fawcett (1990) that dyslexic children have a general automatization deficit. This claim
was based on evidence from a dual task in which participants were required to balance while at the same time performing a secondary task. The possibility that a subset of their population had a co-morbid attentional impairment was not assessed. Recently, Wimmer, Mayringer and Raberger (1999) found that if those children presenting with high ADHD (Attentional Deficit Hyperactivity Disorder) ratings were excluded then no decrement in performance was observed. A second criticism that has been widely levelled is that only a subgroup of any dyslexic sample are ever shown to be impaired in either the auditory domain (e.g. Adlard and Hazan, 1997) or in the visual domain, (e.g. Cornelissen, Richardson, Mason, Fowler and Stein, 1995). That the majority of the dyslexics perform within the normal range across nearly all studies represents a serious obstacle for early sensory processing accounts of dyslexia. A third, and largely untested, consideration is that poor task performance may in fact be secondary to poor verbal processing. If it is the case that a task involves some component of verbal mediation then those participants with poor phonological processing may perform that task less efficiently. The aim of this chapter is to investigate the hypothesis that phonological processing ability may contribute to performance of an ostensibly non-verbal task.

Surprisingly few studies have addressed the role of phonological processing in nonverbal tasks. Huba, Vellutino and Scanlon (1991), compared normal and impaired readers’ ability to retain of a set of visually presented target letters. They disrupted phonological encoding of the target stimuli by requiring participants to concurrently shadow letter names presented auditorily. This was found to eliminate the superior performance of the normal readers on this task, indicating their greater reliance on phonological encoding. Here a group of normal readers were shown to be advantaged over poor readers, not by their superior visual memory, but by their superior ability in phonological encoding. This is perhaps not surprising in view of the fact that the items used were nameable letters. Nevertheless it demonstrates the possibility that a perceived performance decrement by dyslexic individuals may be attributable to their poorer ability to employ verbal mediation. The question arises whether this would apply even to those tasks that are not ostensibly verbal in nature. For example, a number of the tasks in both the visual and auditory domains require an implicit linguistic response, where a participant is required to alternate between two choices – for example, identifying the temporal order of two tones, 'low-high' or 'high-low'
(Tallal, 1980) or labelling visual arrays as ‘moving’ or ‘non-moving’ (e.g. Cornelissen et al., 1995). The question arises whether any observed deficit in performance may be partly attributable to a compromised ability in employing verbal labelling – even implicitly – to control and effect task performance.

The possibility that dyslexic individuals may be impaired in verbal mediation follows naturally from a process-based account of the phonological deficit. According to the phonological competition hypothesis dyslexic individuals are less able to resolve the competition between two simultaneously activated phonological codes. It has already been suggested that this may impact on reading an opaque orthography (Experiment 1) or on rapid picture naming (Experiment 2). The same processing weakness may also become evident when an individual is alternating between two or more responses that have become encoded at the phonological level. That a task does not explicitly entail a verbal response does not preclude the possible influence of verbal mediation. Is it possible to demonstrate that verbal mediation occurs even when not explicitly required?

The current study aimed to investigate precisely this possibility. Unlike the visual memory task employed by Huba and colleagues (1990) here a manifestly non-verbal task was chosen. Stimuli were not explicitly assigned verbal labels but it was predicted that participants would nevertheless assign them phonological representations. The paradigm had been previously employed to evaluate an attention deficit in non-dyslexic patients with damage to the cerebellum (Akshoomoff and Courchesne, 1994). In that study participants were required to rapidly shift their attention between two visual targets. In a series of repeated visual items, the target alternated between two shapes, while the other items were distracters to be ignored. In the shape condition for example, participants responded first to the oval target by pressing a key. After this response, the target immediately shifted to a square; now any oval stimuli that appeared were to be ignored. Once the square appeared, the participants pressed a key and now waited for an oval shape to appear, ignoring squares and the distractor shapes, and so on. In this way, participants were required to rapidly shift attention between two potential targets. Akshoomoff and Courchesne (1994) reported that their patients with cerebellar damage performed poorly on this task. If dyslexic participants were found to be impaired on this task then this could be
interpreted in the context of Nicolson and Fawcett's (1990) cerebellar hypothesis which postulates a general automatisation deficit in dyslexia.

The current study sought to elaborate this design in order to assess explicitly whether a verbal deficit in itself, arising from an inefficiency in resolving phonological competition, would give rise to a differential pattern of performance across groups, and across conditions. Manipulating both the visual and phonological similarity of the targets allows specific predictions to be made. Firstly it is assumed that increasing the confusability of the targets by increasing their visual similarity will increase the likelihood of verbal encoding. This can be shown to be the case if in the visually similar conditions participants are shown to be more sensitive to the phonological characteristics of the targets. For example performance should be hampered by targets that shared sounds (e.g. pen – pencil) relative to those that did not (e.g. dog – goat). In view of the fact that all other aspects of these conditions are matched, one would not predict a difference across these conditions on the basis of different attentional demands. Secondly, if dyslexics are impaired in alternating rapidly between two phonological representations, as predicted by the phonological competition hypothesis, they should be less able to successfully engage in such phonological encoding of the targets when the visual confusability of the targets would encourage such a strategy. The performance of the control participants is therefore predicted to be superior to that of the dyslexics when the targets are visually similar.

The aims of this study were therefore twofold. Firstly, to demonstrate the principle that even in a task that does not require an explicit verbal response, and where no verbal labels are assigned to the responses, verbal processing can influence performance. Secondly, to demonstrate that dyslexic individuals would be impaired on such a non-verbal task, not because of an attentional impairment, but because their deficit in resolving phonological competition precludes efficient verbal mediation.
Experiment 6a: Target switching with nameable stimuli

Method

Participants
Sixteen dyslexic university students were recruited, all of whom had been independently diagnosed with dyslexia in childhood or adolescence. These participants were a subset of those who participated in the Experiment 1. As such, all were above normal intelligence (an IQ of 100 or more on the full scale WAIS III) with no history of emotional or behavioural disturbance. Sixteen control participants matched in age, were recruited from the same universities and reported no problems in language or literacy acquisition.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dyslexics (n=16)</th>
<th>Controls (n=16)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.7 (3.3)</td>
<td>20.7 (2.1)</td>
<td>n.s.</td>
</tr>
<tr>
<td>IQ tests (WAIS-R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-scale</td>
<td>118.1 (8.5)</td>
<td>127.4 (7.5)</td>
<td>**</td>
</tr>
<tr>
<td>Verbal</td>
<td>116.0 (8.4)</td>
<td>126.25 (5.8)</td>
<td>**</td>
</tr>
<tr>
<td>Performance</td>
<td>118.0 (9.9)</td>
<td>123.3 (12.4)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Standardized literacy tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading WRAT (standardized scores)</td>
<td>98.0 (9.9)</td>
<td>114.6 (4.1)</td>
<td>**</td>
</tr>
<tr>
<td>Spelling WRAT (standardized scores)</td>
<td>93.9 (13.2)</td>
<td>113.1 (6.5)</td>
<td>**</td>
</tr>
<tr>
<td>Digit naming speed (50 items)</td>
<td>19.8 (4.6)</td>
<td>13.9 (3.0)</td>
<td>**</td>
</tr>
</tbody>
</table>

Table 8.1. Participants: Behavioural profile

All participants received a battery of standardized tasks and related measures in order to evaluate literacy and literacy related skills. A full psychometric assessment of each participant was carried out using the Wechsler Adult Intelligence Scale (III). In addition reading and spelling ability were evaluated using the Wide Range Achievement Test – Revised (WRAT-R; Jastak and Wilkinson, 1984). The results of these assessments are shown in Table 8.1. They indicate that the control and dyslexic groups were matched for Performance IQ but the dyslexic participants were impaired
on the WAIS Verbal IQ measure \[F(1, 30) = 16.61; p<.01\] which contributed to the overall depression in Full Scale IQ \[F(1, 30) = 10.63; p<.01\]. Significant impairments were found in the four ACID subtests: Arithmetic \[F(1, 30) = 7.61; p<.01\], Coding \[F(1, 30) = 6.82; p<.05\], Information \[F(1, 30) = 3.70; p=.06\], and Digit Span \[F(1, 30) = 51.90; p<.01\]. As expected, the dyslexic participants were also impaired on the standardised measures of reading and spelling \[WRAT reading (F1,30) = 38.62; p < .01); WRAT spelling (F1,30) = 27.23; p < .01\)]. In addition, a digit naming task was administered in order to assess naming speed (after Spring and Davis, 1988) since this task has served as a reliable index of weak phonological skill in an adult population (e.g. Brunswick et al., 1999). This indicated significantly slower naming speed by the dyslexic participants \[F(1,30) = 18.53; p<.01\].

**Design**

The design of the task was based on an experiment carried out by Akshoomoff and Courchesne with a group of cerebellar patients (1994). Only one condition from that study was employed in the present design: the shift condition. In this task subjects are presented with a series of repeated visual items. Two of these items represent potential targets, while the other items are distracters to be ignored. Participants must respond in an alternate fashion to the target by pressing a response button. An example is shown in Figure 8.1. Here the two targets are a harp and a shoe, while the distracter items are nonsense shapes. Participants are told to respond initially to Harp as the target picture. However, once such a response is made, the target switches to the other picture, Shoe. The initial target therefore not only serves as a response cue, but as a cue to disengage attention from the current target and shift attention as rapidly as possible to the other target. As shown in Figure 8.3 pictures of Harp are therefore ignored until a Shoe picture appears. The switching of the target occurs irrespective of the participant's response. If the participant responds when a given picture is not the target then this constitutes a false positive. During the task the same pair of distracter items were interleaved between the target pairs; these were two nonsense shapes that were to be consistently ignored.
Figure 8.1.: Schematic drawing of the shift-attention task, with Harp and Shoe as the target pictures, and two nonsense shapes as distracters to be ignored. C, correctly detected target; FP, false positive response. In this sequence the participant pressed a button (arrow) to the first assigned target (a harp). This serves as a cue to shift attention to the other stimulus (a shoe) and to ignore any further pictures of a harp until a shoe appears. In the last stimulus in the sequence the participant fails to make that switch, and presses the button for harp, when shoe is in fact the target. This constitutes a false positive response.

Stimuli and Apparatus
The objects used in this experiment are shown in Figure 8.2. These consisted of 8 pictured items taken from the Snodgrass and Vanderwart set (1980), the first four of which were amended to increase their level of visual similarity: pen, pencil, dog, goat, harp, shoe, bell, and belt. Targets pairs could be visually similar (VS) and phonologically similar (PS) (VSPS: pen and pencil); visually similar and phonologically different (PD) (VSPD: dog and goat); visually different (VD) but phonologically similar (VDPS: bell and belt); or visually and phonologically different (VDPD: harp and shoe). In addition to these real objects, two nonsense shapes, differing in visual appearance from all the target stimuli, were created to act as visual distracters. These are shown in Figure 8.3. Testing was carried out using a Power Macintosh computer. Responses were made using a Superlab 4-key response box, only one key of which was required for the current experiment. Participants were instructed to respond with the index finger of their dominant hand. Presentation of the stimuli and timing of the responses was governed by the Superlab experimental generator package.
Figure 8.2: Target stimuli (real objects) varying along both visual and phonological dimensions.

Figure 8.3: Two nonsense shape distracter stimuli used across all conditions.

Procedure

Items across all conditions were presented in a fixed pseudo-random order, with a presentation duration of 180msec. The interstimulus intervals (ISI) in the Akshoomoff et al., (1994) study were randomised and extended to 1500msec with a maximum of 30seconds between shift cues. In the current study the ISI was fixed at 500msec and the maximum time between the appearance of a shift target was just over 4 seconds. These changes were designed to increase the pace of the task and increase task difficulty appropriately for an adult population. Responses were thus recorded within a window of 680msec after the target appeared. Pilot data indicated an average response time of 300msec, making it likely that responses to each target would be recorded
within this window. Unlike the Akshoomoff et al., (1994) study, all responses were recorded, even if a target had been missed previously. In each condition the two potential target shapes appeared less frequently (20% probability of occurrence each) than the two distracter shapes (30% probability of occurrence each). Only 25% of the total items presented in each condition were actual targets. Feedback was provided for all responses: a correct response elicited a short high tone, while an incorrect response elicited a short burst of white noise. In this way participants could keep track of the identity of the current target. There were a total of 195 items in the sequence for each condition.

Participants were introduced to the task with written instructions which appeared on the screen before each condition. These explained that in this task they had to press a button each time a target appeared and that the target would alternate between two pictures. The pictures were presented on the screen but were not named. The participants were then provided with a practice trial which employed the target pictures that were to be used in that condition. They were shown what the first target would be and pressed a key to begin the practice trial. During this trial, unlike in the experimental trial, verbal feedback was provided in the form of written responses on the screen in addition to the tonal feedback.

For example, on pressing the response button correctly, participants not only heard a high tone but were presented with the message: ‘Well done! The target now switches to...x’ (with x being the picture of the new target). If the participants failed to spot the target, then there was a pause and the message: ‘Oops! You missed the target...[picture of target missed]...the target now changes to...x’. Finally if the participant pressed the response button for one of the targets inappropriately then the low tone was accompanied with the message: ‘No, the target is...[picture of the current target]’. After this practice trial (which consisted of a sequence of 36 items, and 5 shift targets) participants were asked if they were happy with the procedure. Before the experimental condition was initiated by the participant, any queries were clarified by the experimenter. No feedback was given during the experimental trials except for the high and low tones to indicate a correct or incorrect response respectively. Conditions were presented in a counterbalanced order and all began with
a practice trial of identical format to familiarise the participant with the pictures to be used as targets in that condition.

**Results**

The dependent variables were the number of correct responses, latency of response and the number of false positives, all of which were recorded automatically. Mean number of correct responses (out of a possible 50) with respect to group and condition are shown in Table 8.1. A non-parametric analysis was carried out in view of the number of participants whose performance was at ceiling. This indicated no differences in performance across groups. There were also no differences in performance across conditions, except in VSPS (pen-pencil) condition where both groups produced fewer correct responses (Wilcoxon Sign Rank Test; p<.05).

Median response times were calculated from the correct responses made by each participant; these were then averaged to generate the set of means shown in Table 8.2. The median response times were entered into a repeated measures ANOVA, with Group (Dyslexic vs Control) as the between subjects factor, and repeated measures on Phonological Similarity (Phonologically similar vs. Phonologically Different) and Visual Similarity (Visually similar vs. Visually different). This indicated a main effect of Phonological Similarity (F(1,30) = 16.7; p<.001) and a significant interaction between Phonological and Visual Similarity (F(1,30) = 17.3; p<.001). As shown in Figure 8.5, participants in both groups were sensitive to phonological similarity but only when the targets were visually similar. There was no evidence of an interaction between phonological similarity and group.

The number of false positives – defined as a response to a non-target – were calculated for each condition and for each participant; these are also presented in Table 8.2. These data were entered into a repeated-measures ANOVA with the same factors as in the reaction time analysis. This indicated a main effect of Visual Similarity (F(1,30) = 51.6; p< .001) and a significant interaction of Visual Similarity and Group (F(1,30) = 10.4; p< .01). As shown in Figure 8.5, Visual Similarity had only a small effect on the control participants. In contrast the Dyslexic participants tended to produce many more false positives when the targets were visually similar. As in the reaction time analysis, a Visual Similarity X Phonological Similarity
interaction was observed ($F(1,30) = 5.5; p<.05$). Again the effect of Phonological Similarity was evident only when the targets were visually similar.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dyslexics (n=16)</th>
<th>Controls (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean number correct (/50):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VS/PS: Pen - Pencil</td>
<td>44.5 (7.3)</td>
<td>44.5 (5.7)</td>
</tr>
<tr>
<td>VS/PD: Dog - Goat</td>
<td>45.5 (4.5)</td>
<td>47.0 (6.8)</td>
</tr>
<tr>
<td>VD/PS: Bell - Belt</td>
<td>48.0 (3.5)</td>
<td>46.5 (3.7)</td>
</tr>
<tr>
<td>VD/PD: Harp - Shoe</td>
<td>48.0 (2.5)</td>
<td>46.5 (4.9)</td>
</tr>
</tbody>
</table>

| Mean Reaction Time (msec): |                  |                 |
| VS/PS: Pen - Pencil       | 302.9 (44.1)     | 319.4 (58.5)    |
| VS/PD: Dog - Goat         | 277.8 (38.7)     | 282.1 (56.9)    |
| VD/PS: Bell - Belt        | 288.5 (36.9)     | 303.5 (48.0)    |
| VD/PD: Harp - Shoe        | 283.9 (45.8)     | 304.8 (51.6)    |

| Mean number of False Positives: |                  |                 |
| VS/PS: Pen - Pencil           | 11.6 (7.4)       | 8.3 (4.6)       |
| VS/PD: Dog - Goat            | 8.8 (3.4)        | 6.4 (4.0)       |
| VDPS: Bell - Belt            | 3.1 (2.1)        | 5.1 (3.7)       |
| VDPD: Harp - Shoe            | 5.2 (4.3)        | 5.0 (3.8)       |

Table 8.2 Experiment 6a: Task switching performance in relation to accuracy, latency of response and number of false positives produced by the dyslexic and control groups across all four conditions. VS = visually similar; PS = phonologically similar; VD = visually different; PD = phonologically different.

Figure 8.4. Latency of response across conditions for Dyslexics and Controls. —— Visually Different. —— Visually Similar. For both groups the effect of phonological similarity is largely confined to the visually similar condition. All error bars refer to the standard error of the mean.
Figure 8.5. Mean number of false positive responses across conditions for Dyslexics and Controls

Visually Different. — Visually Similar. While both groups show an effect of visual similarity and a sensitivity to phonological similarity when the targets are visually similar, the dyslexic participants produce significantly more false positives in the visually similar conditions.

Discussion

It was predicted that there would be a greater contribution of phonological coding when the target pairs were visually similar; this was based on the assumption that participants would be more likely to engage in phonological encoding of the targets when they were visually confusable. Both the latency data and the false positive data indicated that when the targets were visually similar participants were sensitive to the phonological similarity of the target; this strongly implies automatic phonological encoding of the targets. The second prediction stated that the dyslexic participants would be less efficient with such phonological encoding, and would as a consequence perform more poorly in the visually similar conditions. This was supported by the finding that the dyslexics produced a higher number of false positives in the visually similar conditions. It would be possible however to argue that the observed differences in the visually similar condition could have arisen as a consequence of poorer visual discrimination, or indeed, poorer semantic processing by the dyslexic participants (since the visual and semantic characteristics of the visually similar items pen-pencil and dog-goat were confounded). Similarly if the visually similar conditions were more demanding, then an attentional impairment could account for the differences observed. Two new conditions were designed to address these concerns.
Experiment 6b: Target switching with abstract stimuli

It is hypothesised that the dyslexic participants performed more poorly when target switching because they were less able to employ a phonological encoding strategy. However, such a pattern may have emerged as a consequence of poorer visual or semantic processing. To eliminate the possibility that semantic processing could account for these differences, abstract nonsense shapes were designed that were semantically neutral (see Figure 8.6). If dyslexic participants were impaired in semantic processing then no group differences in performance would be expected with such targets. In view of the fact that these shapes are highly unfamiliar – lacking a known structural description or semantic content – task difficulty should be increased, thereby increasing the likelihood of phonological encoding. On this basis it was predicted that the dyslexic participants would perform more poorly than the controls. In order to explicitly demonstrate the role of phonological encoding, and rule out the possibility that differences in attentional or visual processing demands across conditions could explain the observed results, a further manipulation was made. If it is the case that control participants perform the task more successfully because they are encoding the targets phonologically then preventing them from doing so should eliminate their advantage – specifically by requiring participants to engage in a simple task of concurrent articulation. In contrast, if the dyslexic participants are characterised by an attentional deficit then a concurrent task such as this should serve to impair their performance further.

Method

The participants and all aspects of the procedure were identical to those used in the real object conditions. However, the targets used, as shown in Figure 8.6 were nonsense shapes rather than real objects. This experiment followed a factorial design, with reading ability (dyslexic versus control) as the between-group factor and Condition (switching silently or with concurrent articulation) as the within-group factor. In one condition participants switched between two nonsense shapes in the same manner as with the real objects; in the second they did so while repeating the word ‘bin’ repeatedly throughout the task. The rate of repetition was two words per
second; a rate demonstrated by the experimenter and practiced by the participant before the task began. The order of presentation was counterbalanced.

Figure 8.6. Nonsense shape target stimuli (Experiment 6b).

Results

Accuracy, latency of response and number of false positives are shown in Table 8.3. A non-parametric analysis indicated no significant differences in accuracy across groups or conditions. The latency data were entered into a repeated-measures ANOVA. This indicated a main effect of Condition ($F(1,30) = 24.4; p < .001$) with slower responses for both groups in the concurrent articulation condition. This is consistent with the established finding that a dual task slows performance (e.g. Buenaventura and Sarkin, 1996).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dyslexics (n=16)</th>
<th>Controls (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean number correct (/50):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silent</td>
<td>45.5 (6.0)</td>
<td>47.0 (4.5)</td>
</tr>
<tr>
<td>Concurrent articulation</td>
<td>47.5 (6.8)</td>
<td>47.5 (7.6)</td>
</tr>
<tr>
<td>Mean Reaction Time (msec):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silent</td>
<td>297.7 (40.2)</td>
<td>300.5 (47.7)</td>
</tr>
<tr>
<td>Concurrent articulation</td>
<td>326.1 (53.6)</td>
<td>329.3 (43.7)</td>
</tr>
<tr>
<td>Mean number of False Positives:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silent</td>
<td>6.4 (4.9)</td>
<td>3.5 (2.7)</td>
</tr>
<tr>
<td>Concurrent articulation</td>
<td>7.0 (3.3)</td>
<td>7.3 (4.7)</td>
</tr>
</tbody>
</table>

Table 8.3. Experiment 6b Task switching performance in relation to accuracy, latency of response and number of false positives produced for the dyslexic and control groups with the nonsense shape stimuli in the silent and concurrent articulation conditions.
The false positive data were analysed in a similar fashion. This analysis indicated a main effect of Condition \( F(1,30) = 7.3; p<.05 \). There was a significant Group \( \times \) Condition interaction \( F(1,30) = 4.2; p<.05 \) with a comparable number of false positives in the concurrent articulation condition across groups, but significantly fewer false positives for the controls in the silent condition (planned comparison: \( t(30) = 2.1; p < .05 \)). This differential effect is illustrated in Figure 8.7.

![Graph showing mean number of false positive responses with abstract shapes in both the silent and concurrent articulation conditions.](image)

**Figure 8.7.** Mean number of false positive responses with abstract shapes in both the silent and concurrent articulation conditions.

**Discussion**

It was predicted that in view of the unfamiliar nature of the stimuli participants would engage in phonological mediation to assist task performance, and in addition, that the dyslexic participants would perform such verbal mediation less efficiently. This prediction was supported by the observation that the control participants produced significantly fewer false positives than their dyslexic peers in the silent condition. This difference could not be attributed to poor semantic processing or compromised visual discrimination in view of the fact that the stimulus pairs lacked notable semantic attributes and were visually distinct in appearance. As predicted, the controls’ advantage was eliminated by a task of concurrent articulation, consistent with the hypothesis that their superior performance was attributable to phonological rather than visual or semantic superiority. An attentional explanation could also be ruled out given that the performance of the dyslexic participants (indexed by the number of false positives produced) was not differentially impaired by carrying out an additional task that would have increased attentional requirements even further.
General Discussion

The aims of this study were to assess whether phonological processing would contribute to performance of a non-verbal switching task and whether this would in turn disadvantage dyslexic participants. The results permit two conclusions. Firstly, both control and dyslexic individuals employ verbal labelling spontaneously without explicit instruction, even when a verbal response is not required. This conclusion is based on the observation that participants were sensitive to the phonological similarity of target names, when those targets were visually similar. Secondly, it is suggested that dyslexic individuals are less efficient in employing such phonological coding. This conclusion is based on the observation that the dyslexic participants made a greater number of false positive responses when the target pairs were visually similar. A second experiment was carried out to address the possibility that poor visual, semantic or attentional processing – rather than inefficient phonological encoding – might account for the group differences observed. The same procedure was adopted, but visually distinct and semantically neutral abstract shapes (rather than real objects) were used as targets. The dyslexic participants were again found to be impaired. However, when the possibility of phonological encoding was precluded, the advantage previously shown by the controls was eliminated. It is suggested, therefore, that impaired performance by dyslexics on this task was attributable not to a deficit in visual, semantic or attentional processing, but rather to their phonological processing impairment.

These findings are relevant to other studies of both normal and dyslexic populations, in that they demonstrate a role of spontaneous verbal processing during tasks that are for all intents and purposes, non-verbal. In the study by Akshoomoff et al., (1994) for example, the deficits observed by the cerebellar patients were interpreted entirely within an attentional framework, with no consideration given to the possibility that differences in verbal processing across the groups might have contributed to the observed differences in task switching. Similarly, in the disparate array of studies that have reported non-linguistic impairments in dyslexic individuals, consideration is rarely if ever given to the possibility that less efficient verbal mediation may underlie these impairments. The current findings demonstrate that even if a verbal response is not required, or stimuli are used without associated verbal labels, control participants
are still advantaged, albeit subtly, by their more efficient processing of simultaneously activated phonological codes. These findings are consistent with those reported by Huba et al., (1990). In that study, the retention of visually presented letters was assessed in a group of dyslexic children under normal conditions, and during continuous shadowing. In the same way that the concurrent articulation was found to eliminate the advantage of the control participants during target switching, continuous shadowing eliminated the advantage of the unimpaired children on a task of visual memory.

The dyslexic’s impairment in verbal mediation is consistent with process-based account of their phonological deficit. According to the phonological competition hypothesis dyslexic individuals are less able to resolve the competition between two simultaneously activated phonological codes (see Chapter 2). Such an impairment would affect performance on the target switching task if a verbal strategy was used to plan motor output. For example, according to one simple model, a phonological representation is identified with the target, activated and then sustained in working memory. When an item appears, and its associated phonological representation matches that sustained in the phonological buffer, a button press is made. The phonological representation of the other item must then be selected and placed into working memory, and so on. Two factors however are likely to increase the likelihood that the wrong item will intrude into phonological memory. Firstly, given that both representations are being activated in a rapid and alternate fashion throughout the task, both will maintain a high level of residual activation. Secondly, when an item is not the target and must be ignored, its mere visual appearance is likely to accord greater activation to its associated phonological representation. An inability to effectively inhibit the phonological activation associated with a non-target, or to select between two simultaneously activated phonological codes will increase the likelihood that the non-target will intrude into working memory, and then trigger an inappropriate response – i.e. a false positive. According to the phonological competition hypothesis, the dyslexic’s impairment lies precisely in the selection of one phonological representation if additional representations are simultaneously active. Such an account is consistent with the finding that on this task the dyslexic participants are not slower, nor do they make fewer correct responses. Rather they are simply more likely to respond to a previous target that is still active.
These findings should provide a further reason to exercise caution in the interpretation of dyslexics’ poor performance in whole range of tasks. The literature is full of examples where dyslexic children and adults perform more poorly than their peers; there are far fewer examples where they perform as well or better. This is perhaps unsurprising given the countless reasons why a task might be poorly performed.

Failing to take into account co-morbidity for example is a well-documented shortcoming (e.g. Wimmer, Mayringer and Rabeger, 1999). One further consideration has been explored in the current study: that a task might be performed more poorly because dyslexic individuals are less likely to effectively engage in phonological encoding. Such a consideration is often entirely ignored by those researchers investigating a deficit outside the linguistic domain.

Take for example the standard temporal order judgement task, where participants are asked to indicate whether two successively presented tones came in the order of high then low, or low then high. It has been reported that when the gap between these tones is short, dyslexic individuals perform more poorly (Tallal, 1980). Rather than invoke an auditory processing explanation, one might explain such poorer performance on the basis of an increased likelihood of confusion, when two verbal labels (‘high’ and ‘low’) must be rapidly assigned and alternated over many trials. If the phonological representations of both words are in a sustained state of activation, and if the processes of selection between two active phonological codes are impaired, then dyslexic individuals may produce more errors as a consequence of later – inefficient – decision processes that have a phonological contribution. Indeed, a recent study (Marshall, Snowling and Bailey, 2001) used a version of the temporal order judgement task, with an explicit request that participants use a verbal encoding strategy. This simple manipulation improved the performance of the control participants, but impaired that of the dyslexic participants.

Similarly, in a recent brain imaging study by (Temple, Poldrack, Protopapas, Nagarajan, Salz, Tallal, Merzenich and Gabrieli, 2000), participants were required to carry out a task of pitch discrimination of rapid and slow non-speech analogue stimuli, pressing a button for ‘high’ but not for ‘low’ sounds. The pitch detection task, on which dyslexics were believed to be unimpaired, served to ensure that participants
attended to the stimuli. It was predicted that they would process the rapid acoustic stimuli atypically and that this would in turn be reflected in abnormal brain activation. Reduced activation in a left frontal region (-36,20,32) was reported in the dyslexic group in the rapid stimuli condition. Temple et al., (2000) conclude that this provides evidence of poorer auditory temporal processing by the dyslexics. Yet, on closer inspection these results are in fact more consistent with a phonological explanation. Firstly, both groups found the pitch detection task was more difficult in the rapid condition. In addition, the dyslexics were significantly impaired on this task relative to the controls. This indicates that not only did task difficulty vary across conditions, but dyslexics were performing poorly on a task on which it was predicted that they would be unimpaired. This difference at the behavioural level alone could be sufficient to explain the differences in brain activation reported. Secondly, the left frontal region of reduced activation reported by the authors is in fact an area associated with phonological and articulatory processing. Two studies report reduced activation in a very similar location in a group of dyslexics engaged in silent tasks involving reading (Rumsey et al., 1997: -40, 14, 24; Brunswick et al., 1999: -40,4,22). Both these considerations make it very likely that the differences observed actually reflect differences in the level of verbal mediation across conditions (greater in the more difficult rapid condition) and across groups (greater in the controls than in the dyslexics). It is arguably more parsimonious to conclude that the dyslexics are impaired both at the behavioural level and the neural level, not because of any impairment in rapid temporal processing, but because they are less able to engage a verbal strategy during performance.

Further studies are required to explore the possibility that impaired verbal processing might account for the ‘pan-modal’ deficits reported in dyslexic individuals. An inability to resolve phonological competition has been shown here to compromise the ability to switch rapidly between two ‘non-verbal’ targets. This Competition hypothesis provides a parsimonious account of how deficits across these disparate modalities might arise. Further investigations are necessary to explicitly assess the degree to which verbal mediation might account for the reported auditory, visual and ‘automaticity’ deficits in dyslexic individuals.
OVERVIEW AND FUTURE DIRECTIONS

9.1 Introduction

The empirical and theoretical work presented in this thesis has been guided by the idea that the phonological deficit can be characterised as an inefficiency in phonological processing. The phonological competition hypothesis provided the basis for the experiments presented here and has been used to explain the larger picture of behavioural impairment observed in dyslexia. This hypothesis overcomes some of the limitations of an account that focuses solely on inadequate phonological representation. One main task is to incorporate this cognitive level of analysis within a neuro-cognitive framework: a common left hemisphere temporal region appears to reflect impaired phonological retrieval during reading and naming while a difference in right hemisphere activation is interpreted as the result of compensatory processing. In this chapter the evidence for these claims is examined. This discussion will also consider some limitations of the experiments presented in the thesis and suggest directions for future research.

9.2 An overview of the evidence

The behavioural evidence presented in this thesis throws light on how the phonological deficit might be characterised at the cognitive level, and moreover provides a clearer picture of how developmental dyslexia manifests in adulthood. In Experiment 1 the efficiency of phonological retrieval was assessed in a task of word reading and in a task of picture naming. In both tasks the dyslexic participants responded just as accurately as their peers – a striking contrast to the impaired pattern of performance observed on both of these tasks in dyslexic children. At first glance this indicates that dyslexic adults can, to some extent, overcome their earlier phonological difficulties. However while these individuals appear to have somewhat compensated for their earlier literacy difficulties, the limits of this compensation were
clearly evident in three respects. Firstly, although reading accuracy was unimpaired in the experimental conditions, the dyslexic participants were significantly impaired on a standardised test of reading (Wide Range Achievement Test – Revised: WRAT-R). The advantage of the experimental stimuli can be explained as follows: all the words used were drawn from a set of pictured items which, by definition, were concrete highly imageable nouns and included no examples of particularly rare or irregular words. In contrast, irregular abstract words such as ‘beatify’ and ‘misogyny’ from the WRAT were mispronounced by almost every dyslexic participant. It may be that the repeated exposure of familiar words (such as ‘telescope’ and ‘sandwich’) partly contributes to the dyslexics ‘compensation’ in learning to accurately read such words.

Secondly, the limited nature of the dyslexics’ compensation was illustrated by their slower reading latencies, even for short high frequency monosyllabic words that they could read with faultless accuracy. While there were significant effects of both length and frequency (with slower responses with longer lower frequency words), it was remarkable that even for the simplest of stimuli decoding had not, even by early adulthood, reached normal levels of efficiency. In contrast, when they were naming the same stimuli as pictures, the dyslexics’ performance was normal both in terms of accuracy and speed of response, even for long low frequency picture names. A third limitation in the dyslexics’ degree of compensation was established in Experiment 2. Here the time to name fifty pictures in a continuous format was significantly longer than in normal controls, and longer still when the picture names were words from dense (as opposed to sparse) phonological neighbourhoods. This finding demonstrates that deficits in word retrieval during picture naming persist into adulthood, but are manifest only under certain conditions. That is, the cognitive impairment is sufficiently subtle as to lead to detectable behavioural impairments only when the level of phonological competition is particularly high.

Two functional imaging studies were carried out as part of this thesis. These were designed to investigate the neuro-anatomical correlates of impaired phonological processing in dyslexia in tasks that (i) did not entail orthographic decoding and (ii) did not give rise to performance deficits in the dyslexic group. In Experiment 3 participants were required to name a series of pictures; for comparison they were also presented with a series of words to read. Previous studies have reported reduced
activation in dyslexic adults in the left posterior inferior temporal lobe during reading and in other tasks that required orthographic decoding (Rumsey, Nace, Donohue, Wise, Maisog, and Andreasen, 1997; Brunswick et al., 1999; Paulesu, Demonet, Fazio, McCrory, Chanoine, Brunswick, Cappa, Cossu, Habib, Frith, and Frith, 2001). It has been postulated that this pattern of reduced activation reflects the dyslexics' impairment in phonological retrieval (Brunswick et al., 1999). The findings of Experiment 3 served to support this position. Here the dyslexic participants were found to show reduced activation in BA37 not only for word reading but also for picture naming, even though behavioural performance was matched across groups. This indicates that disordered processing in this region in dyslexia is not specific to word decoding but rather reflects a more general impairment in phonological retrieval. In addition, this finding is problematic for the claim that this region specifically represents a 'visual word form area' (Cohen, Dehaene, Naccache, Lehericy, Dehaene-Lambertz, Henaff, and Michel, 2000). The failure to detect differences in the angular gyrus suggests that reduced activation in this region by dyslexics in certain previous studies may merely reflect their poorer behavioural performance.

In Experiment 4 phonological processing was investigated in a non-visual task. Participants were scanned during three conditions: repeating real words, repeating pseudowords and rest. In both groups speech repetition relative to rest elicited widespread bilateral activation in areas associated with auditory processing of speech. Irrespective of word type the dyslexic group showed less activation than the control group in the right superior temporal and right post-central gyri and also in the left cerebellum. Notably, the right anterior superior temporal cortex (BA22) was less activated in each of the eight dyslexic subjects, compared to each of the six control subjects. This deficit appears to be specific to auditory repetition as it was not detected in Experiment 3 during picture naming, nor in previous studies of reading which used the same sets of stimuli (Brunswick et al., 1999). It is suggested that the lower right hemisphere activation in the dyslexic group may reflect an attentional bias in the dyslexic group possibly as a result of compensatory processing, and indicate reduced processing of non-phonetic aspects of speech. A more general implication is that the neural manifestation of developmental dyslexia is not confined to those regions of the hemisphere that are specific to phonological processing. How the deficit in
phonological processing interacts with other, spatially and functionally distinct neural regions, is a matter that requires further investigation.

In Experiment 5 participants were required to generate spoonerisms, a phonological awareness task in which they had to switch the initial sounds of two words. Previous studies have reported extremely high rates of error on this spoonerism task even in adult dyslexics (e.g. Brunswick, McCrory, Price, Frith, and Frith, 1999). In the current study, rate of presentation was slowed and participants were required only to output the first word of the spoonerism pair. Performance accuracy was found to be significantly higher than in previous studies. What was notable, however, was that even for those trials where correct responses were given, the dyslexic participants were significantly slower than their peers. This mirrors the slow but accurate responses in Experiment 1 during word reading. The dyslexics were particularly slow with the multi-syllabic relative to the monosyllabic word pairs, yet even small differences in phoneme length were shown to slow the processing speed of the dyslexic group.

Experiments 6a and 6b investigated the contribution of phonological processing to an ostensibly non-verbal task. Dyslexic individuals have been shown to show subtle performance deficits on a range of tasks that lie well beyond the domain of literacy, including the processing of visual motion coherence (Cornelissen, Richardson, Mason, Fowler, and Stein, 1995) and rapid temporal processing (Tallal, 1980). If performance on these tasks is even partially mediated at the verbal level then the dyslexics’ poorer phonological processing ability may contribute to their impaired performance. The task employed in Experiment 6 required participants to shift their attention rapidly between two possible targets. Both control and dyslexic participants were sensitive to the phonological characteristics of the stimuli when the targets were visually confusable, suggesting that both groups employed some degree of verbal mediation. However the dyslexic participants produced significantly more false positive responses suggesting that they were able to employ such mediation less effectively. When a concurrent task of articulation was carried out the advantage previously observed in the control group was eliminated. This supports the contention that even in an ostensibly non-verbal task, verbal processing is automatically employed and at
least partially mediates performance. The results indicate that such processing is less efficient in dyslexic individuals.

It is the overall pattern of these results which are intriguing: normal word reading accuracy in the context of slower reading speed; normal picture naming accuracy and speed in a paced single trial format, yet slower picture naming speed in a continuous format; and largely accurate but slower performance on the spoonerism task. The dyslexics' impairment in phonological processing is not pervasive, nor entirely resistant to amelioration, certainly in relation to response accuracy. Any cognitive explanation of the phonological deficit in dyslexia must (i) account for this pattern of performance across tasks, and (ii) explain why processing remains slow even when normal accuracy has been attained.

9.3 Rethinking the phonological deficit in dyslexia

A primary objective of this thesis has been a re-evaluation of our understanding of the phonological deficit in dyslexia. The current theoretical position with most widespread support postulates an impairment in the quality of dyslexics' phonological representation. Despite its wide currency this theory remains remarkably unspecified. Phonological representation has been taken to reflect the degree of segmentation of words at the syllable, onset-rime and phonemic levels. The ability to access and manipulate word segments at each of these levels has been interpreted as de facto evidence that such segments exist at the cognitive level. Yet this position fails to account for the variability in the manifestation of the phonological deficit. This is illustrated by three examples drawn from the experiments in this thesis. The dyslexic participants in Experiment 1 were slower in reading a set of relatively frequent concrete words but not when they were required to name those same items as pictures. In Experiment 2 naming was shown to be impaired when the format was altered as to increase naming rate. And finally in Experiment 5, although the dyslexic participants were able to successfully manipulate word pairs at the phonemic level they did so significantly more slowly than their peers. If short monosyllabic words are segmented at the phonemic level (as indicated by the high level of spoonerism accuracy in Experiment 5) then why are these items read and manipulated more slowly? Can a
phonological representation be segmented at the phonemic level and still remain
‘fuzzy’ or ‘poorly specified’?

Tasks of phonological awareness cannot demonstrate whether particular phonological
segments have a cognitive basis but rather they index the efficiency with which
phonological information can be accessed. This allows for the possibility that the
informational specification of a given word is fluid and dynamic rather than finite. An
individual may be able to successfully segment a given word at the phonemic level,
but an increase in the task demands in relation to short term memory (Landerl and
Wimmer, 2000) or the pace of presentation (e.g. Experiment 5), will increase error rate
significantly. The phonological representations themselves, if seen as fixed entities,
have not changed across these conditions. What does differ is the functional
availability of the phonological information. That is, a word or word segment may be
efficiently retrieved in one task (that is, it is functionally available), but a change in
task demands may lead to a failure to retrieve the very same word segment. So while
the phonological specification of a given word may be complete, the functional
availability of that representation or its individual components is context sensitive.
Therefore phonological representations may be best viewed as dynamic rather than as
fixed entities. These representations in dyslexics may be more susceptible to
interference and characterised by longer refractory periods.

In this way the difficulties of phonological access both at the lexical and sublexical
level are accounted for by a single explanatory construct: phonological competition. If
we are required to name a picture that activates and selects the phonological
ingredients of its word form, then we will be slowed if other lexical competitors are
simultaneously encoded. These compete with the target. The present theory proposes
that dyslexics are impaired in resolving this competition. A similar situation arises if
we are required to selectively output a single phonemic constituent of a word. Again
activation of a wordform will activate a set of phonological ingredients. Now,
however, the competition is at the sublexical level since we are required to select a
single component from within this activated set of sublexical competitors. These
compete with the target. Again the present theory suggests that dyslexics are impaired
in resolving this competition. By adulthood many dyslexics resolve this competition in
phoneme awareness and reading tasks with a high degree of accuracy. But even in
these instances they are slowed by their inefficiency in addressing competition at the phonological level. Factors which increase the level of competition (e.g. naming rate, phonological neighbourhood size) serve to extend this process – and slow performance even further.

Reading in an opaque orthography, it is argued, generates a particularly high level of phonological competition, notably at the level of the vowel. This competition is a direct consequence of the multiple mappings between a single grapheme and an array of possible phonemes. Reading even the word ‘cat’ (/kæt/), for example, will generate competition at the vowel slot between the correct vowel /æ/ and the vowel /a/ which is also represented by the letter ‘a’ but in other lexical contexts (e.g. ‘car’ - /kar/). This kind of competition is less fierce in a transparent orthography such as Italian where there is an unequivocal relationship between the graphemes and the phonemes of the language. Individuals with dyslexia will therefore find reading in opaque orthographies such as English most challenging, since these generate the highest levels of phonological competition. However, one would predict that deficits in rapid naming would be a universal marker for dyslexia, given that the competition generated here is independent of orthographic consistency.

In the discussion of Experiment 3 it is suggested that the differential degrees of activation observed in the posterior inferior temporal lobe may reflect those cognitive processes that are engaged by normal readers to resolve competition at the phonological level. One possibility is that this differential activation represents neural activity associated with the inhibition of inappropriate phonological competitors. This suggestion is consistent with the observation that skilled English readers show a greater level of activation in this region relative to their Italian counterparts. Dyslexic adults show reduced levels of activation in this region during word reading (Experiment 3; Brunswick et al., 1999) picture naming (Experiment 3) and this effect has been shown to be independent of orthography (Paulesu et al., 2001). That is, while the degree of activation in this region in skilled readers is contingent on the orthography, dyslexic readers show comparable levels of activation here irrespective of orthography. This is consistent with the view that dyslexics are universally characterised by an underdeveloped set of processes dedicated to resolving phonological competition.
9.4 Limitations

Two obvious limitations of the experiments carried out in this thesis warrant consideration. The first relates to the restricted age level of the participants, while the second relates to the use of a chronological age matched design. These will be discussed in turn.

Early studies of reading difficulty in adults examined the reading and phonological skills of adults who are poor readers (Byrne and Ledez, 1983; Labuda and DeFries, 1988; Liberman, Rubin, Duques and Carlisle, 1985; Mason, 1978; Palmer, MacLeod, Hunt and Davidson, 1985; Pratt and Brady, 1988; Read and Ruyter, 1985; Scarborough, 1984). More recently, however, there has been a shift of emphasis towards the investigation of reading skills in adults with known histories of childhood dyslexia (Bruck, 1990, 1992; Brunswick, McCrory, Price, Frith, and Frith, 1999; Felton, Naylor and Wood, 1990; Gross-Glen, Jallad, Novoa, Helgren-Lempesis and Lubs, 1990; Paulesu, Frith, Snowling, Gallagher, Morton, Frackowiak and Frith, 1996; Pennington, Van Orden, Smith, Green and Haith, 1990; Russell, 1982; Snowling, Nation, Moxham, Gallagher and Frith, 1997). Such an approach is preferable since it addresses the question of whether children with developmental dyslexia continue to show continuing deficits in phonological processing in adulthood. These studies have uniformly reported that adults with childhood diagnoses of dyslexia continue to show persistent deficits on a range of phonological tasks, even in the context of compensated literacy skills. The advantages, however, of studying an adult dyslexic population are several. First, in view of the increasing numbers of students currently entering higher education the clinical relevance of understanding dyslexia in the young adult population is greater than ever. It is necessary to deepen our understanding of how their pattern of impairment contrasts with that of dyslexics much earlier in development. Second, a university population of dyslexic adults is most likely to provide ‘pure’ cases of dyslexia. These individuals will invariably be well motivated, bright and unlikely to be characterised by sensory, motor or emotional impairments. While the discrepancy definition may be hard to justify from a clinical perspective, here, within a research context, it reduces the likelihood that any observed effects are the consequence of co-morbidity. In addition, there will often be a documented history of dyslexia that extends over a number of years, precluding the possibility of an
erroneous diagnosis. Third, and perhaps most importantly from a research perspective, more subtle measures of performance may be taken (notably response speed) which are often difficult to acquire in a younger population.

The second limitation relates to the question of what constitutes an appropriate control group with a high functioning adult population. In developmental studies of school age children a reading-age (RA) matched control group is often included in addition to a group of chronological-age (CA) matched control group. With a RA-matched group comparison is made between younger normal readers and dyslexics who are reading at the same level. The disadvantage of RA matching is that differences in general experience and skill are almost inevitable in view of the large age gap between the groups. So younger and less skilled children might be compared with older and more ‘seasoned’ dyslexic children or adults. Any differences in performance, or indeed the absence of group differences might be due to greater strategic skill in the older dyslexic participants. The advantage of an RA match is that it overcomes one major problem inherent in contrasting the performance of dyslexic children with chronological age matched controls (Backmen, Mamen and Ferguson, 1984; Bryant and Goswami, 1986; Goswami and Bryant, 1990). CA matched controls are, by definition, better readers than the dyslexics – a difference which in itself may explain their superior performance on any given task. In a RA-matched design, any differences in performance cannot be attributed to differences in reading abilities, since reading levels are matched across the groups.

A small number of adult studies have used the reading level matched design in which dyslexic adults were compared not only with normal readers of the same age, but also with younger reading-age matched controls (Pennington et al., 1990; Bruck, 1990, 1992) given that some models posit a bi-directional relationship between phonological awareness and reading skill (e.g. Morais, 1987). For the experiments in this thesis only CA matched control groups were included. A RA matched design was not used in view of the theoretical and ethical limitations such design entails (Backman, et al., 1984). Firstly, It is not possible to scan children with Positron Emission Tomography (PET) the method of functional imaging used in two experiments of this thesis. In the remaining experiments speed of response was taken as a primary index of performance. In view of the fact that general processing speed improves with age, the
inclusion of an RA matched control group would have presented significant problems of interpretation. Even when groups are matched for reading age, any difference, or indeed lack of difference, in performance could arise due to differences in strategic or executive processes that are better developed in the older dyslexic adults. The findings, reported in Experiment 6, highlight precisely this difficulty. Here a task involving target switching previously used with 10 year-old children was adapted for this thesis (Akshoomoff and Courchesne, 1994). A comparison of the response times of the children in the original study (who were of above average IQ) with the participants tested here indicate that they were over 200 milliseconds slower.

9.5 Future directions

There are many outstanding research questions regarding the neurocognitive basis of dyslexia that require further investigation. Three of these will be discussed in this section: (i) the need to further specify the nature of the phonological deficit at the cognitive level (ii) to explore the more subtle impact of the phonological deficit in ostensibly non-verbal tasks, both in relation to response accuracy and reaction time; (iii) to investigate the significance of activation differences in the right hemisphere, the left posterior basal temporal lobe and the left angular gyrus.

Developing the process account

The perspective presented in this thesis considers the efficiency of phonological retrieval as indistinguishable from the question of phonological representation. However while the competition and the representation accounts are no more than descriptions at the cognitive level, they are critical in shaping how we think about and investigate the phonological deficit in dyslexia. The notion of a developmental impairment in the segmentation of word sounds suggests that such segments are instantiated at the cognitive level and are either present or absent in a given lexical form for a given individual (e.g. Swan and Goswami, 1997b). In contrast, the competition hypothesis considers the assembly of the set of phonological ingredients associated with a given word form as a dynamic process. The retrieval of a word or a subset of its components will be influenced by the level of concurrent phonological competition. A broad range of factors may influence the level of this competition:
phonological word length, presentation rate, phonological neighbourhood size, semantic specificity and orthographic consistency are several factors that have been considered in this thesis. These factors can alter the landscape of phonological activation when a single word or word component is accessed by increasing the level of phonological competition. The contention is that non-dyslexic individuals, across development, develop processes to efficiently sculpt this phonological space and eliminate everything but the target form. In contrast, dyslexic individuals do not appear to achieve such efficiency, even by early adulthood.

The level of competition during retrieval of the same phonological representation can therefore be varied. This may lead to successful access in one instance but not in another. For example, an increase in the temporal proximity at which phonological access occurs will impair the dyslexic in terms of accuracy and/or speed. Here, the level of phonological competition is augmented given that the activation associated with the previous response has not fully decayed. This will affect access across task paradigms. So, for example, onset deletion of a bisyllabic word should be achieved with a high level of accuracy in adult dyslexics if the pace of the task is slow; but increased rate at which the same items are presented would lead to an increase in error rate. Likewise, in naming, an increase in the rate of presentation should impair performance, irrespective of whether the items are presented continuously or in a single trial format.

A novel way in which phonological competition might be manipulated is with the use of a modified Stroop paradigm. For example, the naming of a series of digit groups (e.g. a set of four 5's) would elicit privileged phonological encoding of the digit (in this case 5) making it more difficult to name the actual number of items present (in this case four). Both would be encoded at the phonological level and directly compete for selection. On the basis that dyslexics are inefficient in resolving such competition, it would be predicted that they would be particularly poor in this task. Alternatively, a more subtle approach might be to vary the level of phonological competition at the sublexical level by the use of priming. The paradigm used by Berent and Perfetti (1995) could be employed to determine whether a longer prime duration is required in dyslexic relative to normal readers. For example, consider naming a target such as rake. Berent and Perfetti found that a consonant preserving prime (e.g. RIKK) speeded
pronunciation in the first ‘cycle’ (15msec) while a vowel preserving prime (e.g. RAIB) speeded pronunciation in the second ‘cycle’ (30-40msec). If the later priming is a function of the greater level of competition for the vowel position due to its greater ambiguity, then one would predict that much longer prime durations would be required to produce priming in dyslexic readers with the vowel prime (i.e. much greater than 40msec). This is because they would take significantly longer to resolve the competition for the vowel position, requiring that the prime be exposed for a longer duration. In contrast, it is possible that dyslexic readers differ little from normal readers in the first, consonantal cycle, given the reduced level of ambiguity and competition in consonant pronunciation.

**Generalised effects of the phonological deficit**

Chapter 8 explored the possibility that an impairment in phonological processing may partly underlie the subtle deficits reported in dyslexia across a broad number of domains. There is an increasing diversification in the number of apparent deficits in dyslexia reported in the literature. However, poor performance on a given task at the behavioural level can arise for a variety of reasons. If it is the case that we employ verbal strategies consciously or otherwise to mediate performance across a broad range of domains then a weakness in such mediation may impair our performance. This mediation is not likely to be necessary to perform the task successfully, but would subtly improve performance. If dyslexics are impaired in their ability to retrieve and manipulate phonological forms then such a subtle improvement may elude them, leading to a mild, but nonetheless detectable difference in performance.

One task that might be explored is the choice reaction time task. It has previously been reported that dyslexics are slower in making response decisions to two stimuli but are unimpaired in a simple choice reaction time task (Nicolson and Fawcett, 1994). Such a difference may arise from inefficient verbal encoding when there are two or more stimuli. In Experiment 1 no differences were found in a choice reaction time task where participants had to make a semantic decision and decide whether a pictured item was living or non-living. In view of the fact that every target was different, responses were most likely made at the semantic level, prior to phonological encoding. In addition, participants weren’t required to respond to the non-targets. In contrast, a
task in which participants were required to respond to two targets (unlike Experiment 6 where again only one response was required) may set up a strong association between an established or temporary verbal label and the visual stimulus. For example, participants may be asked to press one key on the appearance of a red shape, and another key on the appearance of a blue shape. Control participants would be capable of readily associating ‘red’ with one finger and ‘blue’ with another. Such an association may be inefficiently established if the activation of the phonological labels of the targets is unstable. In the dyslexic participants, the appearance of either target will lead to competition between the phonological forms of the targets, and poorer performance in the dyslexic participants. The advantage gained by the control participants could be reduced by using unfamiliar shapes and a concurrent articulation task to discourage verbal mediation.

Future imaging investigations

Future studies are necessary to address a range of outstanding issues with regard to activation differences in several brain regions: the right hemisphere; left BA37; and the left angular gyrus. With regard to auditory processing in the right hemisphere, future studies are required to investigate the specificity of any auditory processing differences to the linguistic domain. Currently the issue is unresolved. For example, an auditory processing study using mismatch negativity (MMN) reported group differences in dyslexic children for speech stimuli but not for tonal stimuli during a passive listening task (Schulte-Körne, Deimel, Bartling, and Remschmidt, 1998). However an investigation of non-linguistic auditory processing using PET which required memory for tonal sequences reported reduced activation in several right hemisphere areas including the right superior temporal region (Rumsey, Andreason, Zametkin, King, Hamburger, Aquino, Hanahan, Pikus and Cohen, 1994). In order to address this question fully future studies are required to systematically manipulate both the class of stimuli (speech and non-speech) and the cognitive task demands (active and passive) applied to those stimuli.

With regard to the angular gyrus it has been suggested in this thesis that the reduced activation reported in this region in previous studies (e.g. Rumsey et al., 1997; Shaywitz et al., 1998) may simply reflect the degree of semantic processing elicited in
a given task; a factor that would be influenced by general performance accuracy. One way to address this question would be to compare the pattern of activation in two groups of non-dyslexic readers, one of average reading ability and the second of above average reading ability who read the same set of words with different degrees of accuracy. It would be predicted that the group of readers who make more errors would show correspondingly lower levels of activation in the angular gyrus. This would demonstrate that reduced activation in angular gyrus activity in dyslexics is not a cause but a consequence of their reading impairment. It would also underline the importance of performance accuracy as a potential confound in interpreting differences in brain activation.

A second line of investigation might further our understanding of the abnormal pattern of activation in BA37. It would be important to demonstrate that dyslexic individuals show a similar pattern of reduced activation even when word retrieval occurs in the absence of visual input. This question could be addressed in a paradigm in which the participants are presented with a series of familiar environmental sounds that they have to name. Given that this task also entails phonological retrieval it would be predicted that dyslexic participants would show reduced activation in this region as they did when naming pictures. Comparing activation across development, in both normal and dyslexic readers using fMRI rather than PET, represents a primary task of future studies. It is very likely that the pattern of activation observed will change as children learn to read. For example, the reduced activation in the posterior inferior temporal lobe may reflect the absence of a set of cognitive processes that have developed in normal readers to resolve phonological competition during reading. Differences with dyslexic children in this region may not be so apparent in the early stages of reading development. One might speculate that dyslexic children would show, in contrast, an over-activity of the left frontal region. If it is the case that the posterior inferior temporal lobe and the frontal operculum represent aspects of the same system (Price and Friston, 1997), then this over activation may reflect the excessive output from the posterior region. That is, the over-activation reported in the adult dyslexics in the frontal operculum may not represent compensatory processes as has been suggested (Shaywitz et al. 1998; Brunswick et al., 1999) but the failure of the posterior component of the system to limit the number of phonological codes competing for output.
9.6 Concluding remarks

The aim of this thesis was to investigate the neurocognitive basis of the phonological deficit in developmental dyslexia. The use of non-orthographic tasks in conjunction with sensitive behavioural and neural measures of performance characterised the studies presented here. The empirical evidence presented suggests that this approach may provide a promising method to further explore the architecture of phonological processing in dyslexia.
Bibliography


207


Appendix I

a. Word stimuli used in the repetition task, Experiment 4 (taken from Brunswick et al., 1999).

<table>
<thead>
<tr>
<th>apron</th>
<th>cherry</th>
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<tr>
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<td>collar</td>
<td>tractor</td>
</tr>
<tr>
<td>penny</td>
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<td>mirror</td>
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<tr>
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<td>window</td>
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<td>blanket</td>
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<td>hammer</td>
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<td>kennel</td>
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<td>locker</td>
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<td>jelly</td>
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<td>saddle</td>
</tr>
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<td>motor</td>
<td>berry</td>
<td>river</td>
</tr>
<tr>
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</tr>
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<td>chimney</td>
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<td>tiger</td>
<td>cotton</td>
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b. Nonword stimuli used in the repetition task, Experiment 4 (taken from Brunswick et al., 1999).

<table>
<thead>
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<th>adrel</th>
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<td>chemmy</td>
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<td>pemmer</td>
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<td>tuple</td>
<td>coddar</td>
<td>mudfard</td>
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<td>warler</td>
<td>buffle</td>
<td>elsew</td>
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<td>tafle</td>
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<td>vimmage</td>
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<td>labber</td>
<td>paber</td>
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<td>legon</td>
<td>dospor</td>
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<td>banlet</td>
<td>burron</td>
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<td>cotte</td>
<td>beppy</td>
<td>rassel</td>
</tr>
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<td>mittor</td>
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<td>sapple</td>
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<td>naslin</td>
<td>podret</td>
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c. Experiment 4: Methodological details of the background phonological processing and memory tasks.

Spoonerisms

The Spoonerism task involves the segmentation and manipulation of the constituent sounds of words (Perin 1983). The 24 words used in the Spoonerism task were two syllable highly familiar concrete words selected on the basis that they had clear syllable divisions (e.g. BAS-KET) and no consonant clusters in their onsets. No real words were produced by recombining the onsets and rimes of the pairs of words (see below).

<table>
<thead>
<tr>
<th>Word 1:</th>
<th>Word 2:</th>
<th>Spoonerisms:</th>
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<tbody>
<tr>
<td>Basket</td>
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<td>Turtle</td>
<td>Tutton/ Burtle</td>
</tr>
<tr>
<td>Doctor</td>
<td>Window</td>
<td>Woctor/ Dindow</td>
</tr>
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<td>Fabric</td>
<td>Pocket</td>
<td>Fabric/ Focket</td>
</tr>
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<td>Motor</td>
<td>Tiger</td>
<td>Totor/ Miger</td>
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<td>Mustard</td>
<td>Salad</td>
<td>Sustard/ Malad</td>
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<td>Novel</td>
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<td>Tovel/ Nable</td>
</tr>
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<td>Paper</td>
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<td>Rabbit</td>
<td>Sofa</td>
<td>Sabbit/ Rofa</td>
</tr>
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<td>Radish</td>
<td>Garlic</td>
<td>Gadish/ Rarlic</td>
</tr>
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<td>Razor</td>
<td>Medal</td>
<td>Mazor/ Redal</td>
</tr>
<tr>
<td>Ribbon</td>
<td>Silver</td>
<td>Sibbon/ Rilal</td>
</tr>
</tbody>
</table>

Prior to the test, the concept of Spoonerisms was introduced and defined in the following way: "A Spoonerism is where you have two words and you swap over the beginning sounds of each word to make two new words or pseudo-words. For example, the words RED/ PEN become PED/ REN. Can you hear what I've done? I've taken the /r/ sound from RED and the /p/ sound from PEN and swapped them around to produce PED/ REN". A couple of practice trials followed this introduction as participants were asked "What do the words DESK/ HAT become?" If subjects responded correctly, "HESK/ DAT", they were told that this was correct and they were given the second practice trial, "FISH/ BOX". Responses were scored as correct only
when the word order was maintained in the response. In response to the words BASKET/ LEMON, for example, the subject must respond with "LASKET/ BEMON"; the response "BEMON/ LASKET" would not be allowed. If subjects made errors during practice they were given feedback and a further trial. Word order errors were corrected during the test only the first time they occurred.

Time taken to complete the test was recorded with a stopwatch from just before the first pair was given until the last Spoonerism was completed. The time taken per pair was calculated by dividing this time by twelve. During the task the stopwatch was stopped in the event of any interruptions from outside and during correction of the subject. In the event of hesitation or repeated attempts timing continued. One repeat by the experimenter was allowed per word pair if requested, but timing continued during this repetition. If the subject experienced real difficulty and discomfort the task was discontinued at the discretion of the experimenter.

Phonemic fluency
Participants were first given a practice trial of semantic fluency ("how many animals can you think of in 30 seconds?"), then the phonemic fluency task was introduced. Participants were asked to think of as many words as possible beginning with a particular sound ("list as many words as you can beginning with /s/; when I say 'begin'...Okay?....'Begin'...."). On saying 'begin' the stopwatch was started; at the end of 30 seconds the subject was stopped. The task was repeated for words beginning with /f/. The phonemic fluency score was calculated from the mean number of words generated across these two trials.

Auditory Verbal Memory
Before testing, participants were shown the words to be used in the task. These were 7 short words (worst; sum; yield; harm; bond; hate; twice) and 7 long words (immediately; university; organisation; individual; opportunity; association; representative). Participants were asked to read the words aloud before they were removed from view. Two practice trials were then given in which, as in the experimental trials, participants heard lists of 6 of the words spoken at the rate of one word every second; as soon as the experimenter had spoken the last word from a list the participant was prompted to recall the words in the order of presentation. If a word
could not be remembered participants were told to use the word 'something' to maintain the order of the surrounding words. Only words recalled in the appropriate position were scored as correct. Ten lists of short words and ten lists of long words were presented in alternating order, and the number of words recalled correctly were summed across the two lengths of list.

**Digit naming**

In this task participants were asked to read aloud, as fast as possible, strings of 50 single syllable digits (the number 7 was excluded as the only digit with a two syllable name). Digits were chunked into blocks of 5 (e.g. 68248 83542 99634) although participants were told to read each digit as a single number, i.e. the string 51368 should be read as "five, one, three, six, eight". The task was presented twice with different strings of 50 digits. The time taken to read each string was recorded with a stopwatch, starting from the experimenter saying the word "go" of "ready, steady, go", until the last digit had been said. Accuracy of reading the digits was monitored by the experimenter although it was not scored. When participants (rarely) made mistakes, they always self-corrected immediately; any repetitions were included in the timing. A mean score, in seconds, was obtained over the two trials.